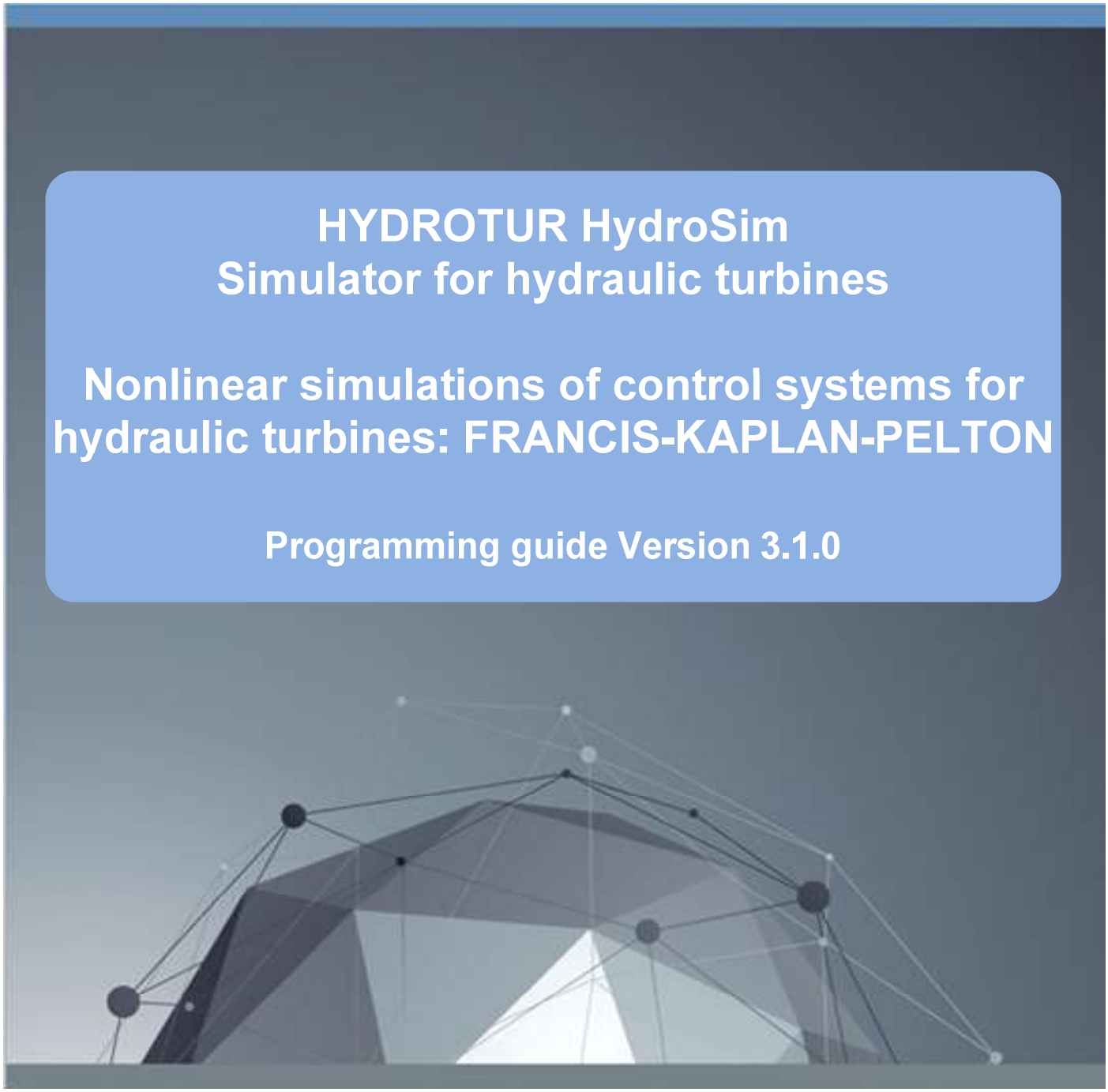


HYDROTUR

HYDROTUR HydroSim
Simulator for hydraulic turbines

Nonlinear simulations of control systems for hydraulic turbines: FRANCIS-KAPLAN-PELTON

Programming guide Version 3.1.0



by Pierre Perrichon

Scilab

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IEC normative references	[4] [5]
Scientific literature	[6] [7] [8] [9]
University documents	[10] [11]

TECHNICAL SUPPORT - CONTACT

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Figure 1 : Technical support for the HYDROTUR project

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1 INTRODUCTION

1.1 Available documents

Document title
HYDROTUR_ HydroSim_Installation_and_User_Guide_Version_3.0
HYDROTUR - HydroSim_Programming_Guide_version_3.0
HYDROTUR – HydroSim - TURBINES - Documentation FRANCIS- KAPLAN - PELTON
HYDROTUR_HydroStab_Solution_User's_Guide_Version_2.3.2
HYDROTUR – HydroSim CALTUR- Calculation note CALTUR - Version 2.4 (en-fr) .xlsx
HYDROTUR - SEGPAL - Graphics components library for XCOS– Reference Guide

1.2 Available models

■ Available ☐ Forecast

Turbine type	Name/Directory	Features
FRANCIS	FR2	Turbine and pipe modelled according to analytical formulas
	FR4	Turbine and water supply modelled using machine hills, Interpolation and extrapolation on torque and flow **(q11,c11)=F(N,O)**
	FR5	Turbine and water supply modelled using machine hills Interpolation and extrapolation on torque and flow **(q11,c11)=F(Arctg(φ),O)**
PELTON **(HYDROTUR Scilab 6 :** **1 single PELTON diagram now covers all PELTON models)**	PELT1	Horizontal-axis PELTON turbine, 1 injector and 1 deflector Deflector following the pilot injector Turbine and pipe modelled using analytical formulas
	PELT2	Horizontal-axis PELTON turbine, 2 injectors and 1 deflector Deflector following the pilot injector Turbine and pipe modelled using analytical formulas
	PELT3	Pelton 3 jets, vertical axis, with or without jet dispatcher. Deflectors following the pilot injector. Turbine and pipe modelled according to analytical formulas.
	PELT4	Pelton 4 jets, vertical axis, with or without jet dispatcher. Deflectors following the pilot injector. Turbine and pipe modelled according to analytical formulas
	PELT5	Pelton 5 jets, vertical axis, with or without jet dispatcher. Deflectors following the pilot injector. Turbine and pipe modelled according to analytical formulas
	PELT6	Pelton 6 jets, vertical axis, with or without jet dispatcher. Deflectors following the pilot injector. Turbine and pipe modelled according to analytical formulas
KAPLAN	KB1	Turbine and intakes modelled using an analytical hill Interpolation and extrapolation based on the geometric mean of blades/vane and speed. **(Reduced torque=** $F\left(N,\sqrt{P*V}\right)$**)** Indirect combination between wicket gates and blades

Figure 2 : List of available models and algorithms

1.3 Organization of the programming guide

1.3.1 General presentation

Where possible, the settings are organized by functional blocks and roughly follow the presentation laid down in the Excel format ".**xls**" setting files or the text format ".**cfg**" configuration files.

Thus, each parameter is framed in a banner indicating its mnemonic, its meaning and its unit, as well as the name of the functional block or the name of the file in which it appears.

Memo therefore designates the name of the parameter in these files and in the simulation circuits.

Memo	Meaning of the parameter (unit used)	Functional block

The names of the functional blocks are those used in the XCOS simulation programs, and their functional diagrams; these are recalled in all the documents « **HydroSim – docs - TURBINES_Documentation**».

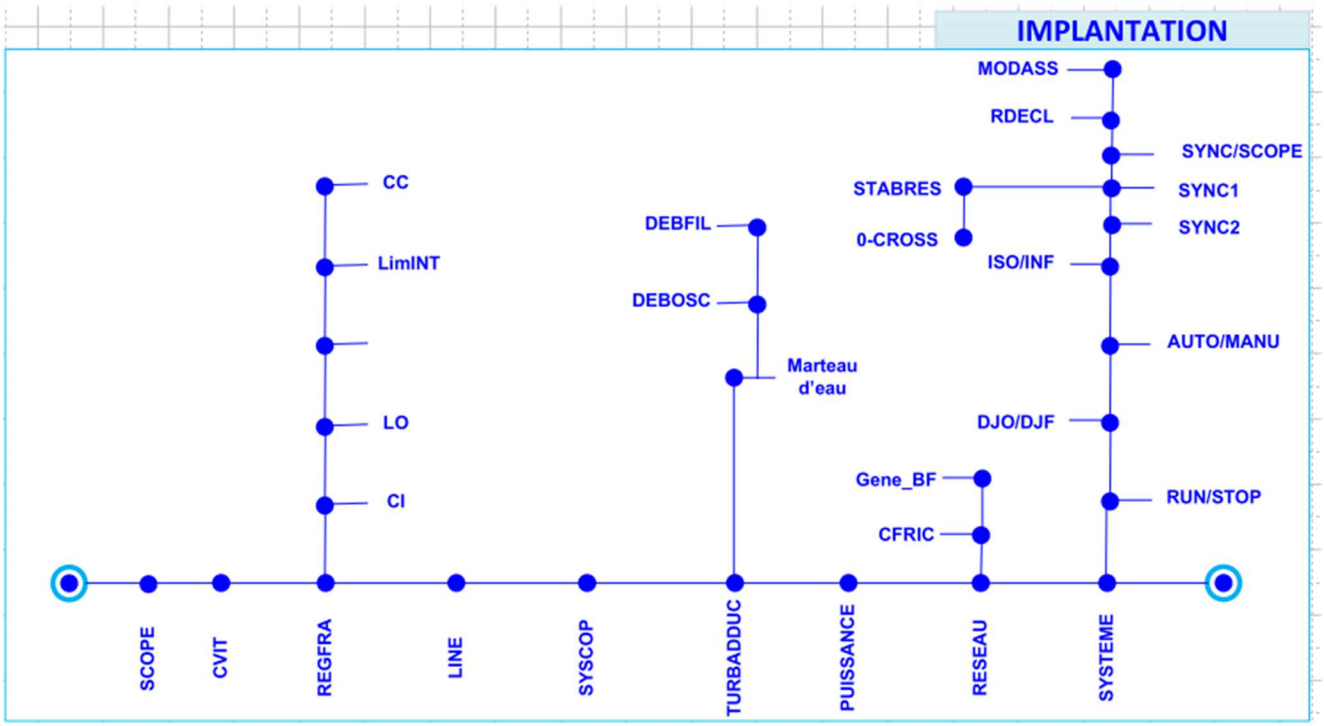


Figure 3 : Example of Functional Blocks – Single-line diagram of the FR5 circuit with machine hills

1.3.2 About the Index Table

The Index Table provides quick access to a parameter's description.

In this table, the parameters indicated in blue, bold characters, are not parameters present in the parameter files, but parameters calculated, in general, in the preliminary calculations (file ".**CTX")** for each simulation circuit (example: parameter **ck_,** calculating the hydraulic resistance of the supply circuit, and present for example in the **TURBADDUC** module of the **FR2** circuit)

2 SIMULATOR PARAMETERIZATION STRUCTURE

2.1 Structure of a directory

Apart from the files specific to the simulation of a machine (see *Figure 2*), located in the **HydroSim\TURBINES** directory, each simulator, for a given site, must have a set of files characterizing its settings in order to be able to launch a simulation:

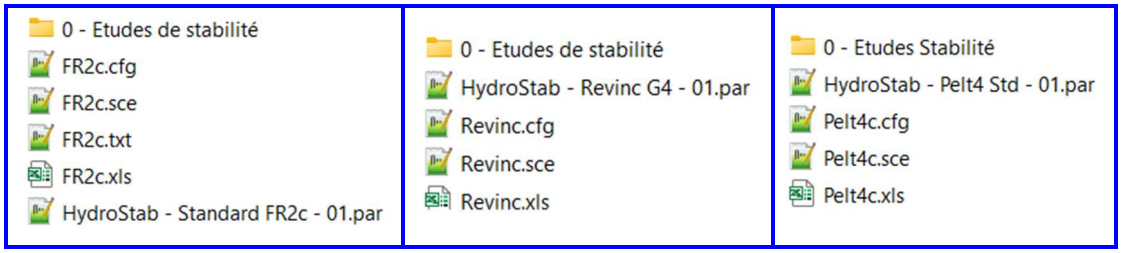


Figure 4 : Simulator parameterization structure

These structures are available in the **HydroSim\demos** subdirectories.

- An XLS file contains constant parameters for a given site. In general, this file must be defined only once, and must remain invariant in all simulations, regardless of the sequence used (generator start-up, load steps, load shedding, etc.)

- The "TXT" file is an optional text file, containing all the simulation parameters. It is produced at the start of the simulation if and only if the parameter bDelTx=0 in the "**VariablesGlobales.sce**" file. (see bDelTx in the index)

- The “SCE” file launches a simulation:
  - Click on an “SCE” file in the “SciNotes” window, then launch the execution of the file with the corresponding Scilab icon:
  - 

Running the “SCE” file initially causes the “HydroSim RUNNER” window to appear, offering a set of menus:

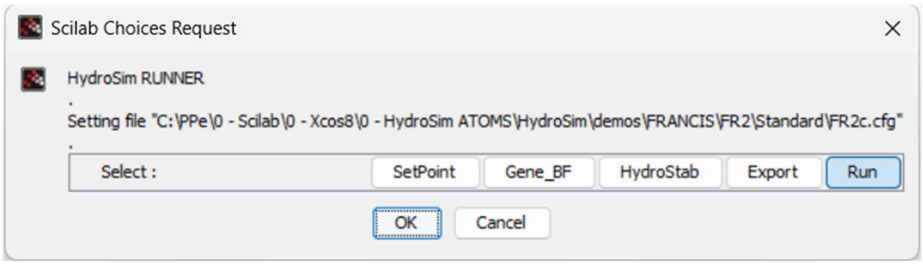


Figure 5 : "HydroSim RUNNER" window when launching an "SCE" file

Then confirm your choice with the OK button.

- The **SetPoint** menu sets the operating points of a simulation (Operating setpoint, isolated/separate network mode, etc.). (*See §3.7.1*)

- The Gene_BF menu initializes the disturbance recorder implemented in the “Network” sheet of all schematic libraries. This device allows the quality and robustness of the simulator to be evaluated following stimuli on the frequency or power loop. (*See §3.8.2, Figure 61*).

- The **HydroStab** menu selects a simulation method from those tested by use in a HydroStab session in the "*HydroStab - xxx.par"* file in the directory. (*See §3.4.3*)

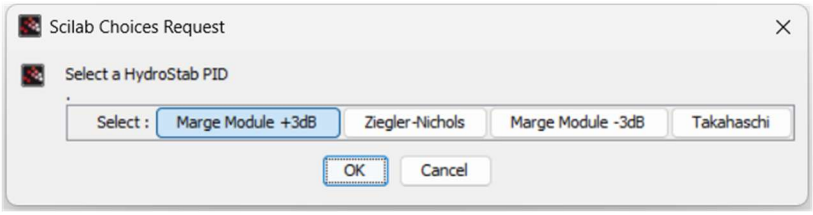


Figure 6 : HydroStab Menu - Selecting an Optimization Method

- The **Export** menu exports a simulation configuration to a selectable directory. This tool is for development use only.

- Le The "*HydroStab - xxx.par*" file is a backup file generated by the operator during a **HydroStab** session. It contains all the machine's hydraulic data, the methods used by the operator, and the associated speed PID settings.

  When recording in a HydroStab session, it is best to perform the recording sequence in a common directory with HydroSim, as shown in *Figure 4* (*See also §3.4.3*).

- The "CFG" file is an editable text file, and contains all the data recorded with HydroSim RUNNER.

  This file is loaded when launching a simulation session using **HydroSim RUNNER➔Run➔OK**, after loading the "XLS" file. As a result, the parameters common to the XLS and CFG files are overloaded.

2.2 Special test sequences outside HydroSim-RUNNER

2.2.1 General information

It may be necessary to add parameters to the "CFG" file to perform certain non-programmable sequences directly after using the RUNNER.

In this case:

- Select the relevant parameters in the "XLS" file
- Copy and paste these settings at the end of the "CFG" file
- Program these parameters to the expected value
- Save the CFG file
- Start the simulation

☞ **Then remove the additional parameters to create a new test suite**

2.2.2 Examples of special sequences

2.2.2.1 Attenuation of oscillations conducted during a hydraulic unit load trip sequence

Driven oscillations can be damped by programming a non-zero opening of the wicket gate of a FRANCIS machine. This feature is possible using the **PosMini** parameter.

We first program a trip sequence using **HydroSim➔SetPoint** for this purpose, then we add the PosMini parameter at the end of the HydroSim\demos\FRANCIS\FR2\Standard\FR2c.cfg file.

We then obtain the simulations saved in the HydroSim\demos\FRANCIS\FR2\Standard\0 directory - Stability studies\Triggering - Pn= 90%.

The reader will be able to consult the "CFG" and "SCG" files saved in this directory

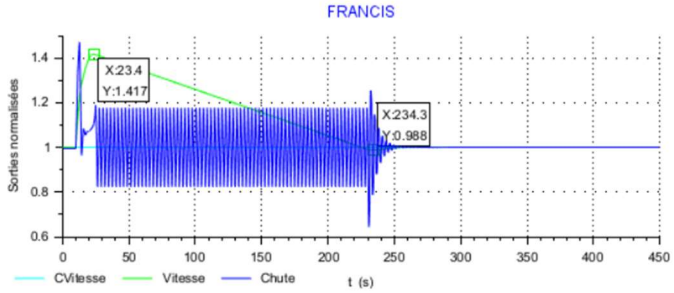


Figure 7 : File HydroSim\demos\FRANCIS\FR2\Standard\0 - Etudes de stabilité\Déclenchement - Pn= 90%\03_Francis -- FR2c - Declenchement - Pn= 90% - PosMini=0.00.scg

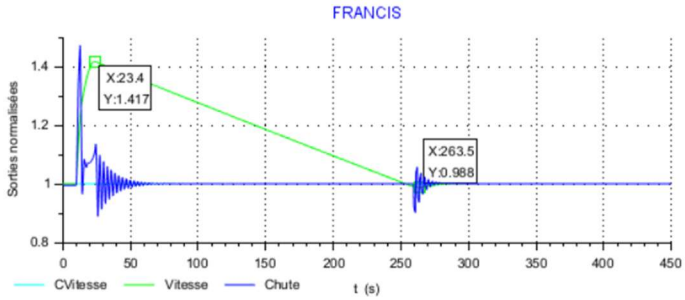


Figure 8: File HydroSim\demos\FRANCIS\FR2\Standard\0 - Etudes de stabilité\Déclenchement - Pn= 90%\02_Francis -- FR2c - Declenchement - Pn= 90% - PosMini=0.01.scg

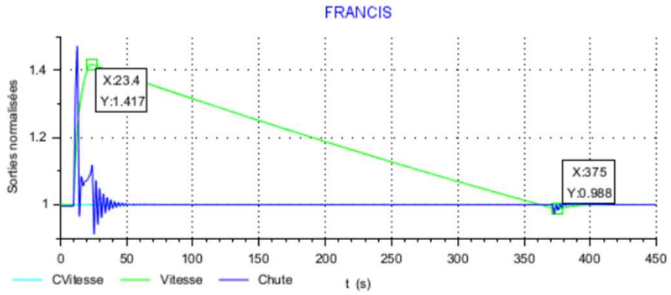


Figure 9: File HydroSim\demos\FRANCIS\FR2\Standard\0 - Etudes de stabilité\Déclenchement - Pn= 90%\01_Francis -- FR2c - Declenchement - Pn= 90% - PosMini=0.02.scg

3 PROGRAMMING GUIDE

3.1 Solver Selection – RUNGE-KUTTA Solver

Xcos offers a substantial list of solvers, available and accessible in the configuration menu:

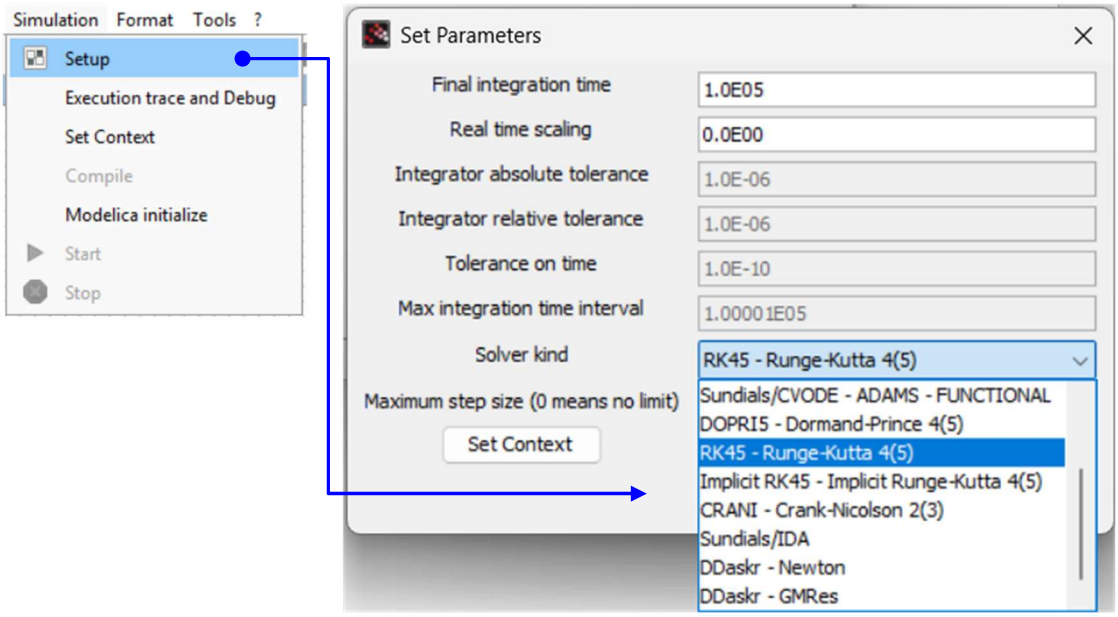


Figure 10 : Selecting the RUNGE-KUTTA solver under XCOS

Historically, all simulation circuits have been tested using the **variable-step** CVCODE NEWTON solver:



Then, the solver 

, **at fixed step**, provides equivalent accuracy, with a much more efficient convergence speed. This latter solver is therefore chosen for all circuits developed using HYTDROTUR. If you have any doubts about the simulations, please return to the NEWTON server.

The reader will obtain more detailed information by launching at the console:

```
➔ doc Solvers
```

Information on XCOS solvers can also be viewed on the website:

https://help.scilab.org/docs/5.5.2/en_US/Comparisons.html

3.2 XCOS Simulation Parameters

TSim	Simulation duration (s)	Main module - SetPoint

TSim sets the time requested for the duration of the simulation. This parameter is as follows:

- All oscilloscopes or recorders present in the schematic libraries (Scope folio) in the schematic libraries)



- The END functional box 

present in the main program of each simulator and turbine model.

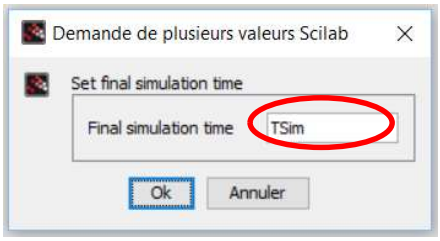


Figure 11 : TSim: Setting the simulation time

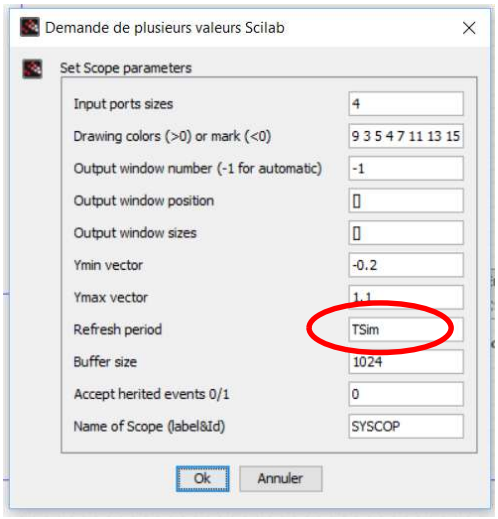


Figure 12 : Lifetime of digital oscilloscopes

The simulator considers the "final integration time" defined in the configuration item of the simulation menu from the time entered in this field of the dialog box.

This parameter is a numeric value or a symbolic variable defined in the XCOS context.

The duration of the TSim time should normally be less than the default value defined in the simulation parameter setting box (10^5 s). It is therefore not necessary to access this instance, which avoids any disruption of it (Final integration time):

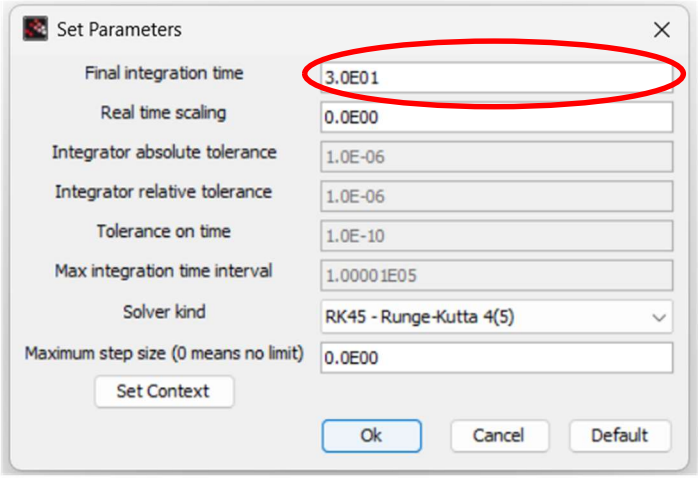


Figure 13 : Simulation parameter adjustment box

TSim can be adjusted according to the sequences to be simulated:

- Operation in positioner mode
- Turbine start-up and connection to the electrical network
- Group sequence coupled with disruption of the network load and load shedding of the group, with return to idle operation or machine shutdown
- …etc.

Notes

Each simulation program is launched from a **.sce** file (Scilab terminology), and includes a set of **tic()** and **toc()** instructions to enter the total effective duration of the simulation. This information is displayed at the end of the simulation in the Scilab console.

Example:

```
Simulation duration : 37.2 s

-->
```

Figure 14 : Displaying the simulation duration in the Scilab console

bDelTxt	Maintain (0) or Delete (1) temporary configuration files in .TXT format	macros\VariablesGlobales.sce

The procedure for loading a configuration file in .XLS format, when executing a model, produces a temporary file of the same name in text format ".txt". The bDelTxt parameter allows the "txt" file to be maintained or deleted for use in search engines (WinMerge for example). **This setting is accessible in the "VariablesGlobales.sce" file.**

3.3 Constants

g	Acceleration of gravity ($m.s^{-2}$)	XLS

☞ Unless otherwise stated, g=9.81 $m.s^{-2}$

ce_	Wave speed (m/s)	XLS

☞ Unless otherwise stated, ce=1000 m/s

rho	Density of water ($Kg.m^{-3}$)	XLS

☞ Unless otherwise stated, rho=1000 $kg.m^{-3}$

mu	Dynamic viscosity of water (Pa.s)	XLS

☞ Unless otherwise stated, mu=$1e^{-6}$ Pa.s

nq	Opening/Flow Rate Adaptation Coefficient (wu)	TURBADDUC (without Hills). XLS

nq is an empirical coefficient to represent the nonlinear relationship between flow rate Q and opening O: $Q = O^{nq}$

☞ Unless otherwise stated, nq=0.7.

This device is used in the simulation of the Turbine + Water supply TURBADDUC block of the FR2, PELT1, PELT6 circuits, or whenever the machine hills are not known (FR2, PELTON circuits)

->nq=0.7 ; x=0 :0.01 :1 ; y=x^nq ; plot2d(x,y) ; plot2d(x,x) ; xgrid ; // Scilab Program

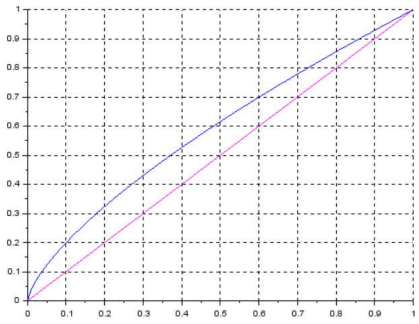


Figure 15 : Flow/Opening Law by default $Q=O^{nq}$

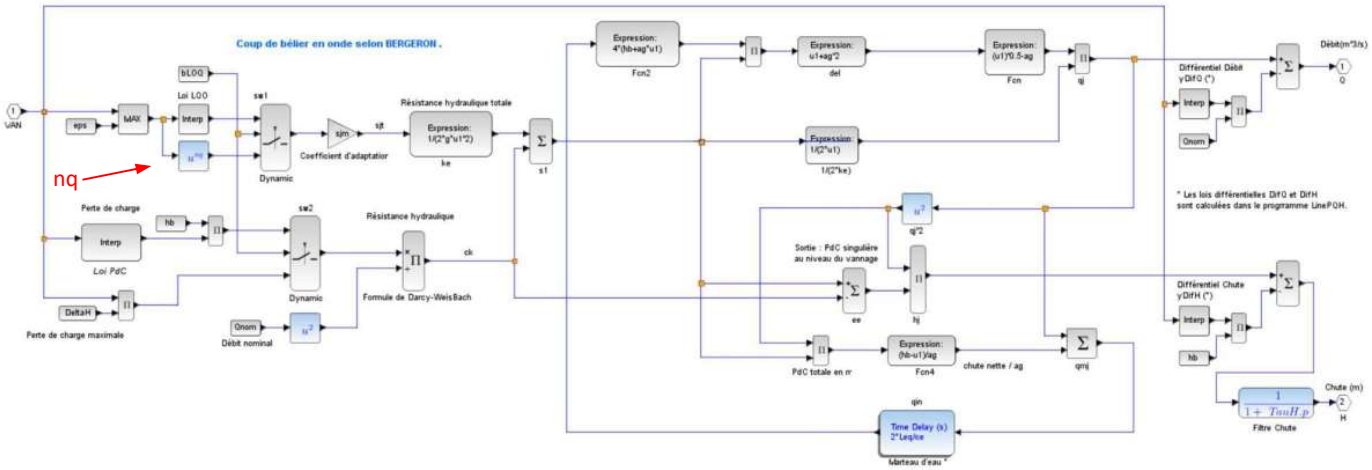


Figure 16 : "Turbine+Adduction" block TURBADDUC of the FR2 circuit

rugo	Pipe roughness (m)	XLS

☞ Unless otherwise stated, rugo=5.e^{-7} m.

The value of the roughness parameter is contained in the roughness interval of steel pipes (in the table, "steel pipes, welded ends, continuous interior").

Roughness is used in preliminary calculations to find the friction coefficient of the pipe (see **Colebrook-White formula**). This device characterizes the load losses of linear losses in the flow of the hydraulic circuit.

☞ See also parameter **DeltaH**, ***Figure 171***

eps	Constant (su)	XLS

☞ eps=10^{-10}. “Epsilon” value used in hysteresis.

Note that the representation of epsilon in Scilab is noted %eps and can be viewed on the console: %esp=2.22.10^{-16}.

However, %eps can, in certain calculations, cause instabilities, and the HydroSim constant **eps** is preferred.

3.4 Setting up the hydraulic circuit and the machine with HydroStab

3.4.1 Use of the HydroStab program in the HydroSim supply

The **HydroStab** calculator aims to calculate the setting of a simplified PID type speed corrector, from data describing a hydraulic circuit.

This program calculates the *a priori* adjustment values of the speed regulator control parameters in small movements, imposing a minimum distance between the Nyquist locus and the critical point. This distance is also called the **module margin.**

This model is thus based on a frequency method, and is only applicable to a linear system.

The objective is to constrain the Open Loop Transfer Function (FTBO regulator + process) to pass through a point P imposed in the Nyquist plane.

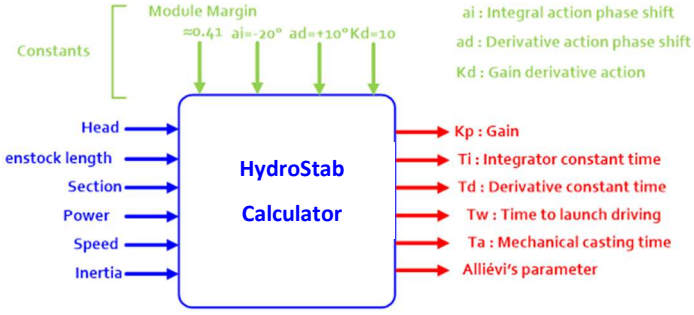


Figure 17 : HydroStab Calculator - Calculate open loop PID parameters

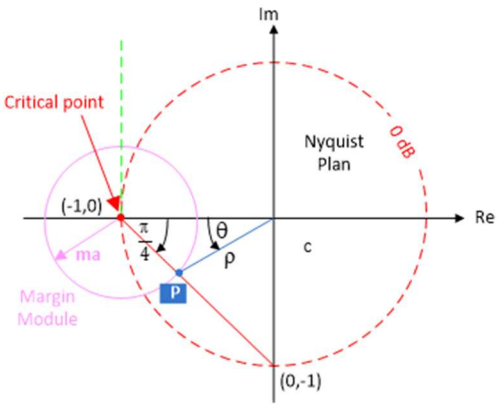


Figure 18 : Module Margin in the Nyquist plane

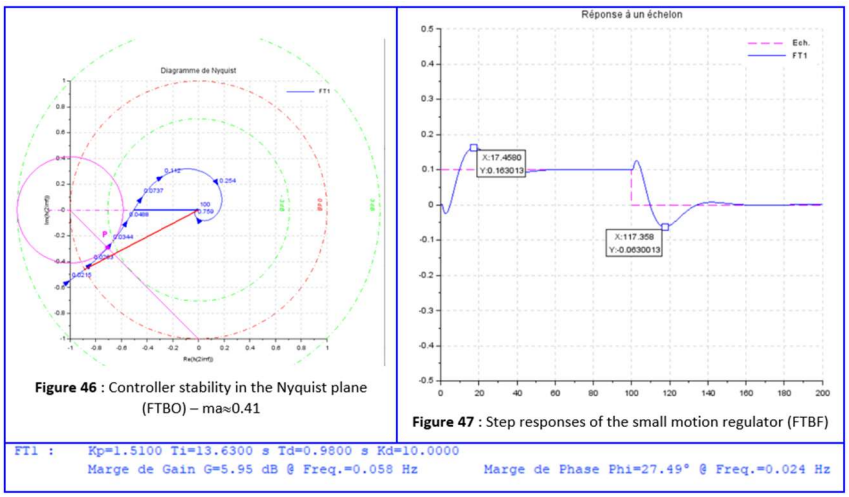


Figure 46 : Controller stability in the Nyquist plane (FTBO) – ma≈0.41

Figure 47 : Step responses of the small motion regulator (FTBF)

Figure 19 : PID Speed adjustment Method by Module Margin in Nyquist Plane

☞ Note that HydroStab also offers another calculation method based on the **Ziegler and Nichols** theory, by oscillation of the transfer function of the simplified closed-loop process, and deduction of the stability parameters of the regulator

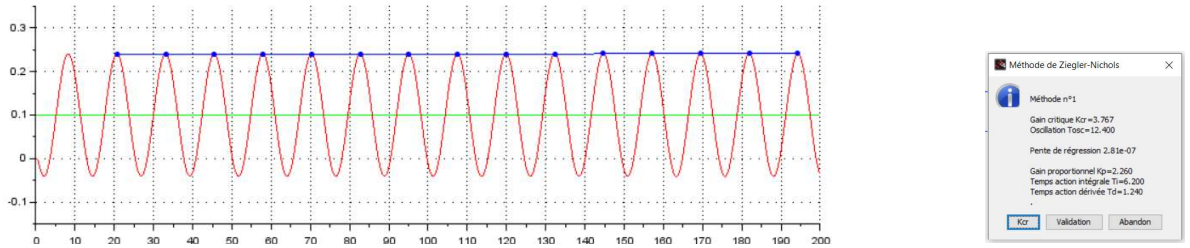


Figure 20 : PID Speed adjustment by Ziegler-Nichols Method

The reader should refer to the document "HYDROTUR - HydroStab Solution - Stability studies of servocontrols". These documents are accessible in the ATOMS HydroStab module[1]

Subsequently, other methods may be implemented without repeating this document.

3.4.2 Data for the HydroStab calculator

The data below must be recorded in **HydroStab** in the ".**par**" parameterization file for the plant and the group studied.

[1] Type "-> atomsInstall("HydroStab")" in the Scilab console to download this module.

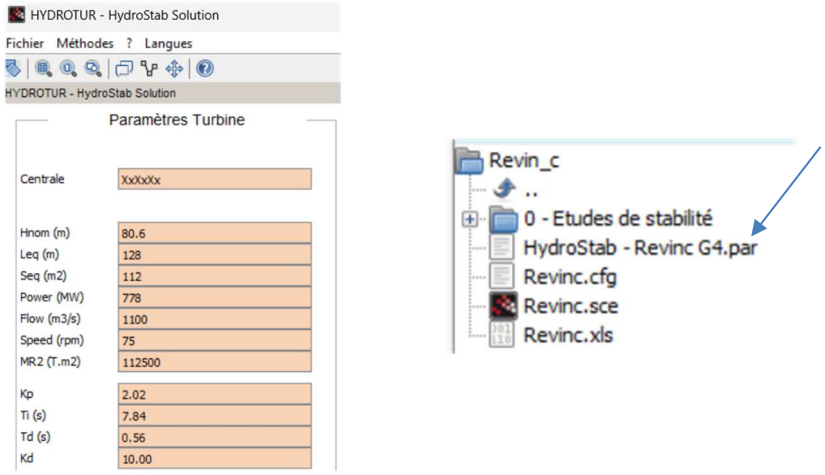


Figure 21 : Retrieving HydroStab data into a HydroSim directory

Head **Hnom**	Head (m)	HydroStab

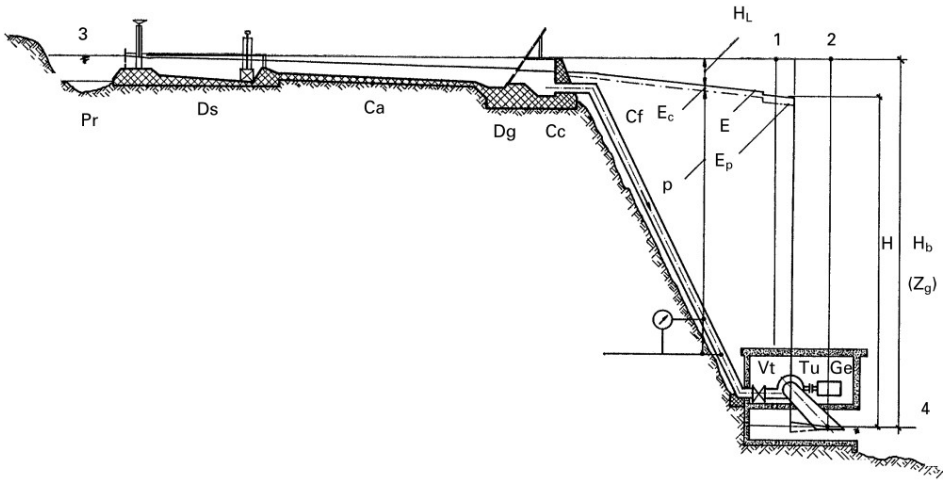
This parameter creates the internal variable **hb**=Head.

In newer versions, the head is rather noted **Hnom**.

In terminology, we distinguish:

- Gross head: difference in water level between the upper basin and the lower basin
- Net head: difference in water pressure at the "terminals" of the turbine, i.e. between the tank outlet and the suction inlet for Francis, Kaplan, or bulb turbines, or between the injector inlet and atmospheric pressure for a Pelton turbine

The difference between the two heads represents the pressure losses in the hydraulic circuit, but this difference is not significant in the context of the simulations considered (generally 2%).



Pr: prise d'eau
Ds: dessableur
Ca: canal/conduite d'amenée
Dg: dégrilleur
Cc: chambre de mise en charge
Cf: conduite forcée
Vt: vanne turbine
Tu: turbine
Ge: générateur

1: point de référence amont de la turbine
2: point de référence aval de la turbine
3: point de référence amont de l'aménagement
4: point de référence aval de l'aménagement
E: ligne d'énergie
E_c: énergie cinétique
E_p: énergie de pression
p: pression
H_b: chute brute
H: chute nette

Figure 22 : Components and longitudinal profile of a small hydraulic power station

Leq	Equivalent pipe length (m)	HydroStab
Seq	Equivalent pipe section (m^2)	HydroStab

It is recommended to consult hydraulic experts to obtain the Leq and Seq input data.

Alternatively, in simple cases, the following documents provided in the HYDROTUR software suite can also be used.

Also see

Document **HydroSim \ CALTUR\Calculation note CALTUR - Version 2.4 (en-fr) .xlsx**

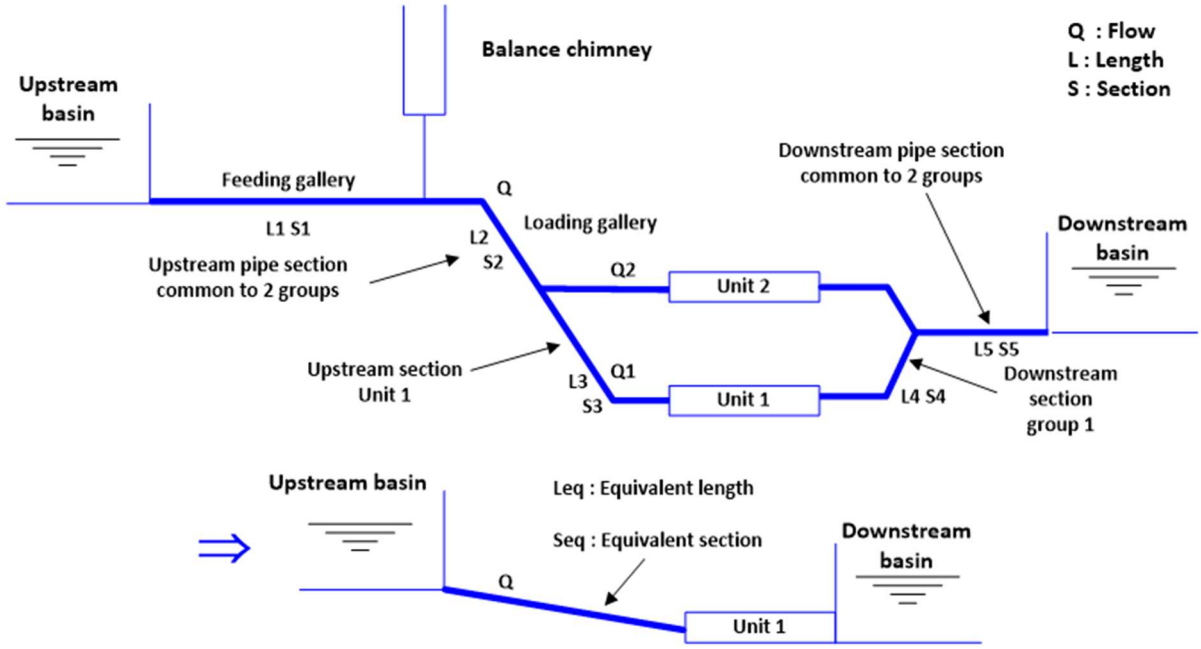


Figure 23 : Preliminary calculation for the stability study of a hydraulic group

The **HydrpStab** calculator uses a simplified model, deduced from a preliminary study of the hydraulic circuit.

This study determines the equivalent length and section Leq and Seq, allowing a complex hydraulic circuit to be reduced to a simple form using known methods, as shown in the figure above.

Non-exhaustive reminder of some formulas used in this study:

$L_{eq} = \sum_{i=1}^{n} L_i$	$\frac{L_{eq}}{S_{eq}} = \sum_{i=1}^{n} \frac{L_i}{S_i} \Rightarrow S_{eq} = \frac{L_{eq}}{\sum_{i=1}^{n} \frac{L_i}{S_i}}$

Of course, it is also necessary to consider the reductions in section in the circuit. For example, for a section of variable section:

	$S = \sqrt{Si * So}$

These parameters create the internal variables:

- **ag** : $ag = \frac{ce}{g * Seq}$ used in certain TURBADDUC blocks, for circuits not equipped with machine hills.
- **Dh** : $Dh = \sqrt{\frac{4 * Seq}{\pi}}$ (m) **Hydraulic diameter**
- The Reynolds number, for information purposes only, **Re :** $\mathrm{Re} = \frac{2 * rho * Qnom}{mu\sqrt{\pi * Seq}}$ or $\mathrm{Re} = \frac{V * rho * D_h}{mu}$

, formula in which **V___** denotes the average speed of the water: $V = \frac{Qnom}{Seq}$

Pnom **PW**	Nominal power of the machine (MW)	HydroStab

Pnom (or PW) normally denotes the mechanical power supplied by the turbine at full opening and nominal speed below the nominal gross head.

Note

A dispute may arise between mechanical power and electrical power, but this confusion only corresponds to a difference of around 2% on the efficiency at the nominal point (alternator efficiency ≈ 98%). As this efficiency is generally not known (modernizations, rehabilitations) and it does not influence the dynamic behaviour, this approximation remains legitimate.

In any case, a check is possible if the nominal flow rate is provided:

$$W = \eta.\rho.g.H.Q$$

with W = mechanical power of the turbine (kW), η = turbine efficiency (≈90%), ρ = density of water = 1 t/m3, g = 9.81 m/s², H = nominal net head (m), Q = nominal flow rate Qnom (m3 /s).

This parameter creates the internal variables:

- **wn** : $wn = PW * 10^6$ (W)
- **Tw** : $Tw = Qnom * Leq / (1. * g * hb * Seq)$ (s) **Hydraulic launch time**
- The **Allievi** parameter, for information only: $Allievi = \frac{Tw * ce}{2 * Leq}$

Qnom	Nominal flow rate (m^3/s)	HydroStab

This data must be entered by the operator.
When it is not known, it can be approximated by the relation:

$$Qnom = wn / (1. * rho * g * hb)$$

Vn	Nominal machine speed (rpm)	HydroStab Reseau

This data is generally available on the turbine nameplate (rehabilitation)



Figure 24 : Example of a nameplate attached to the turbine

This parameter creates the internal variable **om0** : $om0 = Vn * 2 * \pi / 60$ (rd/s)

Inertie	Inertia of rotating masses Turbine + Alternator (T.m²)	Reseau HydroStab

Inertia conditions the transient response of the group: on a demand for electrical power, if the control device has not compensated this demand by an adapted opening, the necessary energy absorbed by the network is taken from the kinetic energy of the group, and results in a slowdown more rapid as the inertia is low.

Notes

In physics, the moment of inertia of a rotating mass is defined as MR², where M is the rotating mass and R is the radius of the center of gravity.

Unfortunately, mechanics prefer to use "PD²", where P is the weight and D the diameter. The concept of weight is already an error insofar as weight is linked to the environment (attraction of gravity) and therefore theoretically depends on the location, whereas inertia is an intrinsic given.

Furthermore, the reference to the diameter gives a ratio of 4 between inertia and PD², hence the risk of gross error.

Therefore, this data must be checked very carefully before using it in a simulation:

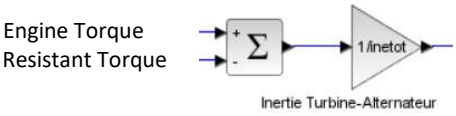
- If the information given is explicitly the PD², calculate the inertia = PD²/4
- If there is any doubt, proceed as follows:
  - ✓ Calculate the mechanical launch time **Ta** : $T_a = \frac{I\omega^2}{W_n}$

    where I is the inertia in kg.m², ω the rotation speed in rd/s, and Wn the nominal power in W.

    Ta is then expressed in s.

    If Ta is approximately between 5 and 15 s, the inertia is probably correct, if Ta is greater than 20 s, there is every probability that the data provided is the PD² and not the inertia.
  - ✓ If Ta is less than 5 s, it is possible that the data provided (inertia or PD²) is that of the turbine and not that of all the rotating parts
  - ✓ In a hydroelectric group, most of the inertia comes from the alternator, the turbine representing only about 10% of the total inertia. If, at the limit, we do not have the turbine inertia, we can take for the group inertia: alternator inertia x 1.1.

This parameter creates the internal variable **inetot** : $inetot = Inertie * 1000\ (kg.m^2)$, variable used in the Model Network module, after calculating the Engine Torque – Resistant Torque differential:



3.4.3 Retrieving HydroStab data into HydroSim

Simulations conducted under HydroStab must be saved in a file "HydroStab – xxxx - yz.par" in the same directory as the files used to launch the HydroSim simulation.

For example, in the case of the simulation of the FR2 machine, we will find in the HydroSim\demo\FRANCIS\FR2\Standard directory, the files:

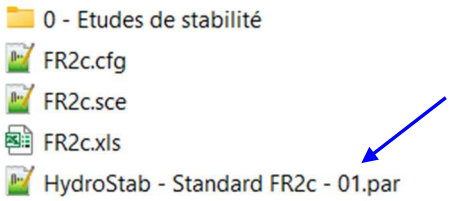
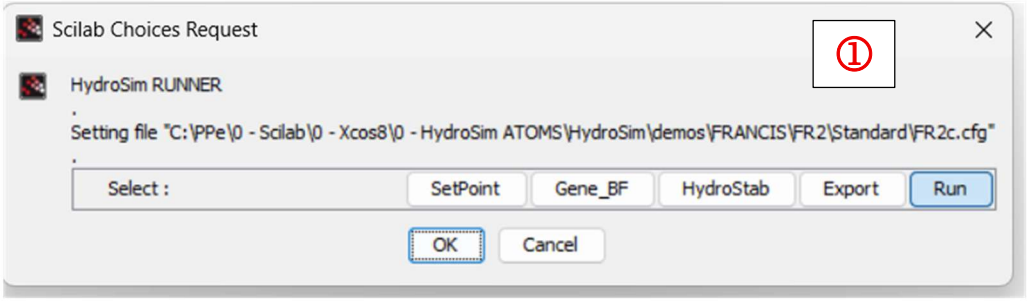


Figure 25 : HydroStab file in FR2 machine simulation

To run a simulation with the desired stability parameters, you must first launch **HydroSim RUNNER** by executing the SCE file in this directory. This will give you the associated list of choices. ① :



By validating the HydroStab choice with the OK button, you obtain a new list of choices between the different methods recorded in the file "HydroStab – xxxx - yz.par" ②

Then select a method, then confirm with the OK key

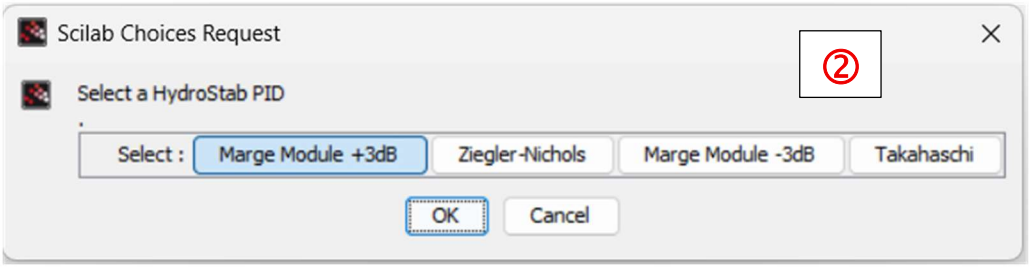


Figure 26 : Retrieving HydroStab data into HydroSim

☞ **The data from the simulated hydraulic machine and the speed PID adjustment are then copied into the CFG file in the directory.**

3.4.4 Other parameters

Dr	Wheel outlet diameter (m)	FR4/ FR5 XLS

This data is a hydraulic characteristic of the machine and allows the consistency of the data to be checked by recalculating power, flow rate, and head.

Note

Dr is data explicitly used in the "Turbine + Adduction" TURBADDUC block, circuits developed with a machine hill (circuits FR4, FR5, ...)

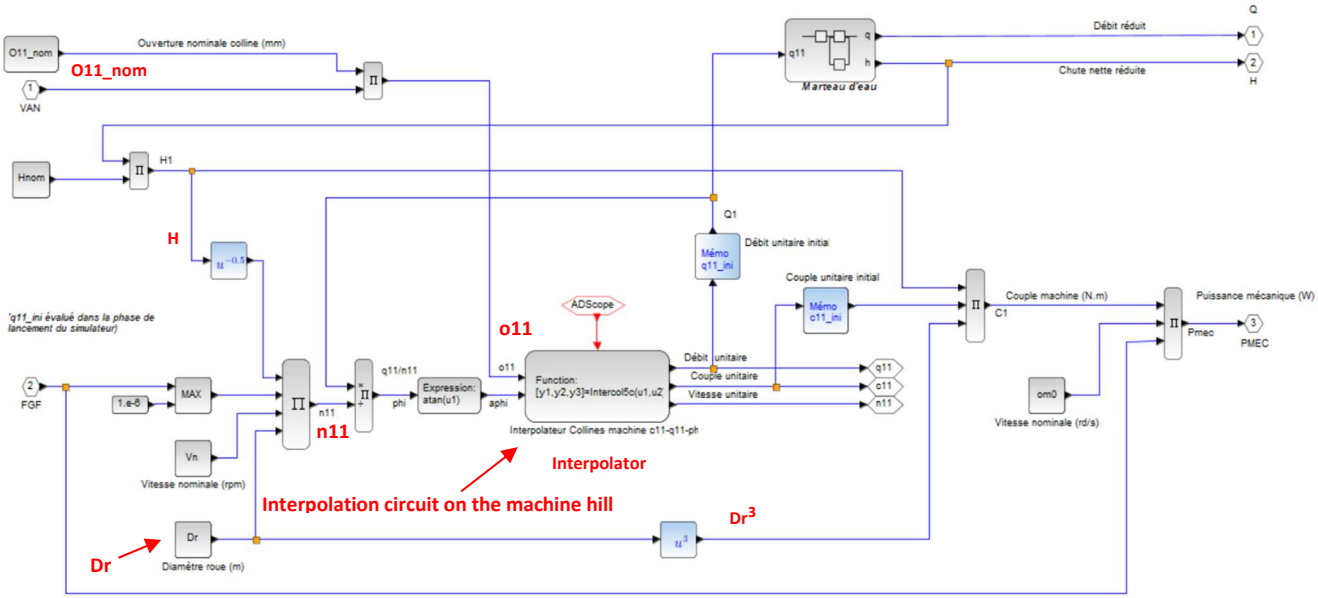


Figure 27 : "Turbine + Adduction" circuit of the **FR5** algorithm with machine hill and interpolator

This circuit[2] uses a machine hill, and the interpolation algorithm uses as input the reduced machine speed **n11**and provides as output the reduced flow **q11**, the reduced machine torque **c11**.

☞ ***The formulas manipulating this data are recalled in Chapter 6***

In the diagram presented above in *Figure 27*, the data **O11_nom** (mm) is calculated automatically by H, in the loading phase of the machine hill. It corresponds to the maximum opening defined in the hill, and allows the normalization of the opening **o11**(su) before the solicitation of the interpolator on the hill, so that

$o_{11} = VAN.O_{11}_nom$ where VAN is the output of the SYSCOP block expressed in reduced coordinates.

CourseSM	Maximum stroke of the valve or injector servomotor (mm)	XLS
CourseSMP	Maximum servomotor stroke of the blades (mm)	XLS

These parameters are mainly used in plotting the linearity laws of the input data (PlotP, PlotQ, PlotH, etc. instructions) to present the x-axes in user coordinates.

[2] *See also chapter 6.5*

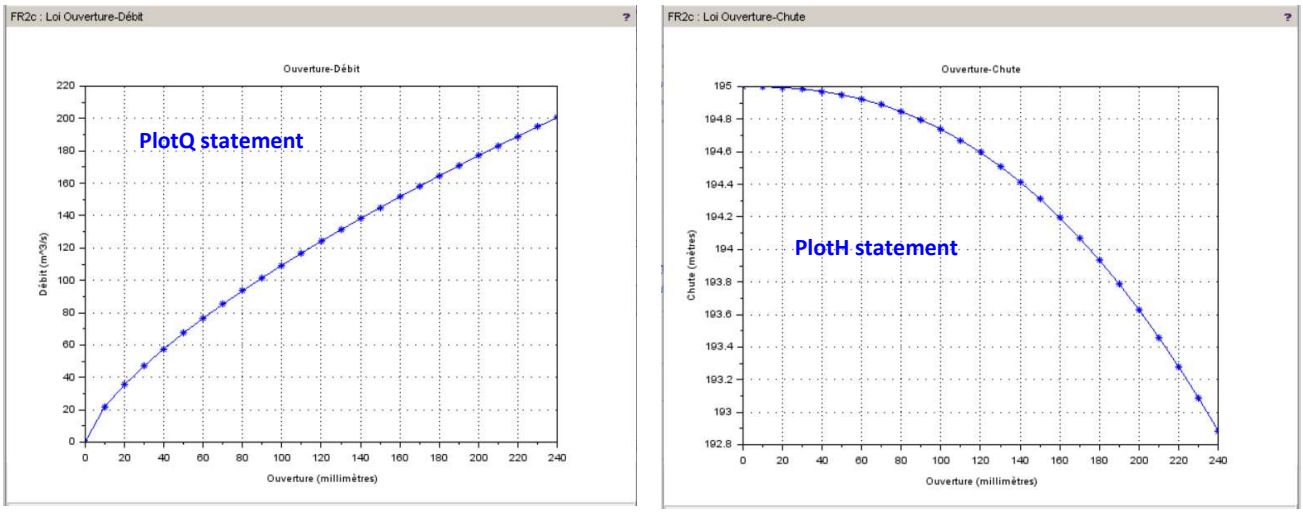


Figure 28 : Example of using the parameter CourseSM=240mm

Omav	Noload opening (mm)	XLS

There are two possible scenarios:

1. If bLOQ=1, Omav represents the estimated noload opening, expressed in millimeters.

   If the data is not known, it can possibly be deduced from the recording of a DE type trigger sequence of the hydraulic unit.

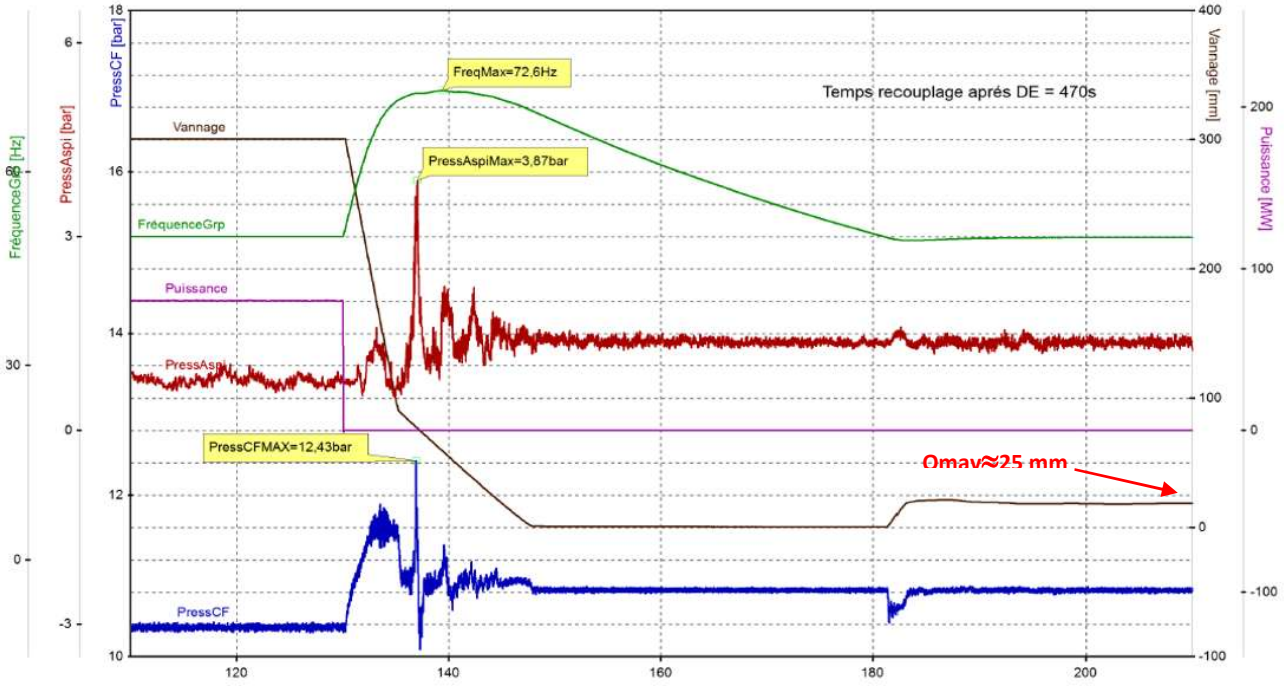
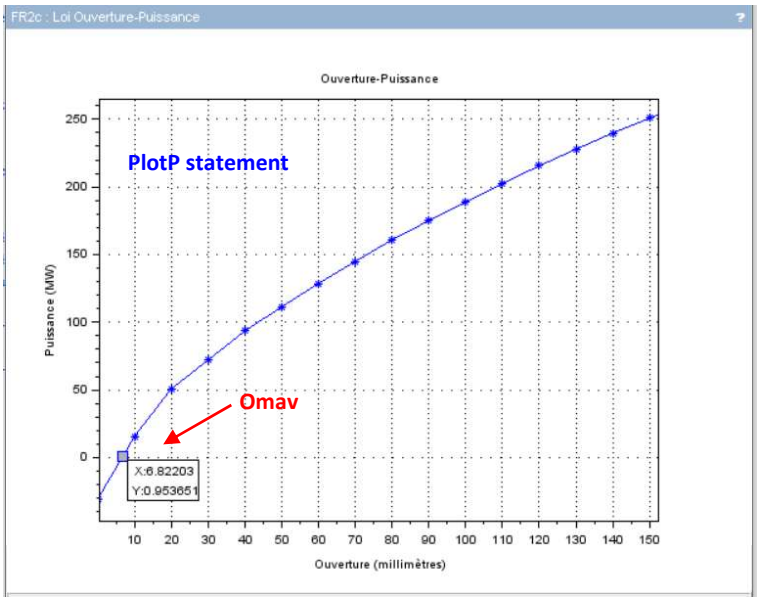


Figure 29 : Evaluation of the Omav idle opening during a DE trigger

2. If bLOQ=0, the Omav parameter is not considered, but evaluated from the Power/Opening linearization law. In this case, Omav is the opening of the servomotor at zero power.




```
if bLOQ==0 then
                                    // Linéarisation du système par la loi analytique Q=O^nq (nq=0.7)
                                    //-------------------------------------------------------------
                                    LinePQH_1()
                                                  Interpolation on the Power/Opening law at point P=0
                                    // Redéfinition de la marche à vide Omav
                                    //--------------------------------------
                                    Omav=interpln([P;O],0)
```

Figure 30 : Evaluation of the Omav noload parameter by linear interpolation on the Power/Opening law (bLOQ=0)

3.5 Speed governor parameters

Kp	Speed Corrector Gain (su)	REGN HydroStab
Ti	Integrator Time Constant Speed (s)	REGN HydroStab

- Kp represents the transient gain of the Proportional/Integral speed governor.

Temporary statism B_t , a term sometimes present in the literature, is expressed by the inverse of the gain K_p :

$$B_t = \frac{1}{K_p}$$

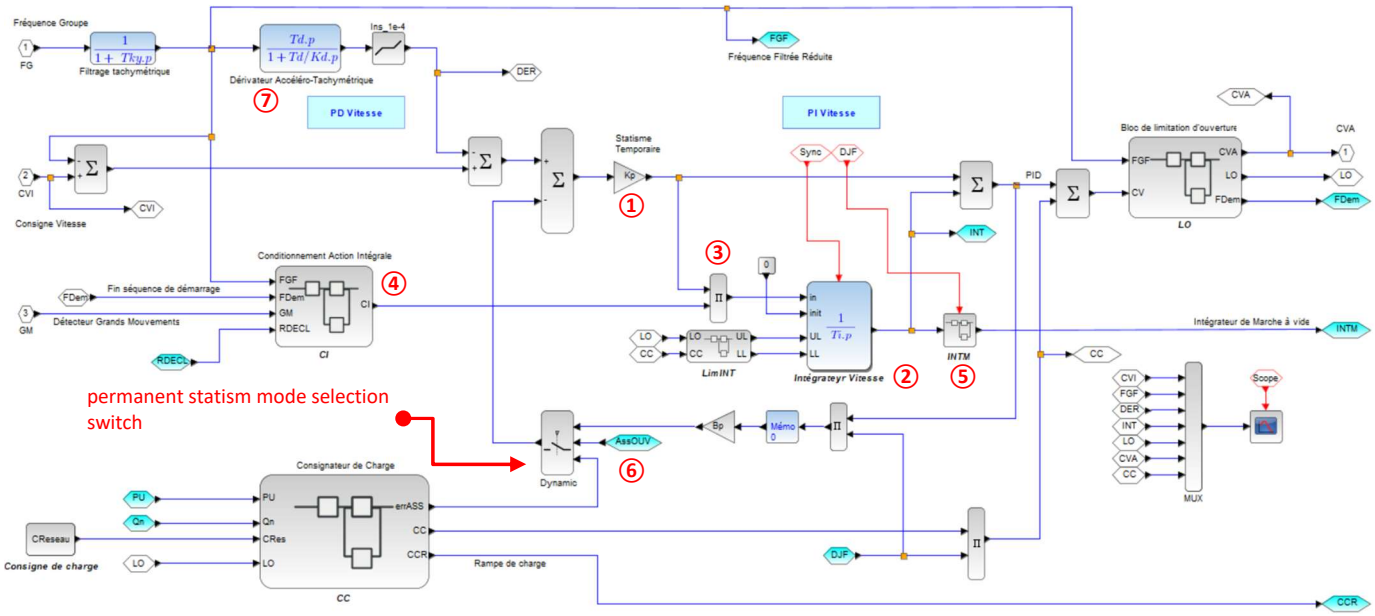


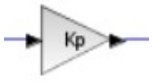
Figure 31 : Speed governor for Francis machine – Francis circuit FR2➔REGFRA

☞ Values to be programmed according to the stability study conducted under **HydroStab**

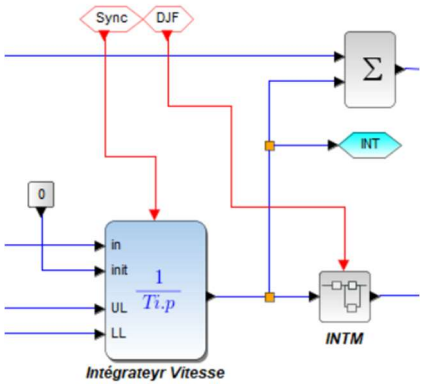
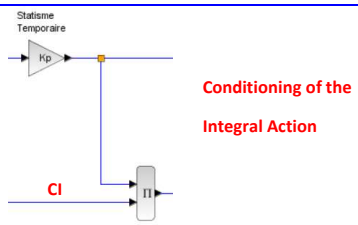
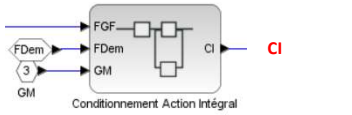
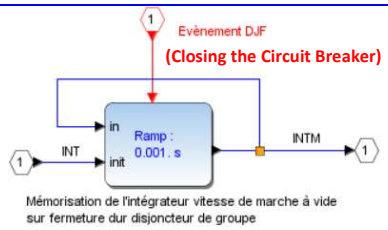
- Ti adjusts the integral action of the PI speed.

The integration component $\frac{1}{T_i * p}$ is made from the **SEGPAL**[3] complementary library, because the integration action requires a mechanism specially designed to avoid saturations of the component in an optimal order.

This anti-saturator is known as the Anti-Win up system, and is the subject of further studies and numerous publications.

①	• PI governor gain Kp	**Temporary stasism** 

[3] The **SEGPAL** library is a palette of XCOS components designed specifically for the **HYDROTUR** project, when the basic components of the XCOS palette do not meet specific needs. These components are colored blue in the simulation circuit schematics.

②	• The integrator receives the signal to be integrated on its “in” input • The components in red provide a logic equation, which, upon detection of a rising edge, causes the Integrator register to be instantly reset to the value specified on the “init” input. (See *Figure 85, Figure 86*) Here, the integrator is reset to 0 at the instant the group circuit breaker closes, and when the unit is triggered for a return to no-load operation. • Two inputs “UL” (Upper Limiter) and “LL” (Lower Limiter) allow dynamic control of the integrator saturation	
③	• The integrator input results from the result of a multiplier whose first term is the regular input of the PI corrector, the second input is a Boolean value CI equal to 0 or 1 • If the boolean is zero, the integrator is therefore fixed at its last value	
④	• The integral action is ultimately conditioned by a set of conditions whose description is indicated in *Figure 121* (**Anti-Win up** device).	
⑤	• The “INTM” block is intended to store the value of the integral term when the circuit breaker closes. • The noload integrator INTM is then used in the initialization of the load setter, when the circuit breaker closes, by performing a tare of the DC recorder ramp • This operation allows bumpless continuity of the electrical control (BMAV block)	

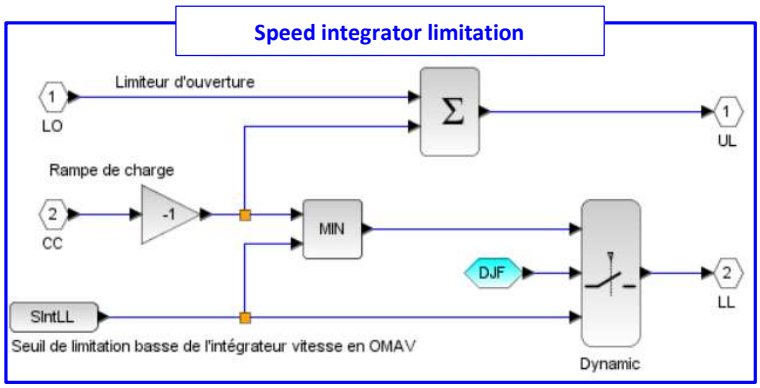
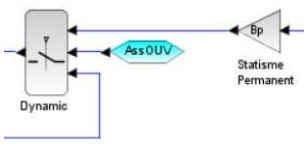


Figure 32 : LimINT block for conditioning the integral action

The speed integrator is therefore bounded by:

- Its upper limitation UL=LO-CC
- Its lower limitation LL=Min(-CC,SIntLL)

⑥	• Speed droop switch Opening / Power / Flow rate when the circuit breaker closes.	

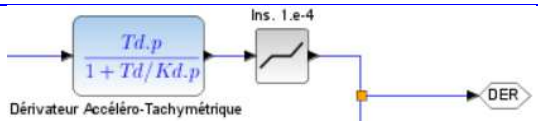
⑦	• Accelerometer-tachometer derivative with speed insensitivity	

Figure 33 : PID Descriptor Speed with static at Opening / Power / Flow

Kd	Accelerometer-tachometer derivative gain (su)	REGN HydroStab
Td	Time constant of the Accelerometer-tachometer derivative (s)	REGN HydroStab

The two parameters Kd and Td adjust the effectiveness of the derivative action of the speed corrector.

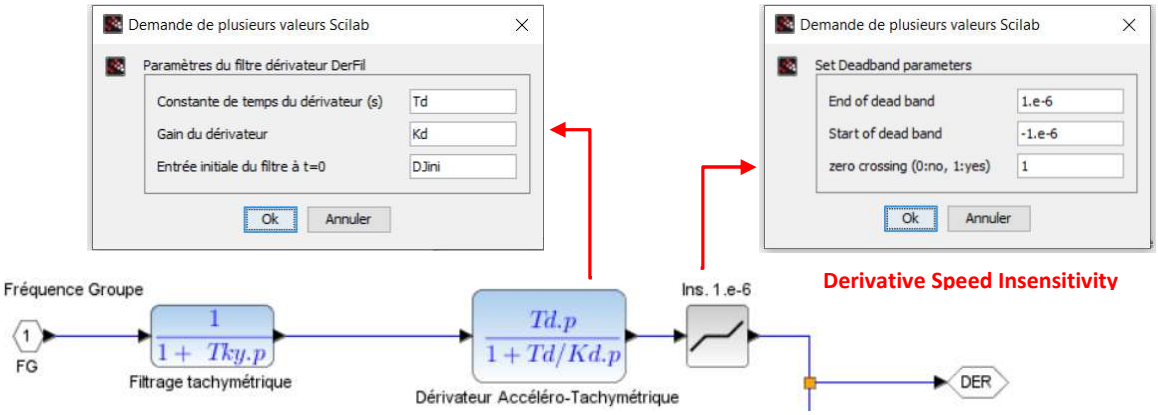


Figure 34 : Accelerometer-tachometer derivative in REGN blocks

The derivative action is calculated from the filtered speed measurement, not from the speed deviation of the PID regulator.

The "Accelero-Tachometric Derivative" function is implemented using a component of the **SEGPAL** library, with the aim of **forcing the derivative action to 0** depending on the initial conditions for launching the simulation:

- If the simulator starts in the "Machine stopped" state (TDJF>0, FG=0 ⇒ **DJini**=0)
- If the simulator starts in the "Group coupled to the network at nominal speed" state (TDJF=0, FG=1 ⇒ **DJini**=1)

This device makes it possible to eliminate an unnecessary transient regime at the start of the simulation.

☞ Kd: Program Kd=10.0 unless otherwise indicated.

☞ Td: Value to be programmed according to the results of the stability study **HydroStab**

The derivative action is equipped with a programmed insensitivity to $\pm 1.e^{-4}$

Bp	Permanent speed droop (Frequency) (su)	REGN XLS

The purpose of permanent droop is to deliberately limit the group's participation in primary frequency control, to balance the contributions of generators connected to the same electrical network.

Permanent droop is expressed by a linear relationship: $\Delta X = -\frac{\Delta F}{B_p}$

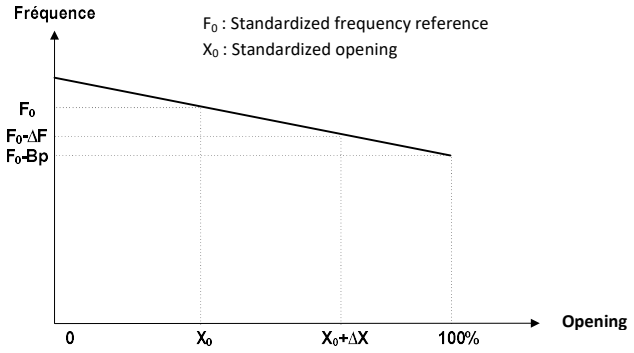


Figure 35 : Permanent droop (Opening)

Bp is therefore an operating parameter of the group, adjusted by the operators.

Note

☞ Permanent droop is only active when the group is coupled to the network. It is therefore not operational during the group synchronization phase.

On the other hand, a stability study of a hydroelectric group is carried out under the most unfavourable conditions, that is, when the group is astatic.

Program Bp=0.04 unless otherwise indicated or tested.

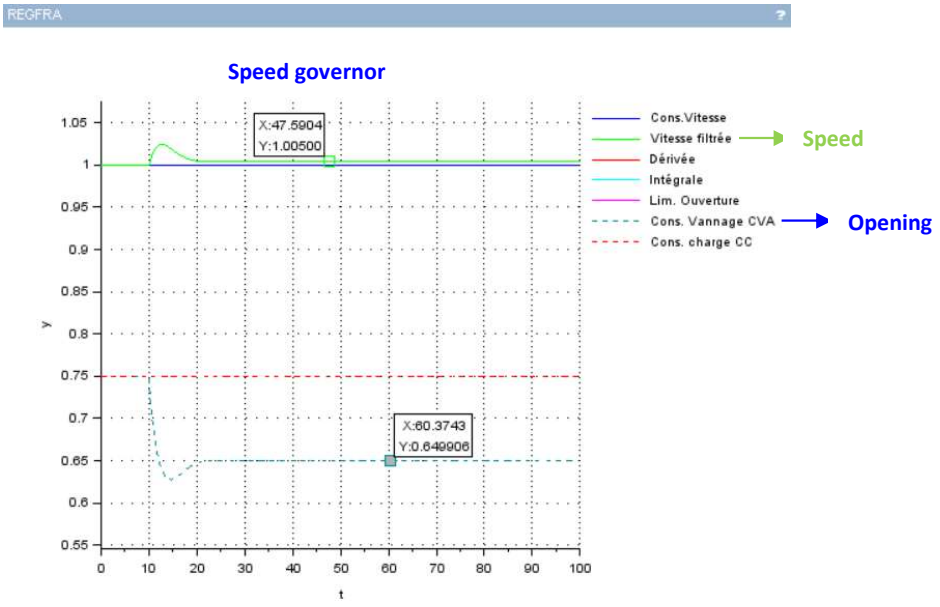


Figure 36 : Droop checking at opening (FR2 Circuit)

Control mode ModAss=0 – Circuit breaker Closed – Load disturbance 10% at t=10s - Programmed droop Bp=0.05

$$Bp = \frac{\Delta f}{\Delta Van} = \frac{5.10^{-3}}{10^{-1}} = 0.05$$

Bp2	Permanent droop Frequency/Flow or Power (su)	REGN – CC XLS

Permanent droop is expressed by a linear relationship: $\Delta P = -\frac{\Delta F}{B_p}$

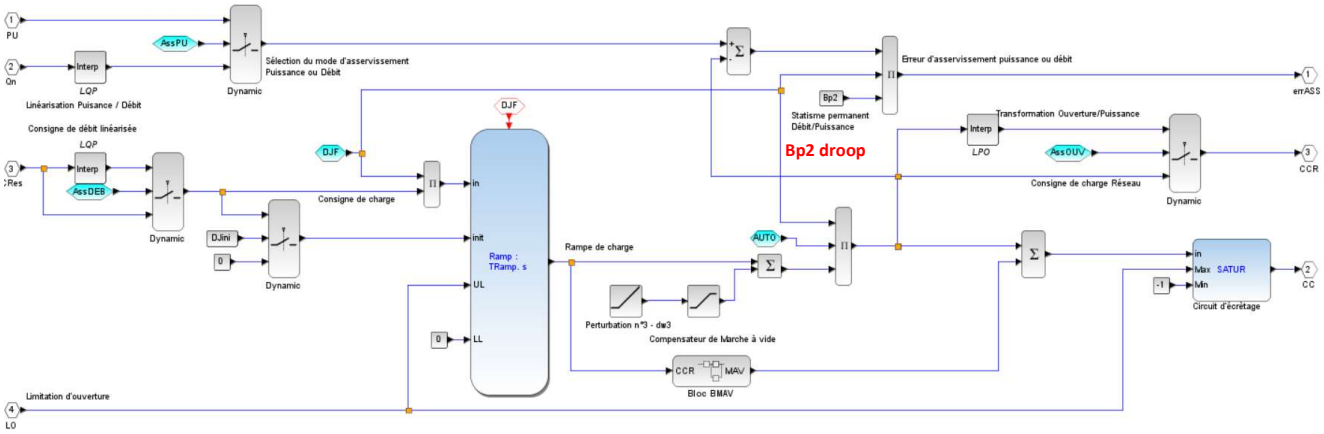


Figure 37 : Bp2 droop in the CC Load Logging Module

Figure 38 : Droop checking at power (FR2 circuit)

Control mode ModAss=1 – Circuit breaker Closed – Load disturbance 10% at t=10s - Programmed droop Bp2=0.01

$$Bp = \frac{\Delta f}{\Delta P} = \frac{10^{-3}}{10^{-1}} = 0.01$$

Tky	Tachometer filter time constant (s)	REGN - XLS

Tky represents the time constant of a first-order low-pass filter positioned on the feedback of the speed chain (Tachometry), developed in the **RESEAU** block.

This parameter is retained in the study to the extent that it brings a phase delay in the processing loop, and is always present in real-time digital regulators.

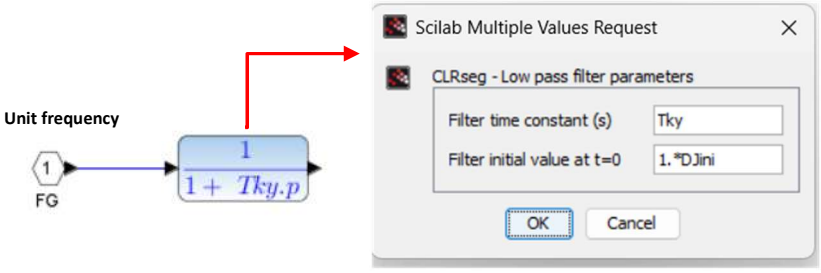


Figure 39 : Tachometric low-pass filtering

This first-order low-pass filter is implemented by a component of the SEGPAL library, with the aim of controlling the value of the filter at the start of the simulation, and avoiding any transient regime:

- If the simulator starts in the "Machine stopped" state (TDJF>0, FG=0 ⇒ DJini=0) the filter is initialized to 0, i.e. at zero speed
- If the simulator starts in the "Group coupled to the network at nominal speed" state (TDJF=0, FG=1 ⇒ DJini=1), the filter is initialized to 1.0, i.e. at nominal speed.

SIntLL	Minimum limitation threshold of the speed integrator in noload mode (pu)	REGN – LimINT XLS

This parameter conditions the minimum limitation LL of the speed integrator.

☞ *See **Figure 32 :***

Program by default SIntLL=-0.05

3.6 Setting operating modes

TStart	Turbine start time (s)	Système - XLS

Following the launch of the simulation, TStart introduces a delay time for the Turbine running order, to ensure stability conditions for starting the group when stopped.

TStart is only significant if **TDJF>0**, i.e. a start of the Open Circuit Breaker group (DJO)

When launching a network-coupled group simulation (TDJF=0), this parameter is therefore not considered.

☞ Set TStart=2.0 unless otherwise specified

TDJF	Circuit breaker closing time (s)		SetPoint
TDJF	**= 0**	Starting the simulator, unit coupled on the grid	
	> 0	Group circuit breaker closing time (s)	

TDJF defines the moment of coupling of the turbine to the electrical network.

If TDJF=0, the turbine start transient is not executed, and the simulation starts with the generator coupled to the network, avoiding any transient regime.

In this case, the TStart time is also ignored.

☞ In Manual mode, the TDJF parameter is not considered, to ensure the consistency of the circuit, in this case.

TDECL	Time of trip sequence of the hydroelectric group (s)	SetPoint

TDECL defines the moment when the group is triggered on the electricity network, i.e. the moment when the group no longer produces energy on the network.

☞ To never trigger the group, program TDECL>=TSim. Otherwise, indicate in seconds the desired value TDECL<<TSim.

MoDECL	Hydroelectric group trigger mode (su)		XLS
MoDECL	**0**	Triggering of the group with machine stoppage	
	1	Triggering of the group with return to noload mode	

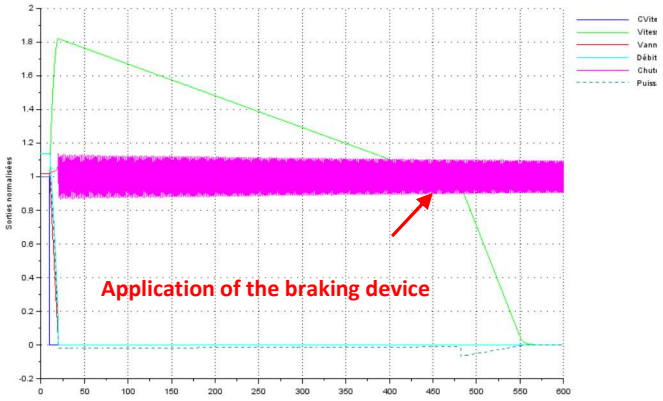


Figure 40 : Group triggering with group stop sequence and braking (MoDECL=0)

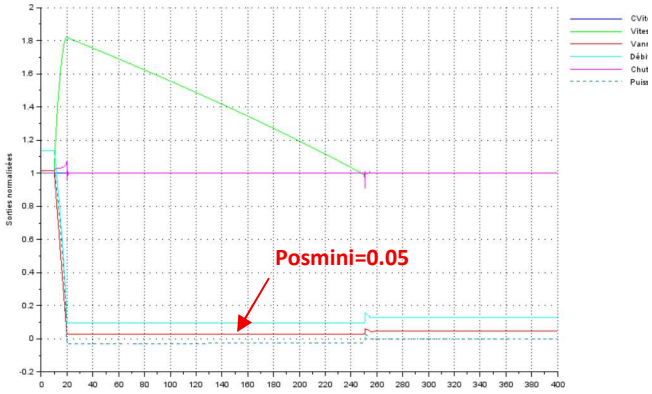


Figure 41 : Triggering of the group with return to no-load operation (MoDECL=1) and action of the RDECL trigger relay

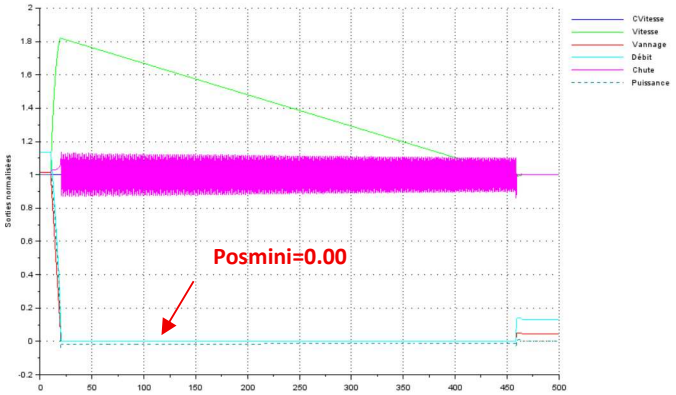


Figure 42 : Triggering of the group with return to no-load operation (MoDECL=1) without RDECL trigger relay

Modem	Turbine start mode (su)		XLS
Modem	**0**	Turbine start in Bang mode	
	1	Turbine start following a speed ramp	

- Bang type starting consists of starting the turbo-alternator group in such a way as to obtain synchronization of the group in minimal time, with maximum acceleration of the machine. (*Figure 43, Figure 56, Figure 57*)

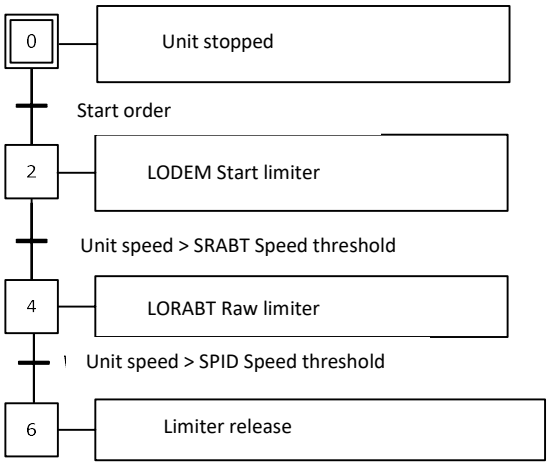


Figure 43 : Bang Start Sequencer

Upon receipt of the turbine run order, the LODEM speed limiter is applied.

This operation causes the instantaneous initialization of the valve setpoint to this same value, and imposes maximum acceleration on the group.

The group then goes up in speed.

When the group speed reaches the SRABT threshold, the LORABT limiter is applied to break the acceleration of the group and thus decelerate it to obtain optimal docking.

When the speed reaches the SPID speed regulation threshold, the opening limiter is definitively released, and the group is ready for the synchronization sequence.

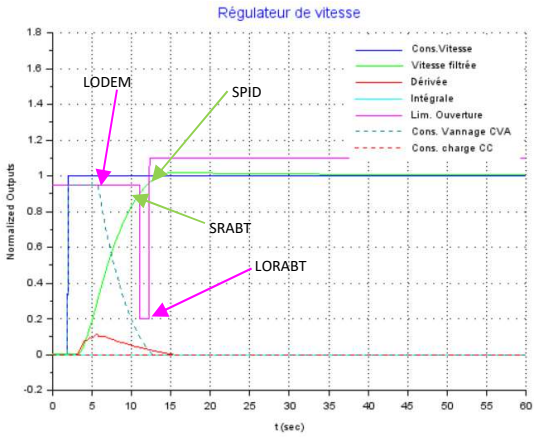


Figure 44 : Bang type start

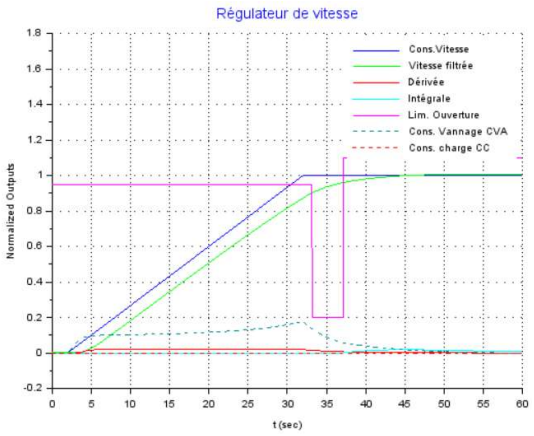


Figure 45 : Starting on a speed ramp

- The start can also be achieved less abruptly by applying a speed instruction following a ramp, varying from 0 to 100% when receiving the machine run command. (*Figure 44*).

☞ **The choice between one or the other of the sequences depends on the inertia of the Turbine+Alternator group, but above all on the amplitude of the unacceptable fluctuations which could appear in the supply circuits or the vibratory mechanisms recorded on the machine.**

It is therefore advisable to be careful in choosing one or other of these sequences.

Riso	Operation in an interconnected network or isolated network (su)		SetPoint
Riso		**0**	Interconnected network operation
		1	Isolated network operation

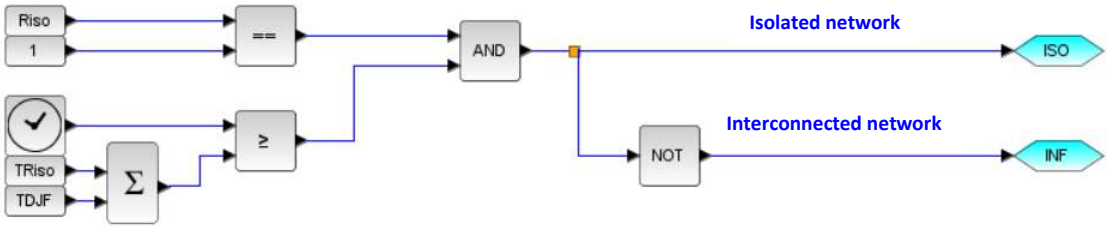


Figure 46 : Implementation of the Riso variable and Sequence of switching to isolated network mode (System block)

The IEC standards [4] and [5] specify the different modes of interaction of the speed governor with the network to which the turbo-alternator group is coupled:

- When operating on an isolated network with a single group (small network), the effective speed and, consequently, the frequency, correspond to the value of the reference signal
- When operating on an isolated network with more than one unit (medium-sized network), the speed governor contributes to frequency adjustment via programmable permanent droop, to avoid oscillations between groups.
- When operating on an interconnected network, the speed being determined by the network frequency, the speed governor contributes to the adjustment of the network frequency via the programmable permanent droop, thanks to the dynamic characteristics of the controlled system.

On the other hand, the fundamental equation of dynamics allows the simplified modelling of the speed of the machine:

$$C_m - C_r = J\frac{d\Omega}{dt}$$

where C_m represents the engine torque (turbine), C_r the resistive torque (network), the inertia of the turbo-alternator group, and Ω the rotation speed of the machine.

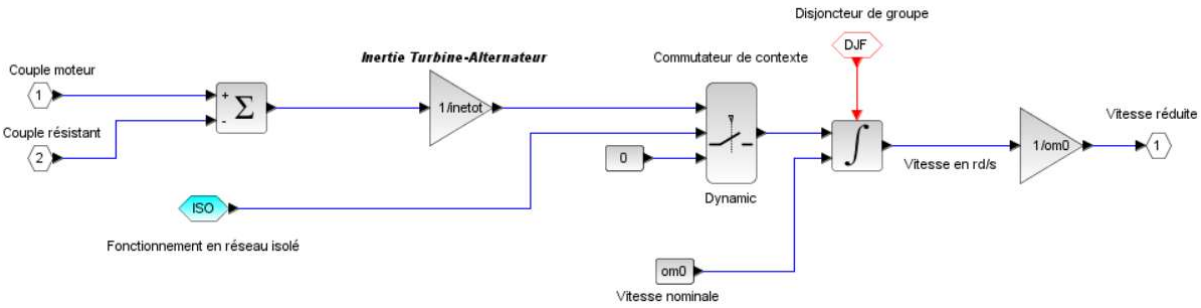


Figure 47 : Simplified diagram of the speed of the turbo-alternator group (Reseau block)

The ISO state variable, in the previous general diagram ((*Figure 47*), is, in reality, implemented in a slightly different way, in order to guarantee all the functionalities of **HydroSim**; in particular during linearity readings and linearizations of the Power/Opening or Flow/Opening[4] loops, in MANUAL mode:

[4] See Chapter 4 : LAWS OF LINEARIZATION

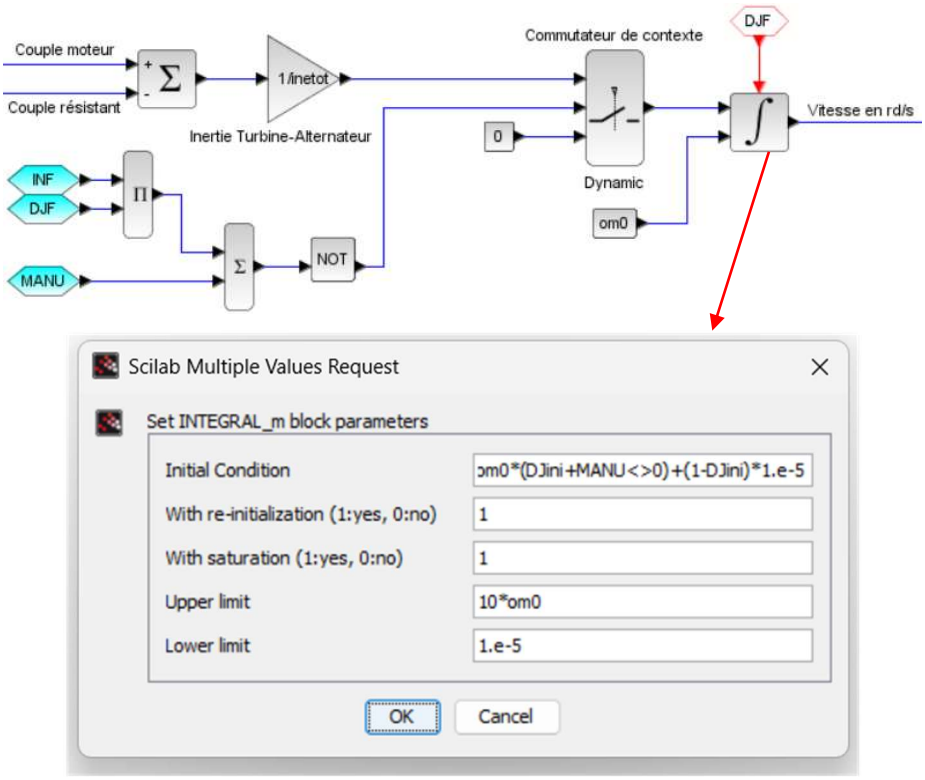


Figure 48 : Implementation of isolated network mode in the **Reseau** block

The integrator is initialized, at the start of the simulation, considering the initial position of the programmed TDJF circuit breaker (⇒ calculation of DJini) or the support of MANUAL mode, and following the speed equation at t=0:

om0*(**DJini**+**MANU**<>0)+(1-**DJini**)*1.e-5 (rd/s)

The simulation therefore starts either at zero speed or at nominal speed.

In the case of a start from stopped mode, closing the DJF group circuit breaker instantly causes the speed integrator to be reset to the nominal speed (Field “With re-initialization” = 1)

TRiso	Time to switch to isolated network mode (s)	XLS

In some simulations, it is sometimes preferable (rare) to delay the closing of the circuit breaker to avoid a transient at the time of coupling (See *Figure 46*)

☞ Unless otherwise stated, set TRiso=0.0 s

ModAss	Control mode Regulator in charge (su)		CC - SetPoint
ModAss		**0**	Opening mode
		1	Power mode
		2	Flow mode

With the machine connected to the electrical network, ModASS defines the operating mode of the turbo-alternator group.

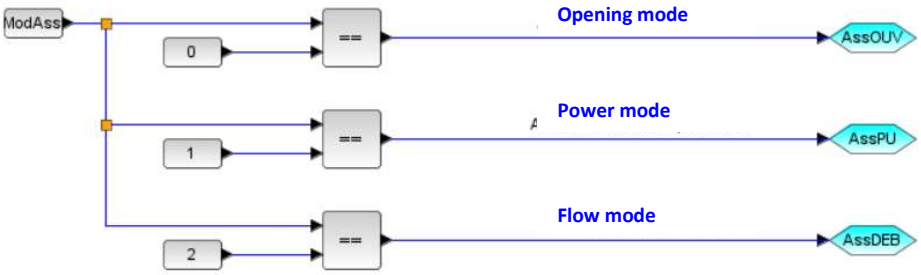


Figure 49 : Operating mode of the group in charge (CC module)

- In opening control, the speed PID is looped back by its permanent droop **Bp** (*see Figure 31*)
- In power or flow control, the PID is looped back by its permanent droop at power or flow **Bp2**.

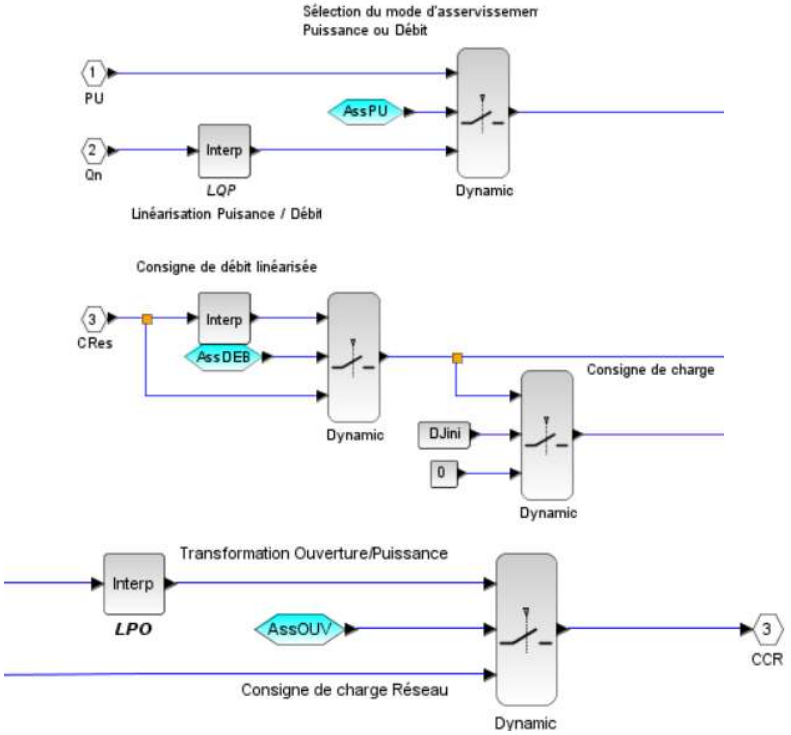


Figure 50 : Power, Opening, or Flow Mode Switches in the CC Block

☞ Set ModAss=1

3.7 Speed governor and Consignment

3.7.1 Principle of consignment

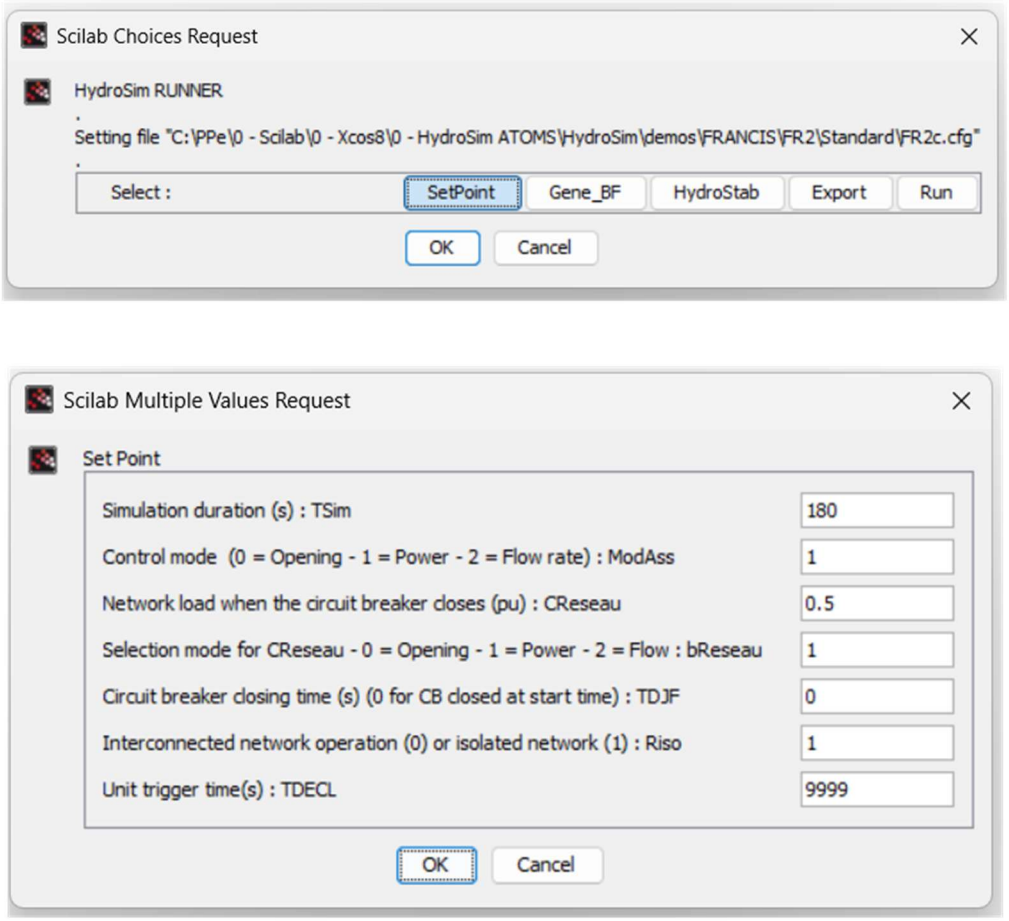


Figure 51 : SetPoint: Access to the main consignment parameters of the hydraulic unit

Access to the main consignment parameters of the hydraulic unit and a simulation is achieved by running an ***SCE file*** in the "***HydroSim\demos***" demonstration directory.

Running the SCE file brings up the ***HydroSim RUNNER*** window, then choose ***SetPoint*** from the list of menus. Confirm with OK.

The parameters in the SetPoint menu describe the behaviour of the unit when the simulation is launched:

- Startup sequence of the group or group already coupled to the network:
- Unit load to be considered
- Operation in isolated network or interconnected units.
- Trigger time of the group with Stop unit or return to noload operation
- …etc

The parameters [Tsim, ModAss, Creseau, bReseau, TDJF, Riso, TDECL] are described in this document and can be directly accessed using the index of this document.

3.7.2 General Settings

CV_Nom	Nominal speed setpoint of the speed consignment (pu)	CVIT - XLS

CV_Nom designates the reference setpoint in standardized value of the speed governor.

☞ Set CV_Nom=1.0.

However, when running at no load, the speed reference can be modified to test operations at intermediate points in speed regulation (*see CVIT block*)

TRampF	Speed consignment Ramp Time (s)	CVIT - XLS

TRampF defines the time taken by the speed consignment to increase the speed setpoint from 0% to 100%

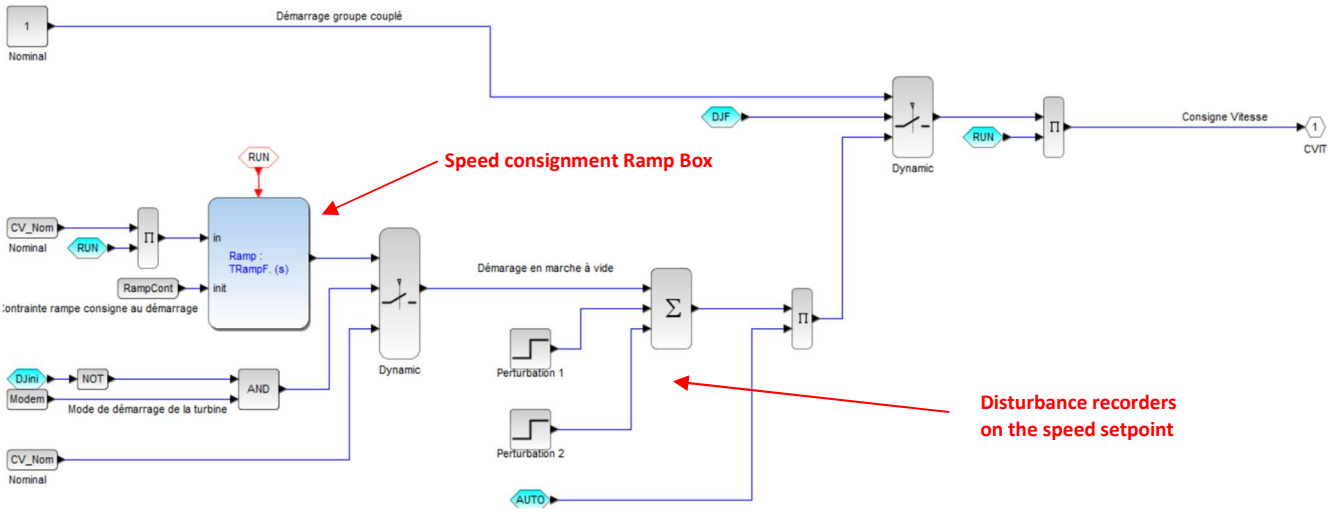
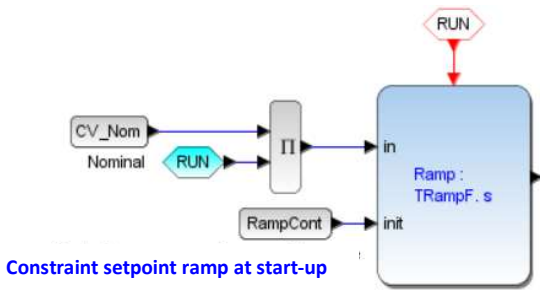


Figure 52 : Speed consignment Ramp Box (CVIT Block)

RampCont	Speed ramp constraint at start-up (pu) (If Modem=1)	CVIT - XLS

RampCont defines a speed ramp initialization constraint, in the Speed consignment module, to minimize conducted oscillations due to the depression resulting from the opening of a valve (if Modem=1, i.e. Starting the group on a speed ramp)



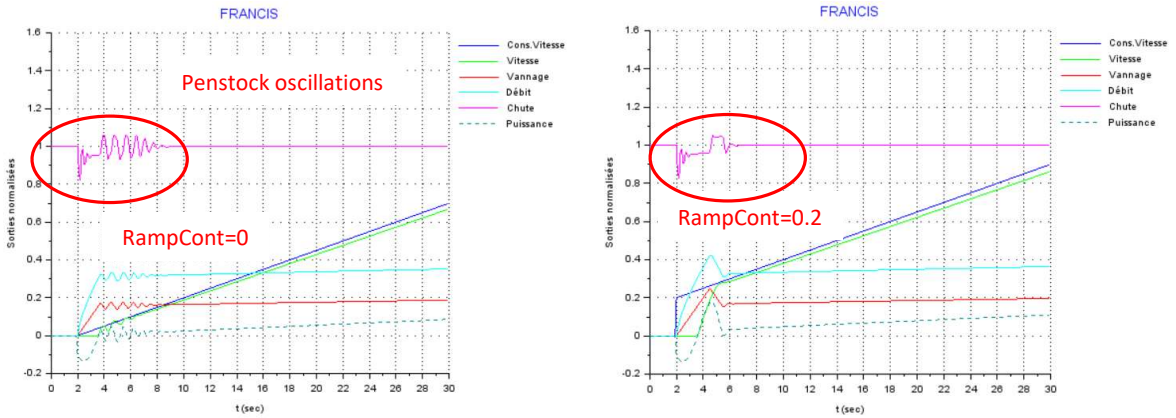


Figure 53 : Pre-stressing of the speed setpoint at start-up on a speed ramp (if Modem=1)

☞ Set RamptCont=0.0 by default

3.7.3 Pertubographs on the speed setpoint

df1	Amplitude of disturbance step no. 1 (pu)	CVIT - XLS
tdf1	Instant of application of disturbance level no. 1 (s)	CVIT - XLS
df2	Amplitude of disturbance step no. 2 (pu)	CVIT - XLS
tdf2	Instant of application of disturbance level no. 2 (s)	CVIT - XLS

This set of parameters is used in the pertubograph introduced on the speed setpoint in the CVIT block.

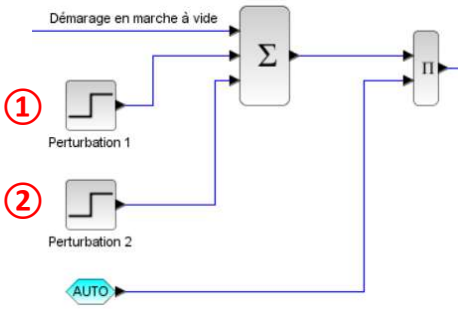


Figure 54 : Speed setpoint disturbances – CVIT module

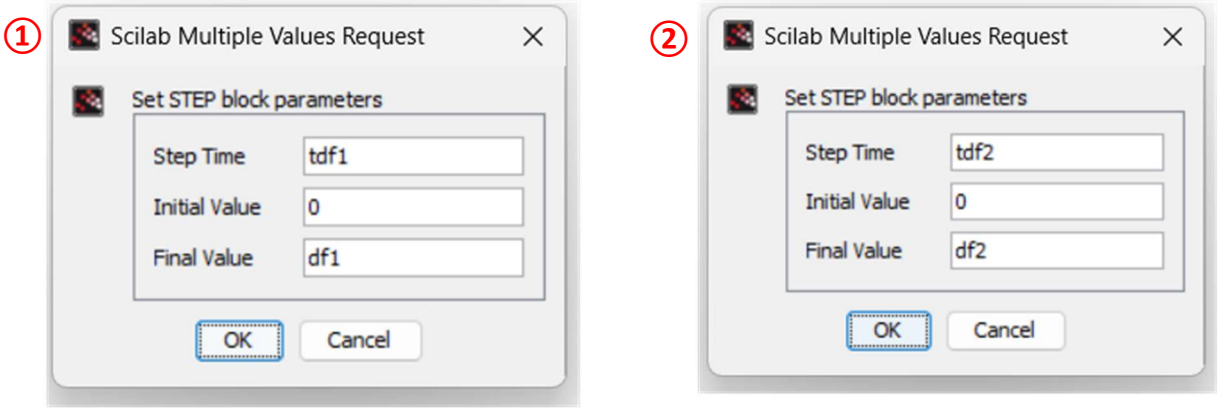


Figure 55 : Setting the speed setpoint steps on the pertubograph – CVIT module

3.7.4 Opening Limit Block Settings

3.7.4.1 Transient Limiters in the BANG Sequence

LODEM	Start limiter (pu)	LO - XLS
LORABT	BANG Limiter (pu)	LO - XLS
SRABT	Opening limiter switching threshold at LORABT (pu)	LO - XLS
SPID	PID Speed Implementation Threshold (pu)	LO - XLS

This group of parameters is used to generate a Bang type start sequence, and are included in the "interp" interpolator of the **LO** block of the opening limiters.

This sequence is only active if Modem=0 (*see Figure 43, Figure 44*)

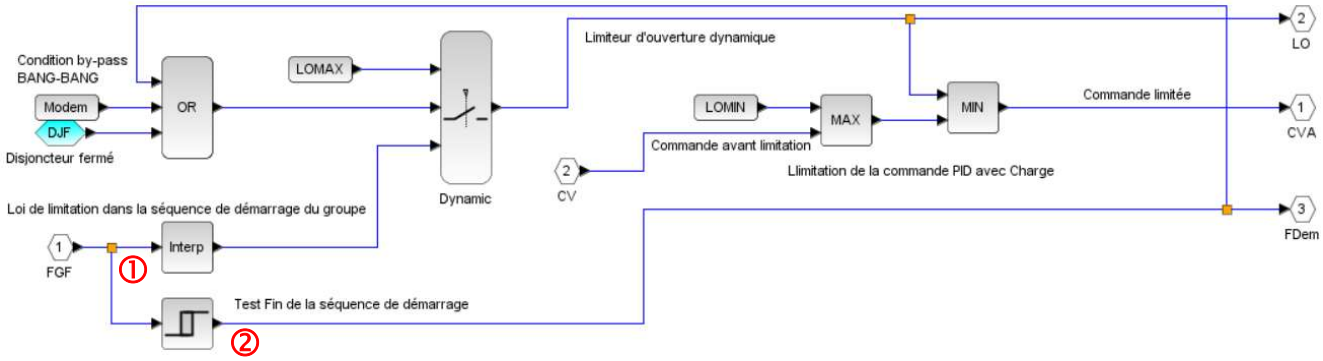


Figure 56 : Instantiation of a Bang type start sequence, in the Opening Limiters module (LO Block)

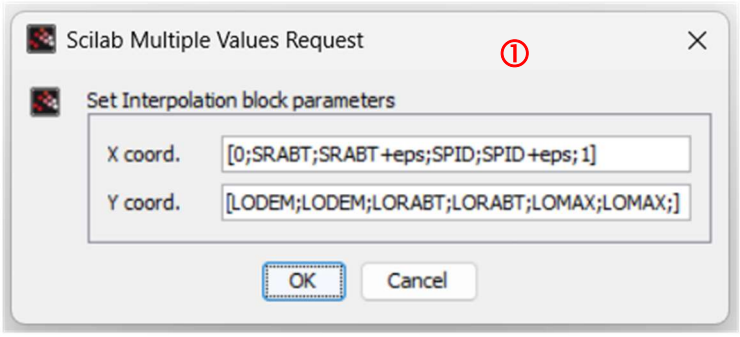


Figure 57 : Bang Interpolator Sequencer at Startup (Modem=0)

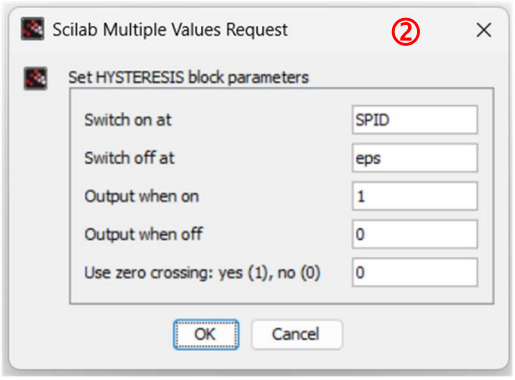


Figure 58 : "End of Start Sequence" Detector

3.7.4.2 Permanent limiters

LOMAX	Maximum limitation of PID speed control (pu)	LO - XLS
LOMIN	Minimum limitation of PID speed control (pu)	LO - XLS

The two parameters limit the command from the Speed PID (*see Figure 56*)

☞ Set LOMAX=1.1, LOMIN=-0.0 , Unless Otherwise Posted.

3.8 Load consignment and operating modes

3.8.1 Network Settings

CReseau	Load setting when closing the circuit breaker (pu)	REGN - SetPoint
bReseau	Selection mode for CReseau - 0 = Opening - 1 = Power - 2 = Flow rate (su)	Set_CReseau.sci - SetPoint

CReseau sets the load imposed on the group when it is coupled to the electrical network.
Creseau depends on the mode of control imposed on the group.
So the parameter specifies, depending on the **bReseau** parameter**:**

bReseau	Meaning of CReseau
0	Load setpoint at opening
1	Load setpoint at power
2	Load setpoint at flow rate

The “CC” module modifies the CReseau setpoint to impose a load of equivalent power CCR in the “Reseau” module.

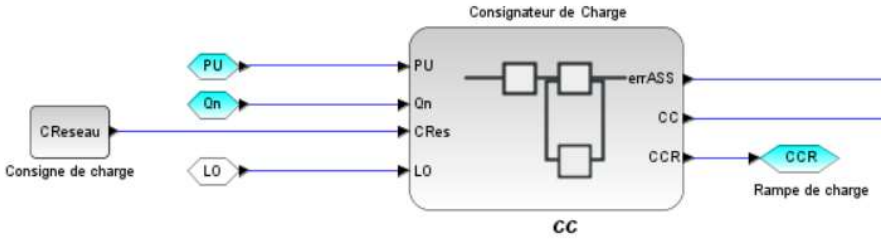


Figure 59 : Considering the load instruction in the REGN block

Also see Figure 50

TRamp	Load Consignment Ramp Time (s)	CC - XLS

TRamp defines the time taken by the load consignment to increase the load setpoint from 0% to 100%.

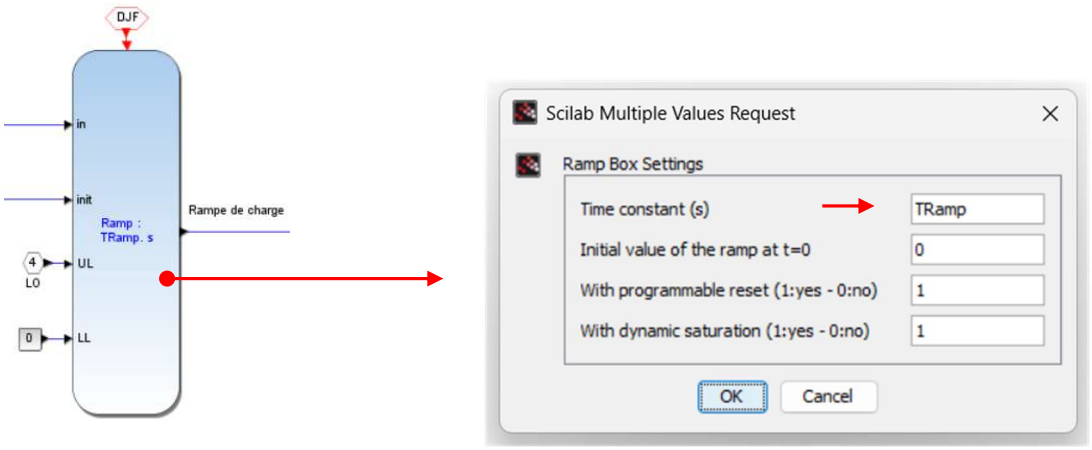


Figure 60 : Load Consignment Ramp Box in CC Module

aut	Self-adjustment coefficient of the electrical network (pu)	Reseau - XLS

When a network includes a significant number of rotating machines, the power required increases with the frequency, which contributes to the intrinsic stability of the network. More precisely, the self-regulation coefficient is the quantity $aut = \frac{\frac{dW}{W_n}}{\frac{df}{f_0}}$, which characterizes the variation in power consumed when the frequency varies.

In this sense, ***aut*** represents a network droop, by analogy with the programmable permanent droop characterizing the Frequency/Opening relationship (see Bp)

Thirty years ago, a self-tuning coefficient of 1 was typical for most networks. Currently, with the widespread use of converter-based power supplies, including for asynchronous machines, the proliferation of electric heaters (pure resistors), etc., the self-tuning coefficient is generally close to 0.

Customers are generally unable to answer this question.

☞ Except in special cases, a stability study is carried out in the most unfavourable case, i.e. auto-tuning aut=0.

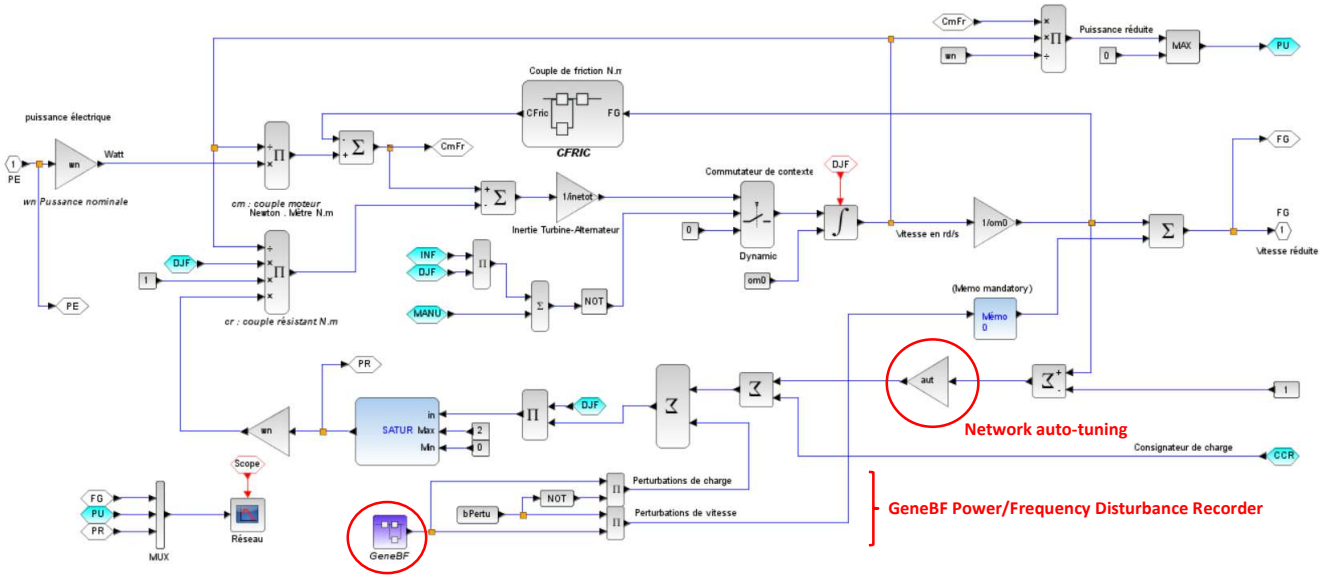


Figure 61 : Principle of electrical network modelling – Network self-adjustment coefficient

3.8.2 GeneBF Power/Frequency Disturbance Generator



The GeneBF generator setting is accessible in the "Gene_BF" menu of HydroSim RUNNER, or when launching an SCE script file [5] :

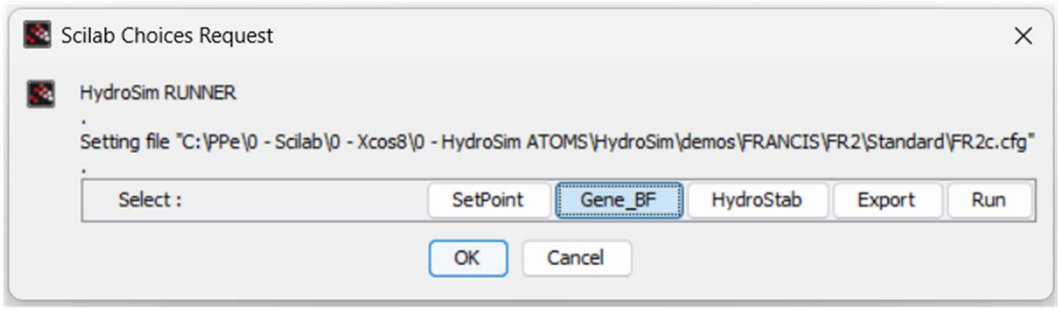


Figure 62 : Setting the GeneBF generator in HydroSim

[5] File FR2c.sce, FR4c.sce, Pell4c.sce, etc., for example

3.8.2.1 Settings

bPertu	Disturbance Type (0=Load - 1=Speed) (0 or 1)	Reseau / Gene_BF
modPer	Disturbance Mode (0=Steps 1=SinuSync (0 or 1)	Reseau / Gene_BF
dw1	Amplitude of disturbance step no. 1 (pu)	Reseau / Gene_BF
tdw1	Instant of application of disturbance level no. 1 (s)	Reseau / Gene_BF
dw2	Amplitude of disturbance step no. 2 (pu)	Reseau / Gene_BF
tdw2	Instant of application of disturbance level no. 2 (s)	Reseau / Gene_BF
tSinus	SinuSync Sine Wave Generator – Sine Wave Start Time (s)	Reseau / Gene_BF
ASinus	SinuSync sine generator amplitude (su)	Reseau / Gene_BF
PSinus	SinuSync sine generator period (s)	Reseau / Gene_BF
tDirac	Dirac comb – Starting time of the comb (s)	Reseau / Gene_BF
ADirac	Dirac comb amplitude (su)	Reseau / Gene_BF
PDirac	Dirac comb period (s)	Reseau / Gene_BF
DDirac	Dirac pulse duration (s)	Reseau / Gene_BF
SDirac	Symmetry of the Dirac momentum (su)	Reseau / Gene_BF

This set of parameters allows to define a new **GeneBF** disturbance recorder, used to emit stimuli either on the load signal or directly on the speed measurement.

The "GeneBF" generator fits harmoniously into the "Network" modules of the HYDROTUR models (*See **Figure 61** or « **Reseau** » block in the diagrams*)**.** A selector controlled by a configurable boolean "**bPertu"** directs the output signal.

The interest of the GeneBF generator is to ultimately request the speed regulator to measure its performance and robustness.

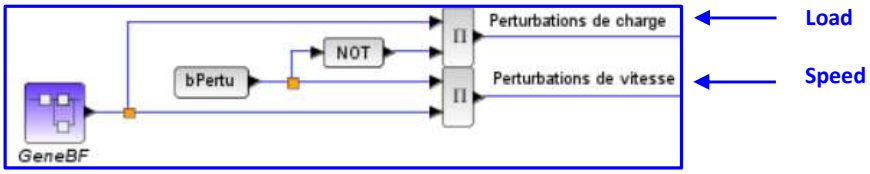


Figure 63 : General principle of the Gene_BF disturbance recorder in the "Reseau" module

- If **bPertu**=0, the excitation is added to the network load setpoint
- If **bPertu**=1, the excitation is added to the speed measurement

HYDROTUR proposes the installation of a disturbance recorder based on a low-frequency signal generator, called GeneBF; this provides as output:

- A sinusoidal signal (**modPer=1**) or steps (**modPer=0**)
- The optional addition of a Dirac comb on the provided output



The generator achieves the equivalent of a "Superblock" in the Xcos sense of the term, and integrates the elementary components performing the function thus described.

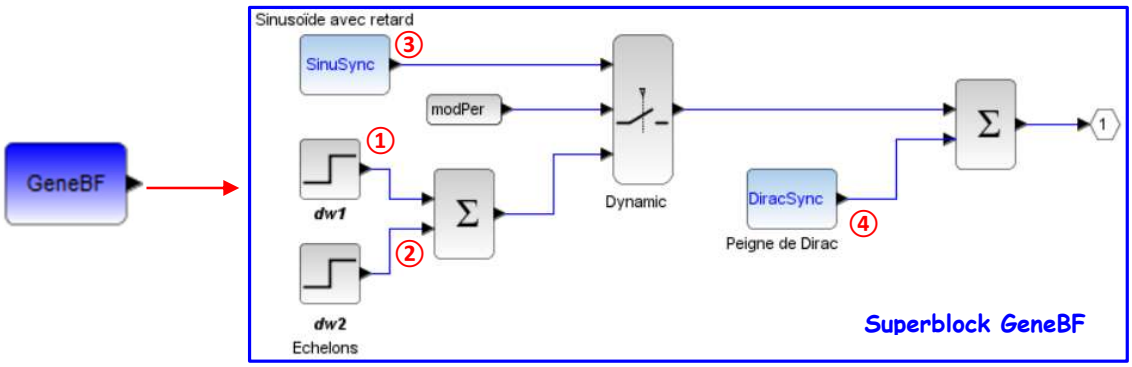


Figure 64 : GeneBF Generator Components

Each component has its own set of parameters, making the elementary functions independent: Start time, Signal amplitude, Period, Duration of a Dirac, etc.

3.8.2.2 Steps Generator (modPer=0)

This generator is programmable from the parameters dw1, tdw1, dw2, tdw2.

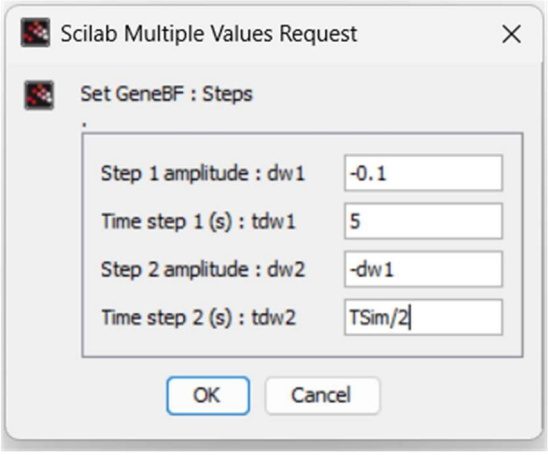


Figure 65 : Adjustment of the load steps on pertubographs no. 1 and no. 2

In general, we program dw2=-dw1 to obtain a symmetry of the perturbation at time Tsim/2

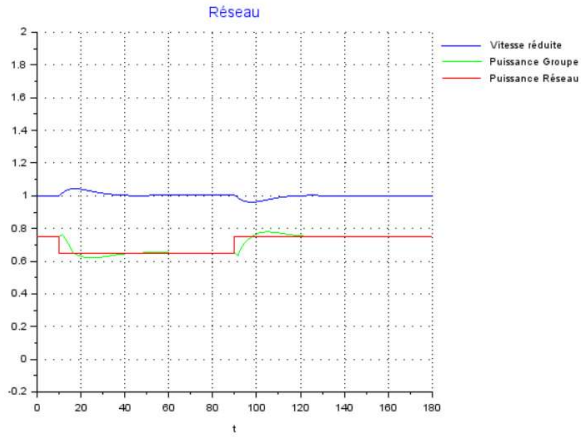


Figure 66 : Example of using the GeneBF generator in “Step” mode on the load setpoint

In the example above, dw1=-0.1 tdw1=10s, dw2=0.1, tdw2=TSim/2 s, bPertu=0.

3.8.2.3 Sine wave generator (modPer=1)

3.8.2.3.1 Descriptor / Interface

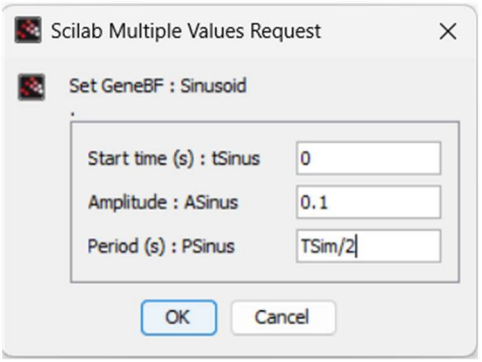


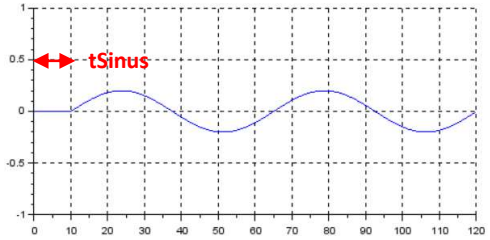
Figure 67 : Parameterization of the synchronized sinusoidal generator

3.8.2.3.2 Function performed

$y(t) = 0$ si $t < t_0$

$y(t) = A\sin\frac{2.\pi}{P}(t - t_0)$ *si* $t \geq t_0$

with A=Asinus , P=PSinus , t_0=tSinus



3.8.2.4 Dirac comb generator

3.8.2.4.1 Descriptor / Interface

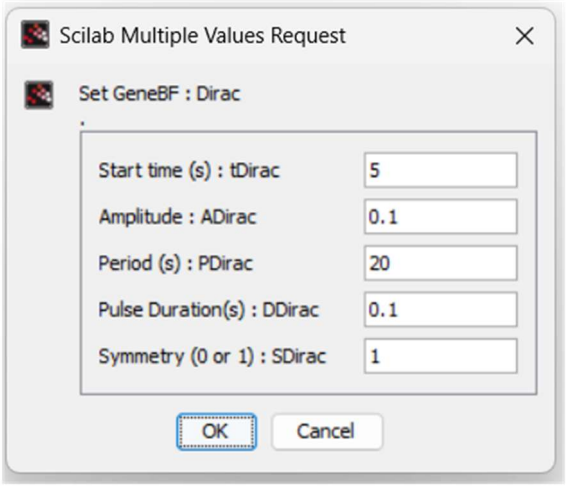


Figure 68 : Parameterization of the DiracSync component

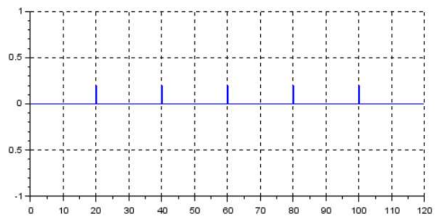
3.8.2.4.1 Function performed

$y(t) = 0$ si $t < t_0$

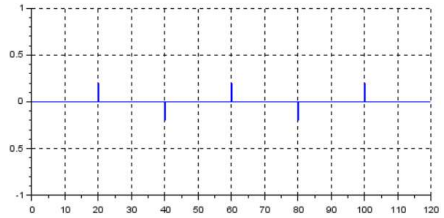
$y(t) = A$ si $t_0 + n.P \leq t \leq t_0 + n.P + D$

$y(t) = 0$ si $t_0 + n.P + D < t < t_0 + (n+1).P$

with t_0=tDirac, A=ADirac, P=PDirac, D=DDirac



The Boolean “Symmetry” SDirac (0 or 1) allows you to alternate the direction of the Dirac at each period of the signal:



☞ In general, the Dirac duration is programmed DDirac=0.1 s, to be also compatible with the sampling period of digital scopes in HYDROTUR.

3.8.2.5 Preview of the Gene_BF function generator before execution

A preview of the Gene_BF generator is available after displaying the previous programming screen:

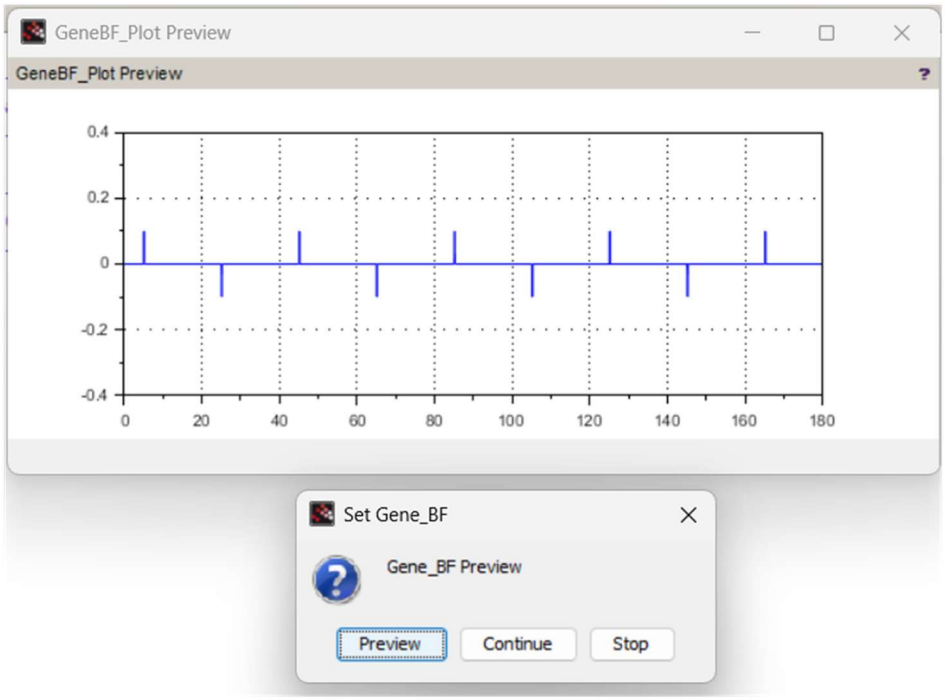


Figure 69 : Preview of the Gene_BF function generator before execution

- The "Preview" button draws a preview of the programmed generator
- The "Continue" button allows the generator to be saved in the configuration file
- The "STOP" button ends the generator session without saving.

3.8.2.6 Saving GeneBF Generator Settings

The generator settings are saved in the .cfg configuration file linked to the .sce[6] launch file, and in the same directory.

[6] Example: FR2C.cfg file if the launch script is the FRC2.sce file.

```
29  //-----------------------------------------------------------
30  // Perturbations sur le réseau ---------------------------
31  //-----------------------------------------------------------
32
33      //-------------------------
34      // Génétateur BF par défaut
35      //-------------------------
36
37  bPertu=0.000;                          // Type de perturbation (0=Charge - 1=Vitesse) bloc Resea
38  modPer=1.000;                          // Mode de perturbation (0=Echelons 1=SinuSync)
39
40  // Générateur Echelons
41  //---------------------
42  dw1=0.000;                             // Amplitude échelon 1
43  tdw1=10.000;                           // Instant échelon 1 (s)
44
45  dw2=0.000;                             // Amplitude échelon 2
46  tdw2=90.000;                           // Instant échelon 2 (s)
47
48  // Générateur SinuSync
49  //--------------------
50  tSinus=0.000;                          // Instant de départ (s)
51  ASinus=0.100;                          // Amplitude
52  PSinus=90.000;                         // Période (s)
53
54  // Générateur Peigne de Dirac DiracSync
55  //-------------------------------------
56  tDirac=5.000;                          // Instant de départ (s)
57  ADirac=0.100;                          // Amplitude
58  PDirac=20.000;                         // Période (s)
59  DDirac=0.200;                          // Durée du Dirac (s)
60  SDirac=1.000;                          // Symétrie
61
62      //-------------------------
63      // Fin Génétateur BF
64      //-------------------------
```

Figure 70 : GeneBF Test Program Parameters – Extract from a cfg file

3.8.2.7 Examples of application of the disturbance recorder

The following examples provide comprehensive information on the behaviour of the disturbance recorder in the “CFG” file.

Programming optimizations are the responsibility of the operator.

3.8.2.7.1 Load setpoint steps

```
//-------------------------------------------------------------------------
// Perturbations sur le réseau (GeneBF)
//-------------------------------------------------------------------------

// Type de perturbation (0=Charge - 1=Vitesse) bloc Reseau
//--------------------------------------------------------
bPertu=0;

// Mode de perturbation (0=Echelons 1=SinuSync)
//---------------------------------------------
modPer=0;

dw1=-0.1;              // Perturbation de charge réseau n°1 (pu)
tdw1=10;               // Instant de perturbation dw1 (s)
;
dw2=-dw1;              // Perturbation de charge réseau n°2 (pu)
tdw2=TSim/2;           // Instant de perturbation dw2 (s)
```

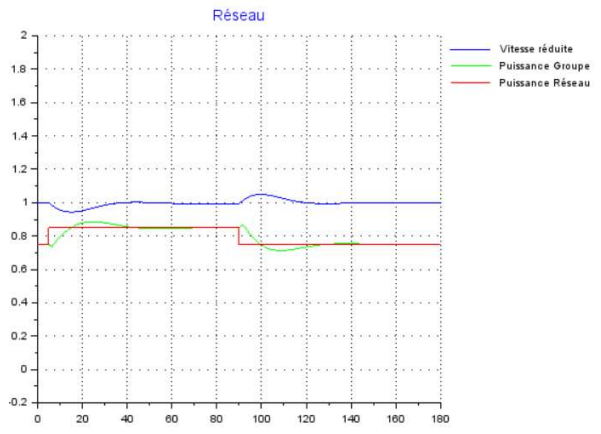


Figure 71 : Response to a load step

3.8.2.7.2 Speed control response to a sinusoid additional to the load setpoint

```
//-------------------------------------------------------------------------------
// Perturbations sur le réseau (GeneBF)
//-------------------------------------------------------------------------------

// Type de perturbation (0=Charge - 1=Vitesse) bloc Reseau
//-------------------------------------------------------
bPertu=0;

// Mode de perturbation (0=Echelons 1=SinuSync)
//---------------------------------------------
modPer=1;

// Générateur SinuSync
//--------------------
tSinus=5;                // Instant de départ (s)
ASinus=0.1;              // Amplitude
PSinus=TSim/2;           // Période (s)
```

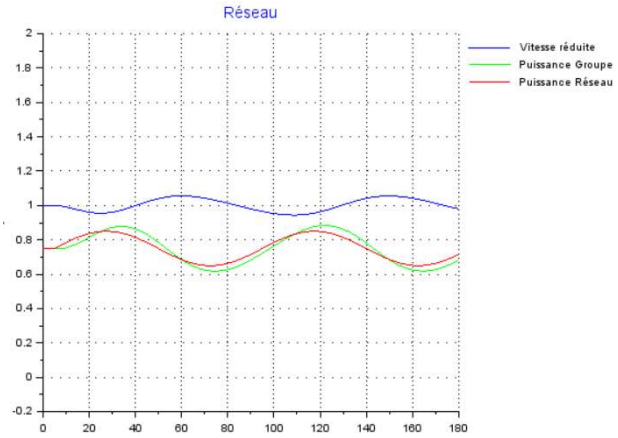


Figure 72 : Continuation of a sinusoid

3.8.2.7.3 Response of speed regulation to a Dirac comb on speed measurement (interconnected network)

```
// Type de perturbation (0=Charge - 1=Vitesse) bloc Reseau
//-------------------------------------------------------
bPertu=1;

// Mode de perturbation (0=Echelons 1=SinuSync)
//---------------------------------------------
modPer=0;

// Générateur Peigne de Dirac DiracSync
//-------------------------------------
tDirac=20;               // Instant de départ (s)
ADirac=0.1;              // Amplitude
PDirac=20;               // Période (s)
DDirac=0.1;              // Durée du Dirac (s)
SDirac=1;                // Symétrie
```

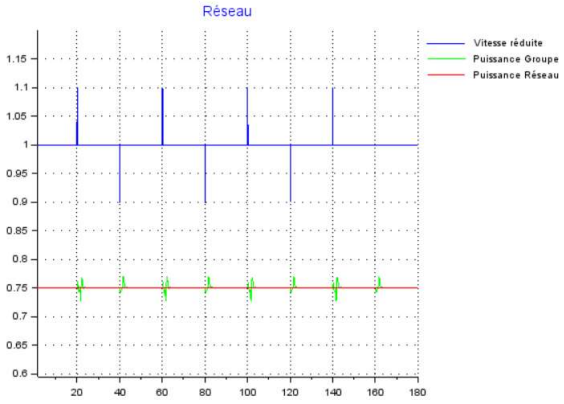


Figure 73 : Response of speed regulation to a Dirac comb on speed measurement (interconnected network)

3.8.2.7.1 Response of the FR2 governor to a Dirac comb (10%) on the load (interconnected network)

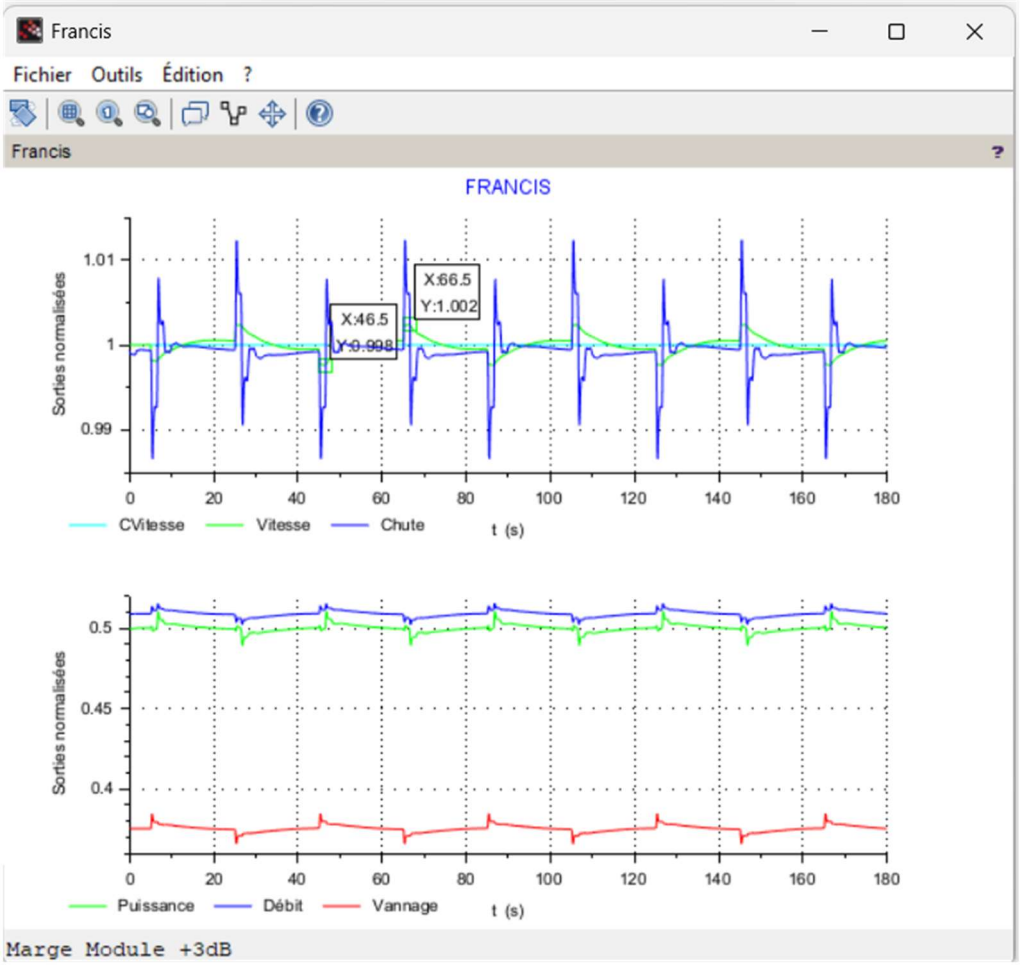


Figure 74 : Response of the FR2 governor to a Dirac comb (10%) on the load (interconnected network)

3.8.3 Additional disturbance on the dw3-tdw3 load setpoint

dw3	Amplitude of disturbance step No. 3 (pu)	CC - XLS
tdw3	Instant of application of disturbance level no. 3 (s)	CC - XLS

Both parameters program the addition of a complementary charging ramp to that of the main consignment.
This device can be used, for example, for 100% load rallies in the hydraulic circuit simulation, after a 50% stabilization stage.

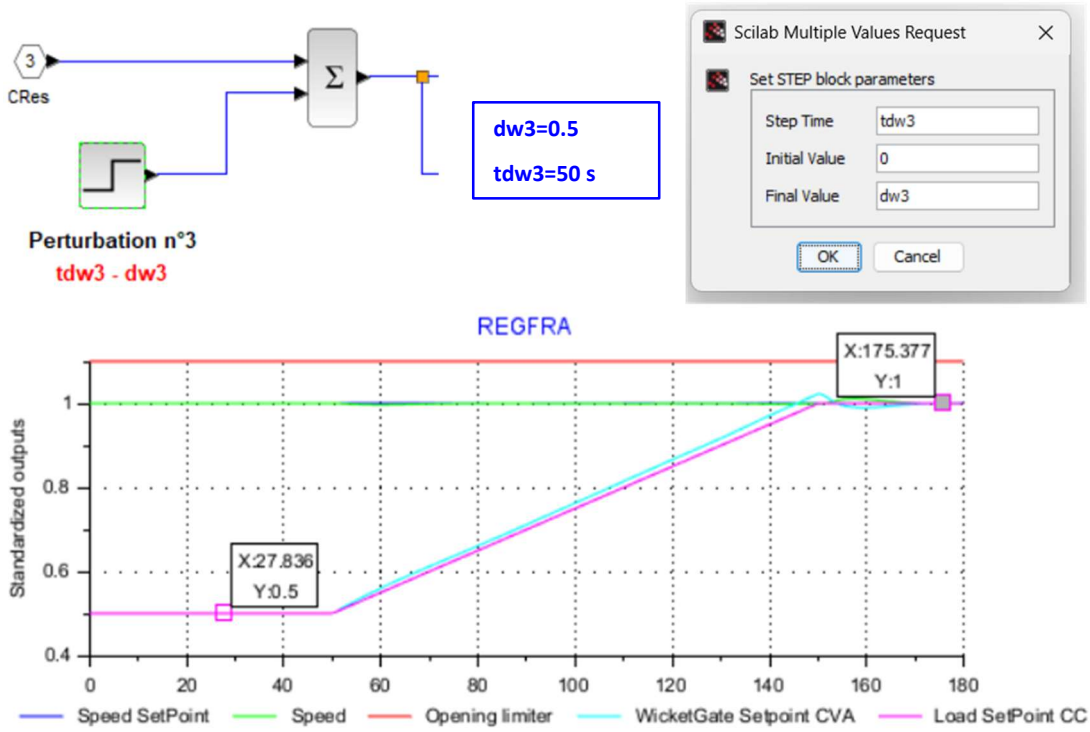


Figure 75 : Setpoint disturbance n°3 for Load/Flow/Power in the CC module

3.9 Efficiency law REND as a function of opening

REND	Efficiency law REND as a function of opening (pu)	General - XLS
xRend **yRend**		

From a table of 2-tuples (xTend, tRend), this law considers the efficiency of the machine in the calculation of the mechanical power supplied by the hydraulic group, following the law:

$$P = \eta.\rho.g.H.Q$$

where η is the efficiency law *Rend*.

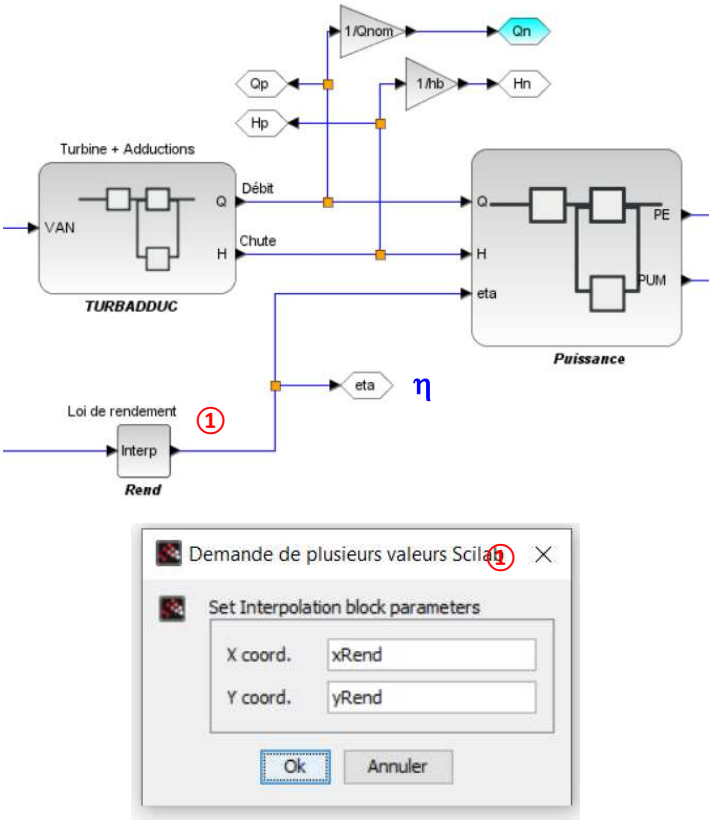


Figure 76 : Considering the Rend efficiency law in the main FR2 module

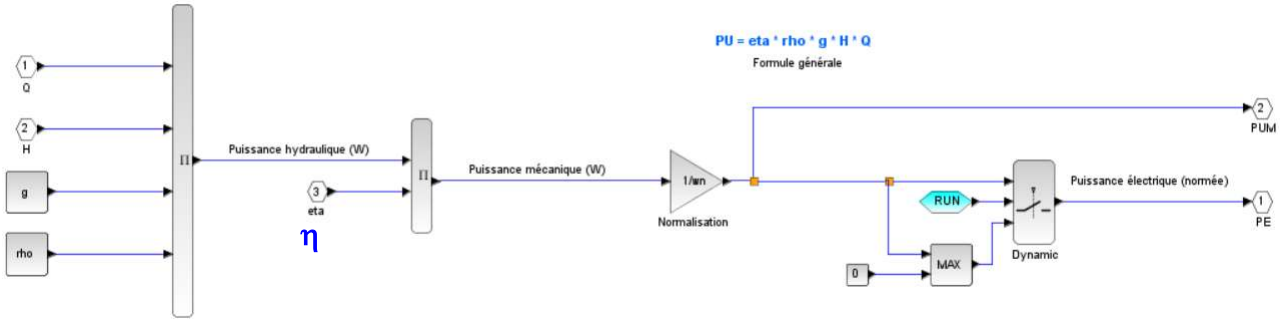
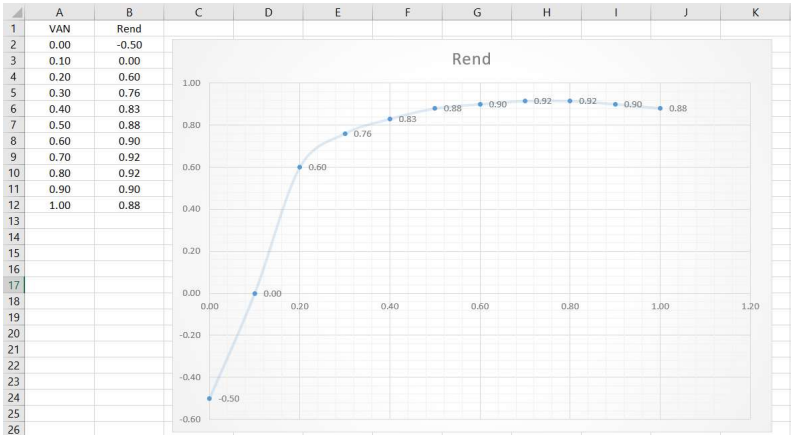


Figure 77 : Considering the Rend efficiency law in the power "Puissance" block of main FR2 module



	A	B
1	VAN	Rend
2	0.00	-0.50
3	0.10	0.00
4	0.20	0.60
5	0.30	0.76
6	0.40	0.83
7	0.50	0.88
8	0.60	0.90
9	0.70	0.92
10	0.80	0.92
11	0.90	0.90
12	1.00	0.88

Figure 78 : Example of an efficiency law in the FR2 circuit (File FR2 - Lois.xlsx)

☞ An efficiency law is defined by default in the "VariablesGlobales.sce" file. This file is loaded when any simulation is launched, and placed in the "HydroSim\macros\" directory:

```
//-----------------------------------------------------------------------------------------------------------
// Loi Rendement par défaut
// Si cette loi ne convient pas, il convient de la reprendre en surchargeant
// le fichier de paramétrisation  "XLS" avec une nouvelle relation (xRend, yRend) dans une feuille REND
//-----------------------------------------------------------------------------------------------------------
Rend=[];
REND=[];        // Rendement si défini dans la feuille XLS

xRend=[0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80  0.90 1.00];    //Ouverture
yRend=[0.00 0.75 0.85 0.88 0.9 0.905 0.91 0.91 0.905 0.90 0.89];    //Rendement
;
```

Figure 79 : The efficiency law defined by default in the "VariablesGlobales.sce" file.

☞ The efficiency law is sometimes directly integrated into a hill machine (FR4, FR5, KB). In this case, multiplication by is not necessary.

The efficiency law can also be redefined in a REND sheet of the XLS file:

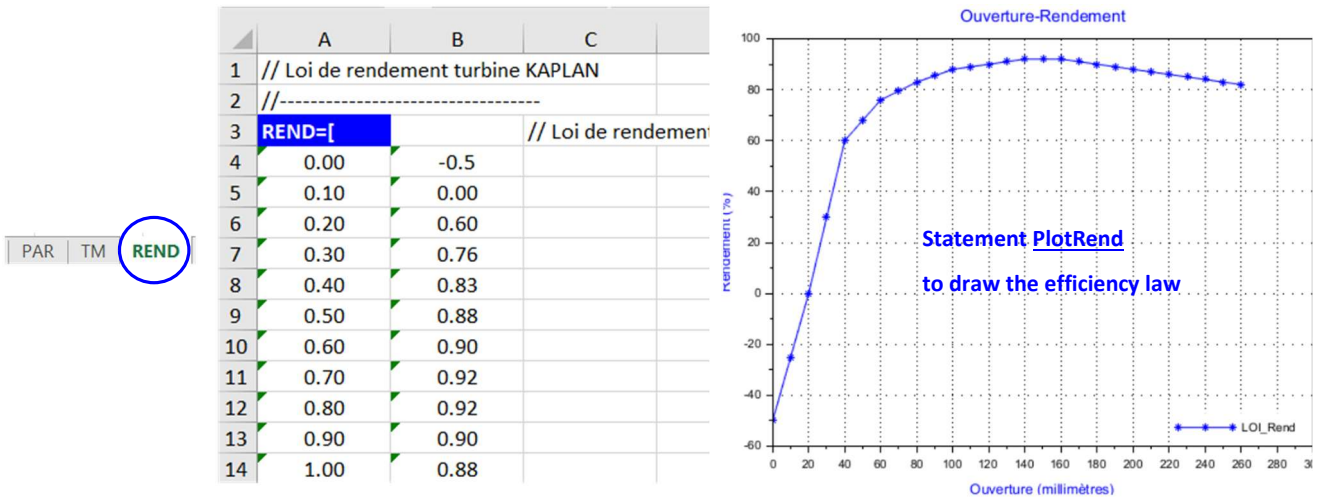


Figure 80 : Efficiency law defined in the file HydroSim\demos\KAPLAN\KB1\Standard\KB1.xls

. The efficiency law can be plotted by entering PlotRend in the Scilab console (*Also see Figure 174*).

3.10 CFRIC braking module

kFric	Friction coefficient of the turbo-alternator group (pu)	CFRIC - XLS
kFrein	Braking coefficient (pu)	CFRIC - XLS
SFrein	Braking threshold (pu)	CFRIC - XLS

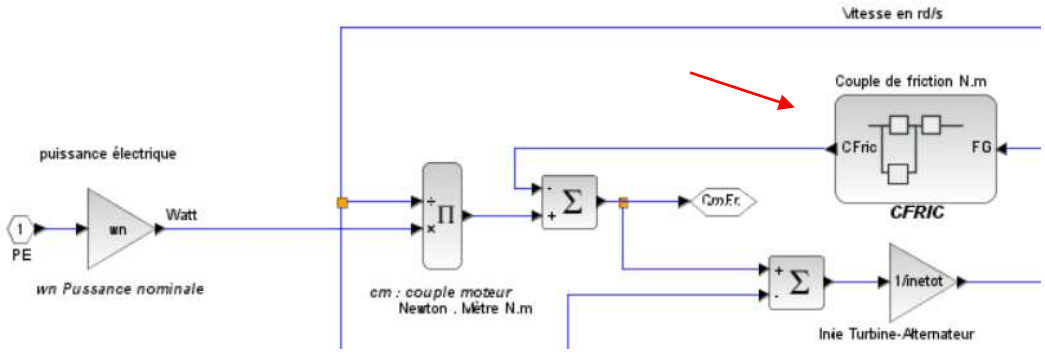


Figure 81 : Application of friction torque in the Network module

The friction coefficient kFric represents a percentage of the maximum torque wn/om0 to bring the machine from zero speed to its nominal speed in noload mode.

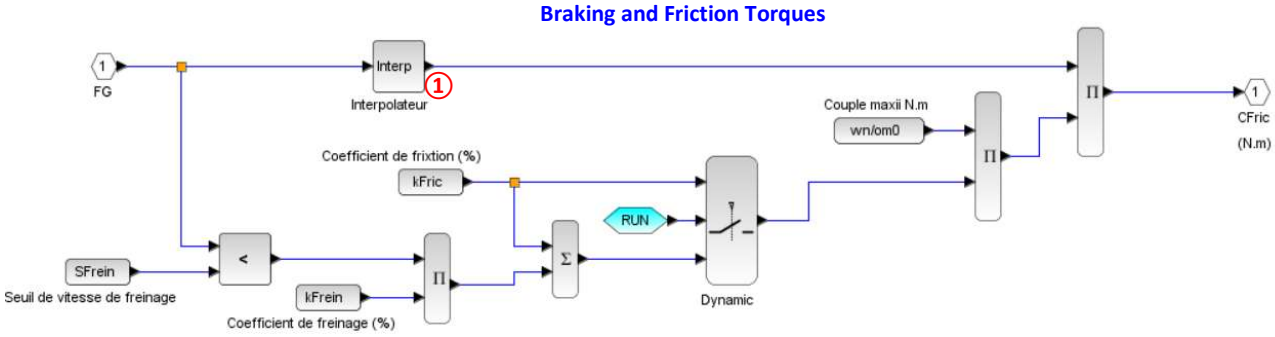


Figure 82 : CFRIC Friction and Braking Torques Mode

When the turbo-alternator group is triggered, with machine stoppage (MoDECL=0, RUN=0), it is possible to add an electric braking torque (or hydraulic, PELTON machine anti-jet for example), making it possible to accelerate or delay the return to zero speed when the machine is on its own inertia.

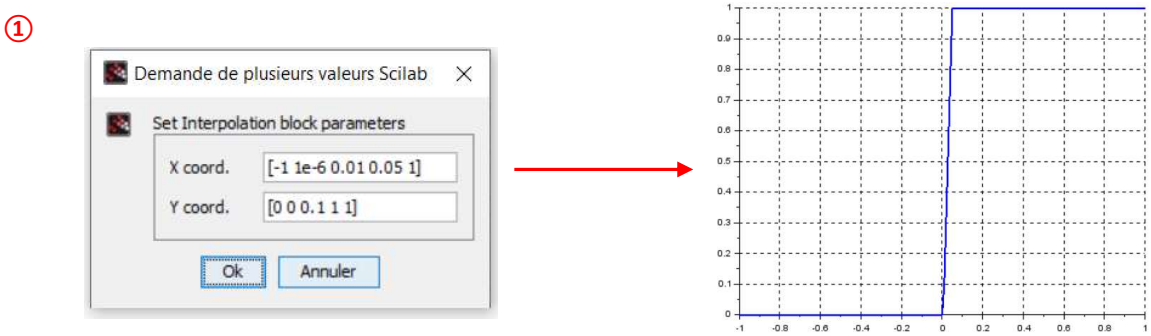


Figure 83 : Interpolator in the CFRIC module

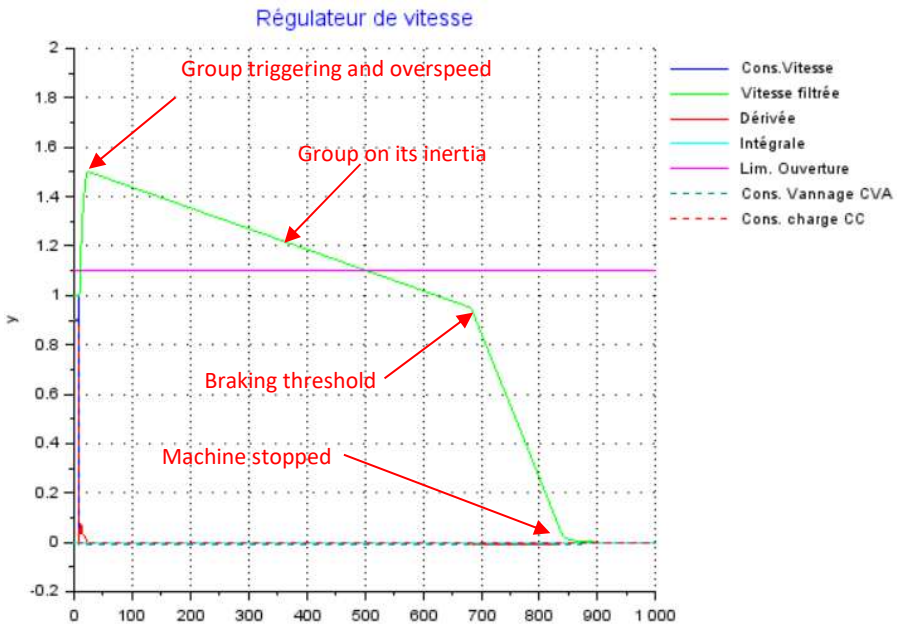


Figure 84 : Group triggering and machine stop (MoDECL=0)

3.11 Resynchronization Sync of the speed integrator

3.11.1 Activation principle

The speed integrator is a key point that is difficult to master in regulation.

It is sometimes necessary to control its efficiency to improve the transient regimes in the operation of the machine:

- When closing the group circuit breaker (DJF event)
- During underspeed or overspeed (Sync1 event)
- On a machine charge load (Sync2 event)
- When the group is triggered (RDECL event)
- …Others

A device is specially designed to provide for the resetting of the speed integrator to 0 upon synchronization of the events described above (non-exhaustive list).

This mechanism, common to all the proposed models, is described in the "**Système**" module of the programs and schematic libraries. All synchronizations are carried on a single signal named "**Sync**", and causing the speed integrator to be reset to 0:

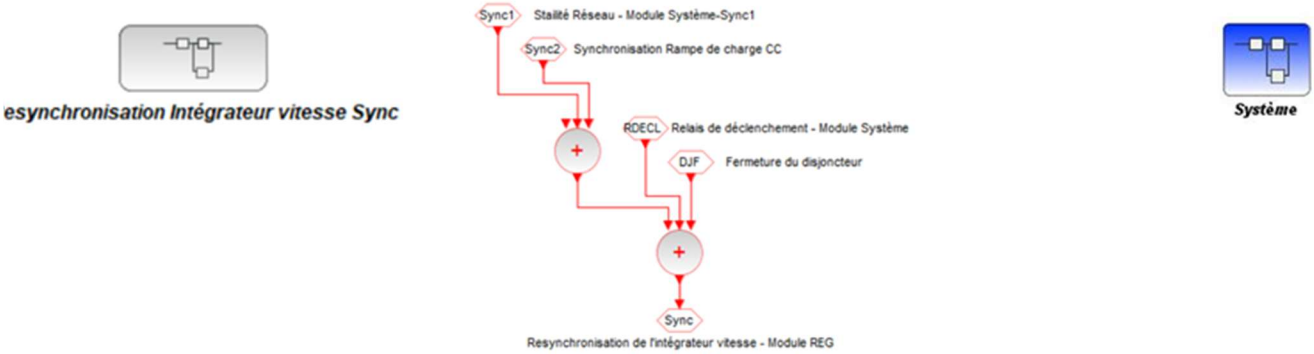


Figure 85 : Speed integrator resynchronization mechanism

Each resynchronization signal is associated with a Boolean value to enable the option. If the Boolean value is zero, the associated synchronization is not emitted (bRDELC for RDECL, bSync1 for Sync1, bSync2 for Sync2).

The use of these synchronization relays must be studied on a case-by-case basis in each model, and depends on the robustness of the stability parameters.

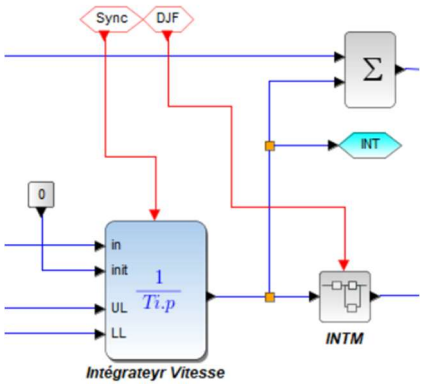


Figure 86 : Pulse reset of the speed integrator on receipt of the Sync signal

3.11.2 RDECL machine trip overspeed relay

bRDECL	RDECL relay validation (0: Invalidation – 1: Validation (default value))	Système - XLS
P_RDECL	Minimum power threshold for implementing the RDECL relay (pu)	Système - XLS
SvOn1	RDSV overspeed relay (pu)	Système - XLS
SvOff1	RDSV overspeed relay (pu)	Système - XLS
SyncErr	Position error threshold for regulation resumption (pu) (resynchronization)	Système - XLS

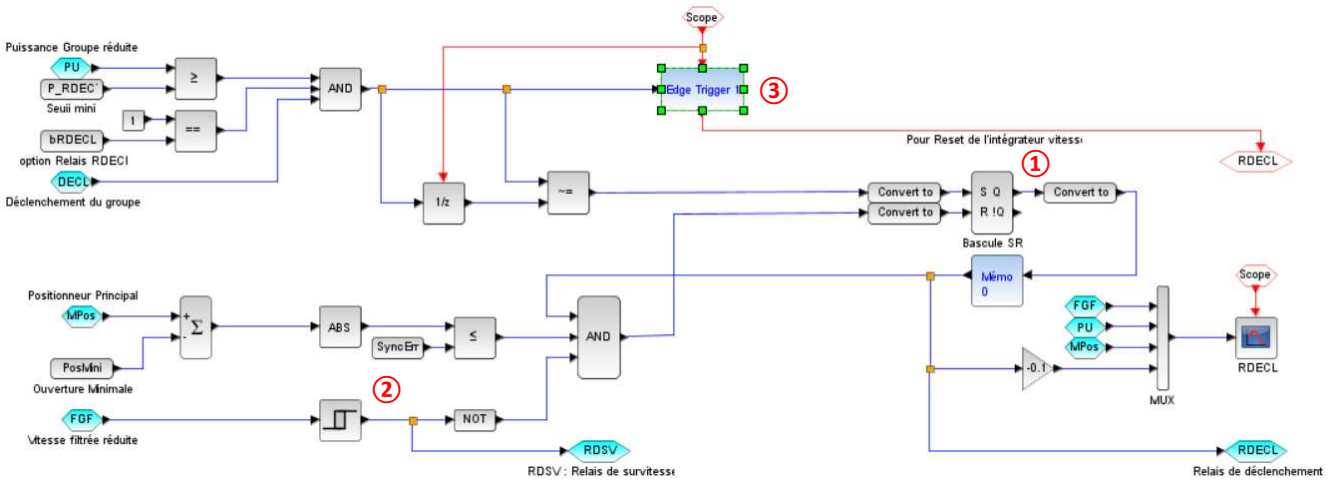


Figure 87 : RDECL Trip Relay Diagram

S	R	Q_n	$!Q_n$	①
0	0	Q_n	$!Q_n$	Maintien
0	1	0	1	Remise à 0
1	0	1	0	Mise à 1
1	1	I	I	Etat interdit

Figure 88 : Truth table of the RS flip-flop

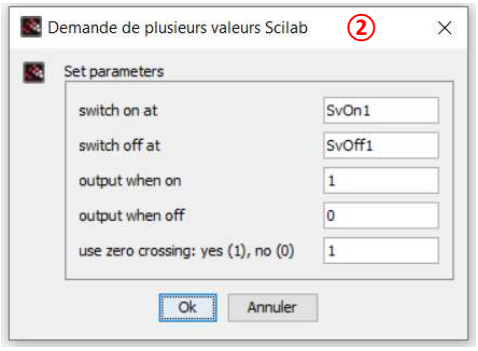


Figure 89 : Hysteresis of the overspeed relay in the RDECL module

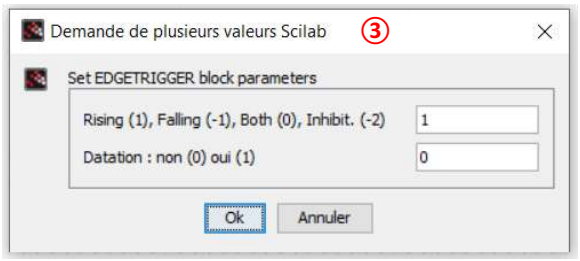


Figure 90 : Edge Detector - Arming the RDECL flip-flop

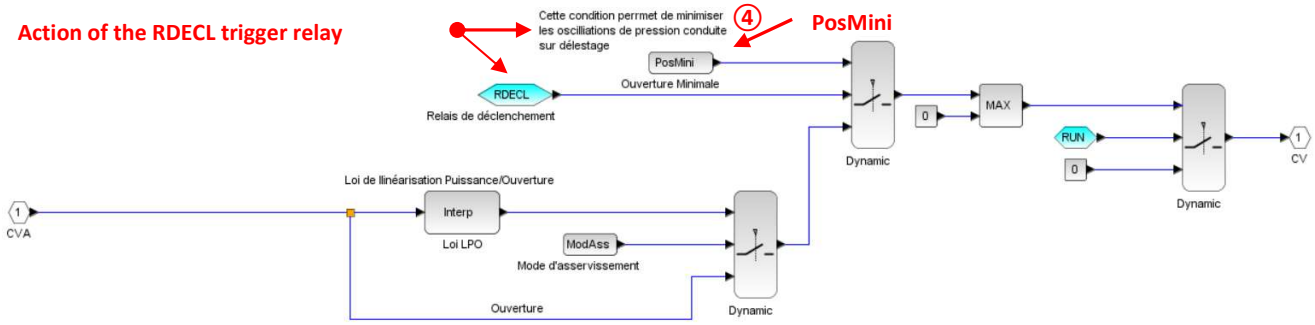


Figure 91 : Action of the RDECL trigger relay on the pre-positioning of the adjustment device (LINE block)

The **RDECL** trigger relay is structured around an RS flip-flop ①.
It causes, under certain conditions, an automatic switch of the group to MANUAL mode, by ordering a pre-positioning of the adjustment organs at a minimum opening PosMini programmable ④, to be optimized, often close to idle operation, depending on the situation. (*see also MoDECL, Figure 41, Figure 42).*
This device allows to attenuate the suppressions in the pipes by controlling the generated wave ram.
The trigger relay can only be applied from a power validation threshold PU≥P_RDECL..
The sequence ends with a reset to 0 of the SR ② flip-flop, memory of the RDECL relay, on a speed threshold programmed around a hysteresis SvOn1 and SvOff1. In this case, the group automatically returns to speed control mode.

This device resets the integrator to 0 during a trigger sequence (*see Figure 31)*

3.11.3 Network Stability Detector - Speed Integrator Reconditioning Sync1 Block

bSync1	Option to resynchronize the speed integrator on overspeed or underspeed thresholds (su)	CI - XLS
SvOn2	Overspeed Relay Sync1 Module (pu)	CI - XLS
SvOff2	Overspeed Relay Sync1 Module (pu)	CI - XLS
SvOn3	Underspeed Relay Sync1 Module (pu)	CI - XLS
SvOff3	Underspeed Relay Sync1 Module (pu)	CI - XLS
TPStab	Delay for detection of return to a stable network (s)	CI - XLS
StabH	High threshold for stable network detection (pu)	STABRES - XLS
StabL	Low threshold for stable network detection (pu)	STABRES - XLS

☞ The purpose of the algorithm shown in the figure below is to control the excursion of the speed integrator to avoid any drag of the latter, in the transients under load of the machine.

This mechanism produces, on option bSync1, a **Sync1** event allowing the resynchronization of the Speed integrator.

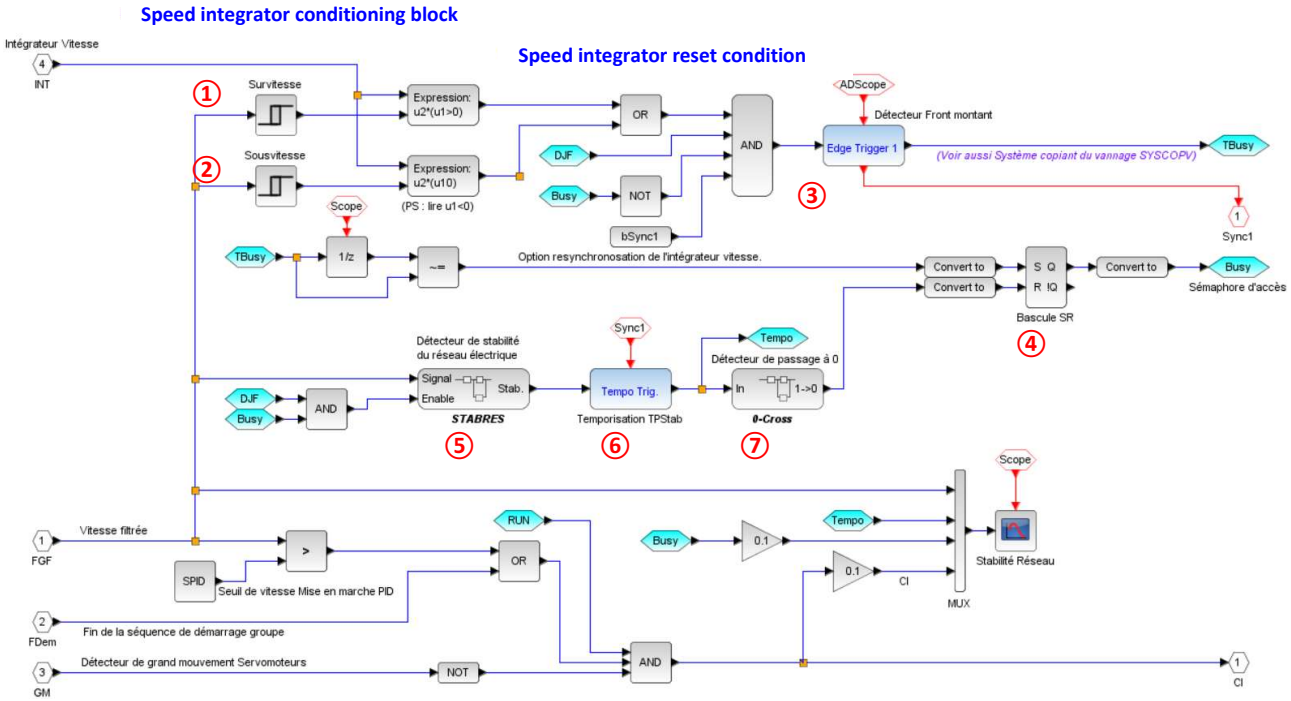


Figure 92 : System Module – Sync1 Resynchronization relay

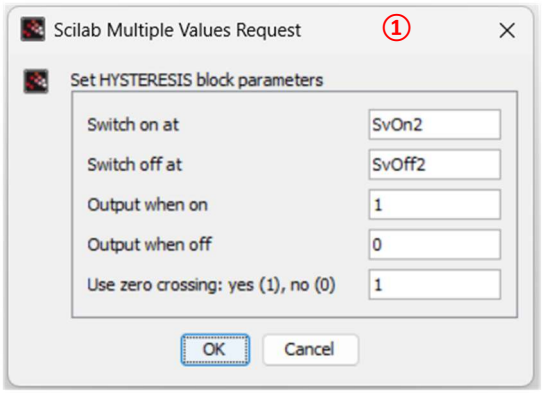


Figure 93 : Overspeed relay - KB

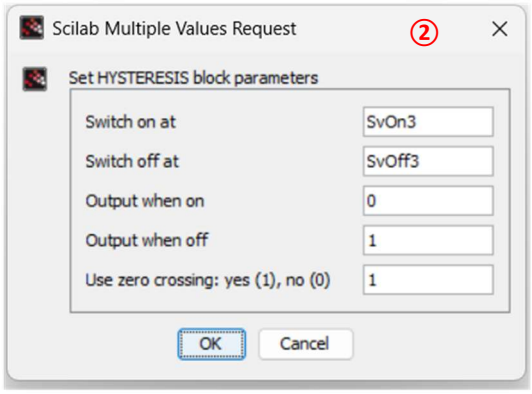


Figure 94 : Underspeed relay – KB

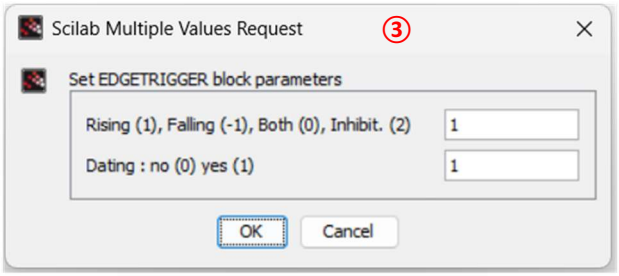


Figure 95 : **Sync1** trigger with **TBusy** time stamp

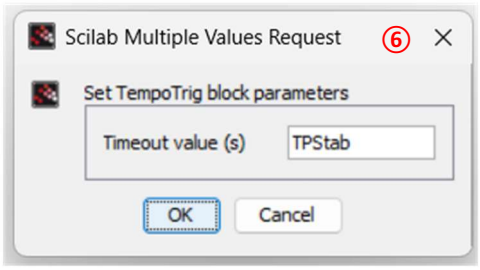


Figure 96 : Resettable time delay for detecting return to stable electrical network operation

Component ③ generates the **Sync1** resynchronization, and its Datation=1 option stores the date of the event on the **TBusy** variable (see SYSCOPV module for use).

If the input of Timer ⑥ is 1, then its output is forced = 1 (rearming, see *Figure 97*)

Otherwise, the timing output scales according to a time constant ramp $\frac{-1}{TPStab}$

A zero-value detection edge, object of the 0-Cross component ⑦, generates a reset of the RS flip-flop ④.

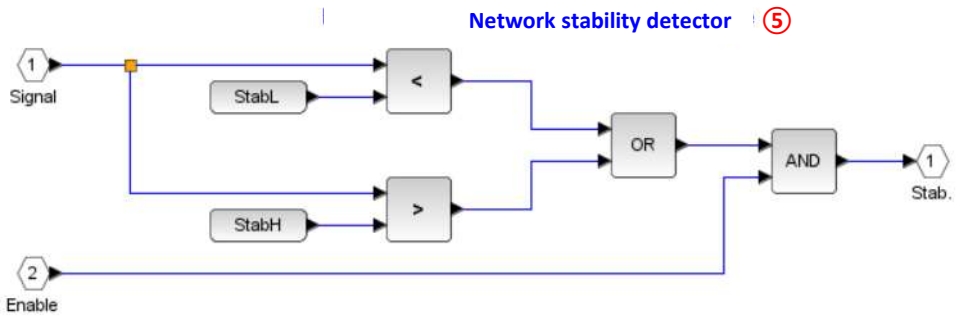


Figure 97 : Network stability detector – STABRES module

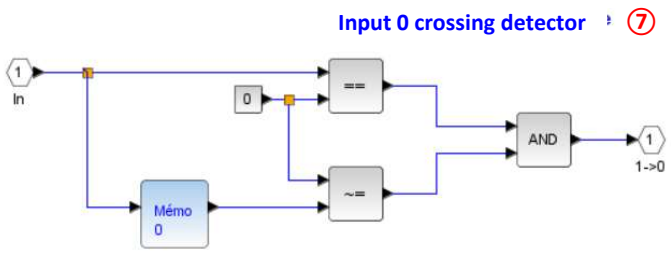


Figure 98 : End of timer detector - Return to stable network - 0-Cross module

A mechanism structured around an RS ④ flip-flop makes it possible to control the transient regime of a Kaplan group coupled to the electrical network.

1) The turbo-alternator group assembly and the electrical network are in a stable state when the simulation is launched. The group is operated at a certain power.
Lors During a load pick-up, or partial load shedding, a variation in network frequency can cause the relays to trigger with overspeed hysteresis ① or underspeed ②, for the programmed thresholds.

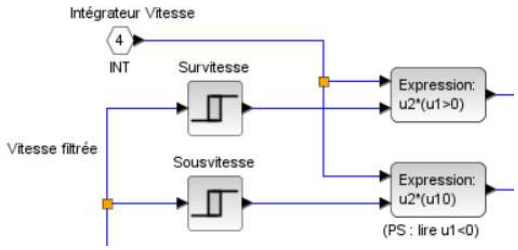


Figure 99 : Speed relay activation conditions for speed integrator control - KB

The arming condition is linked to the value of the speed integrator, to keep it in its active role, or to decide to reset it to 0 if it is in an unfavourable position in the observed sequence, i.e.:

- Overspeed threshold **SvOn2** detected AND Integrator **INT>0**
- Underspeed threshold **SvOn3** detected AND Integrator **INT<0**

If the system has not yet been armed (Busy=0), then it becomes armed (**Sync1**) by detecting a rising edge on component ③, the effect of which is to arm the RS flip-flop ④ to 1 and to position the variable Busy=1.
A first consequence of this detection is also a reset to 0 of the Integrator register of the speed PID (*see Figure 85 and Figure 86*), and an arming of the timer ⑥.

2) From then on, the process waits for a re-stabilization of the network in the range [StabL—StabH] to reset the RS flip-flop ④ to 0. Consequently, the integrator is no longer reset to 0 before the end of this sequence.

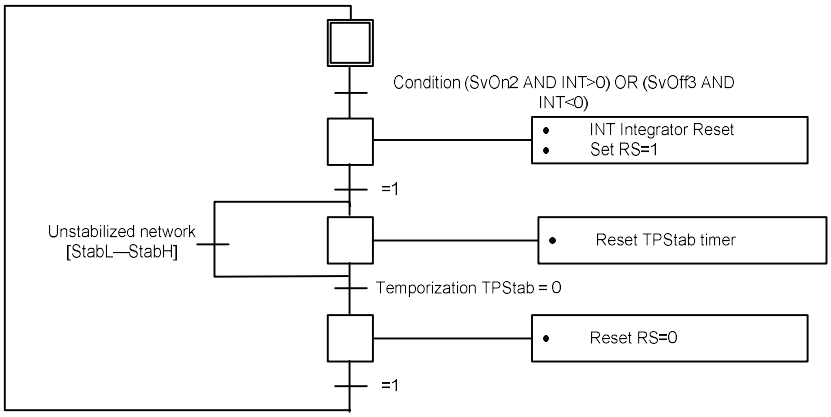


Figure 100 : Simplified Grafcet for Sync1 resynchronization

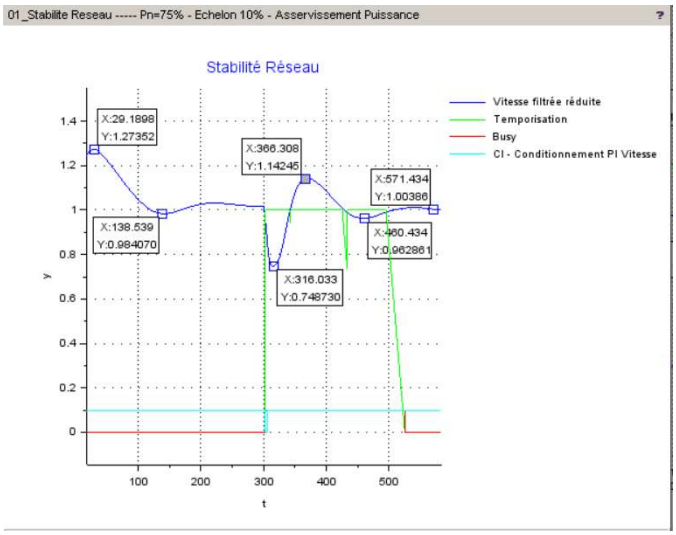


Figure 101 : KB Resynchronization Graph

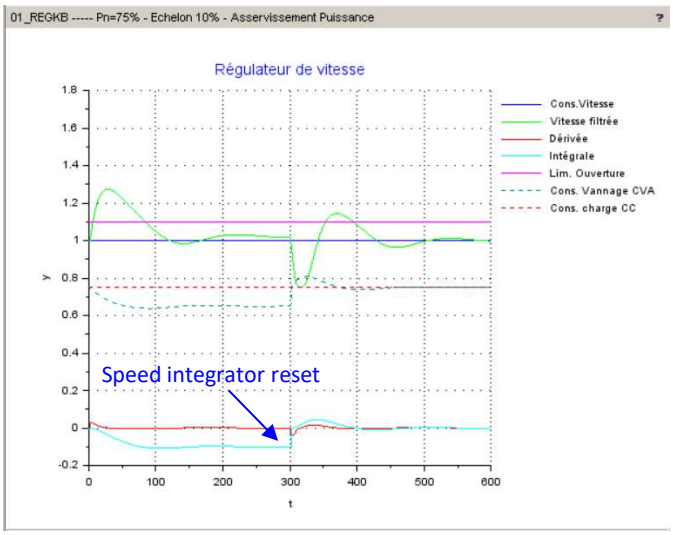


Figure 102 : PID speed - Reset the INT integrator to 0

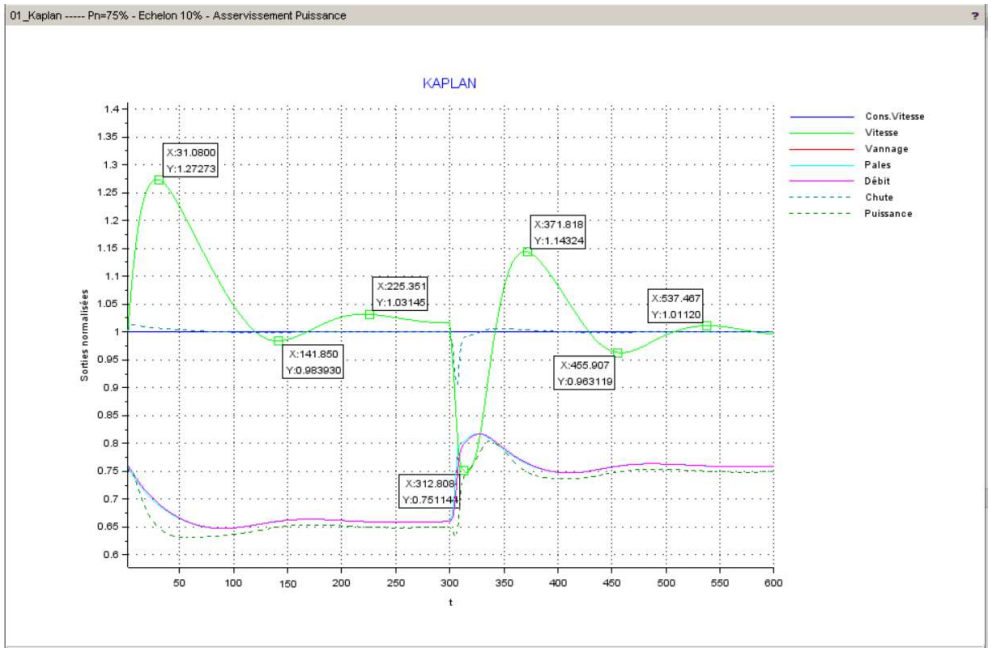


Figure 103 : Kaplan Transient 75% PW - Step 10%

3.11.4 Sync2 resynchronization relay on load intake – Charging ramp approach

bSync2	Speed integrator resynchronization option at the end of charging	CC - XLS

The purpose of the **Sync2** resynchronization option of the speed integrator is to reset this register at the end of the load intake, to optimize the approach, following the drag of the speed PID in its pursuit on the load setpoint ramp.

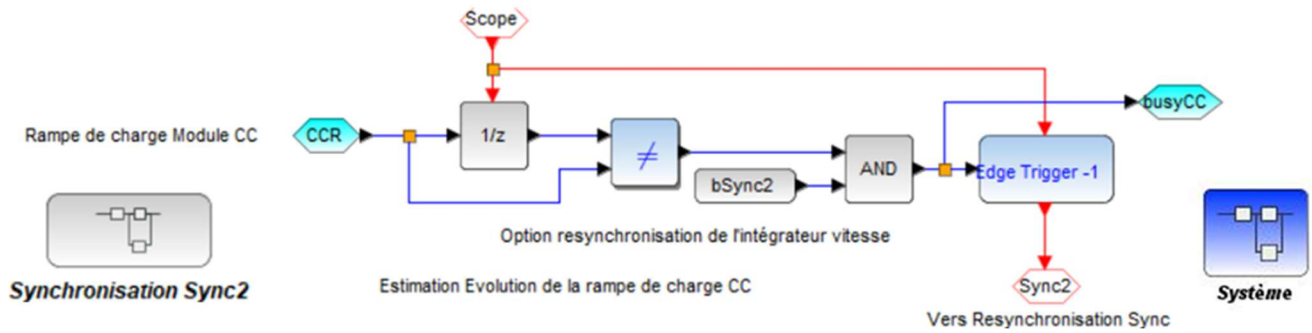


Figure 104 : Sync2 Synchronizer - **Load Ramp Docking**

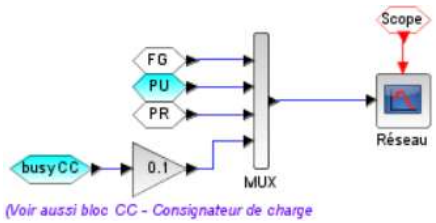


Figure 105 : Visualization of the Busy relay in the *Reseau* module

In ***Figure 104***, we introduce a pure delay z-1 on the load ramp, then a comparator between the current value and the delayed value. The **busyCC** relay gives the status of this comparison, when the **bSync2** option is validated at 1:

- Until the ramp reaches its final value, **busyCC**=1
- When the ramp reaches its final value, **busyCC**=0

- Upon detection of a falling edge of the **busyCC** relay, a **Sync2** resynchronization signal is sent to the speed integrator, and instantly resets it to 0 (*see Figure 85 and Figure 86*).

- The relay status can be viewed in the "Reseau" scope.

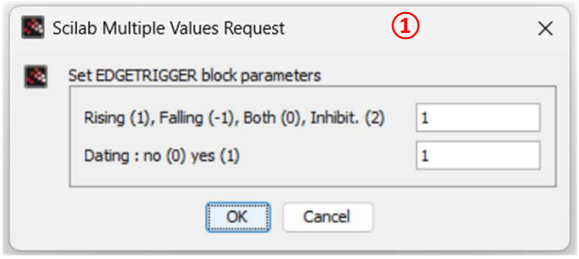


Figure 106 : Programming Falling Edge Detection

The sequences presented below are available in the stability study directory: **HydroSim\demos\KAPLAN\KB1\10 – Sites\0 – Standard\0 - Études stabilité\Pn=50% - Rampe 75% - Essais bSync2.**
The simulation starts with the group coupled to the network (TDFJ=0), at 50% load (CResau=0.5), in power control (ModAss=1).

We use pertubograph No. 3 on the load ramp, indicated in the CC module of the KB simulator (*see Figure 75*)

At time tdw3=10 s, a +25% charge (dw3=0.25) is achieved to bring the generator from 50% to 75% charge. For a ramp time TRamp=300 s, the 75% charge is therefore achieved at time t=10 s + 75 s = 85 s.

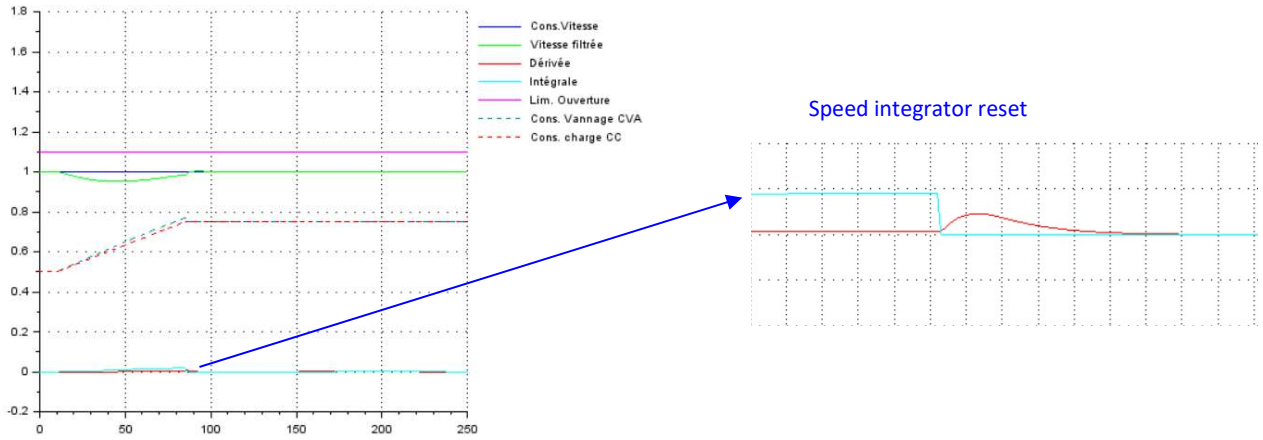


Figure 107 : Resetting the speed integrator to 0 on Sync2 resynchronization

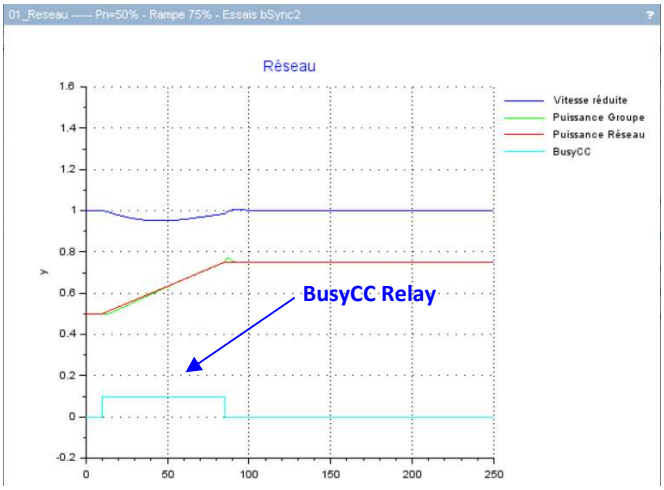


Figure 108 : Load ramp KB1 - Pn=50% - Ramp 75% - bSync2=1

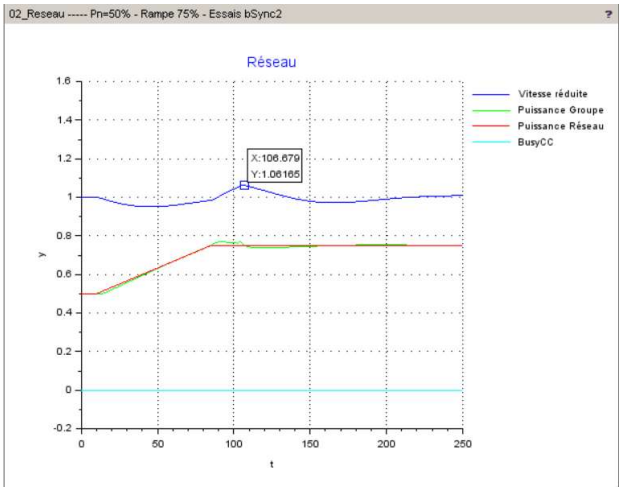


Figure 109 : Load ramp KB1 - Pn=50% - Ramp 75% - bSync2=0

3.12 SYSCOP copying systems (Valve or Injectors – Francis-Kaplan-Pelton turbines)

3.12.1 Oil-hydraulic circuit

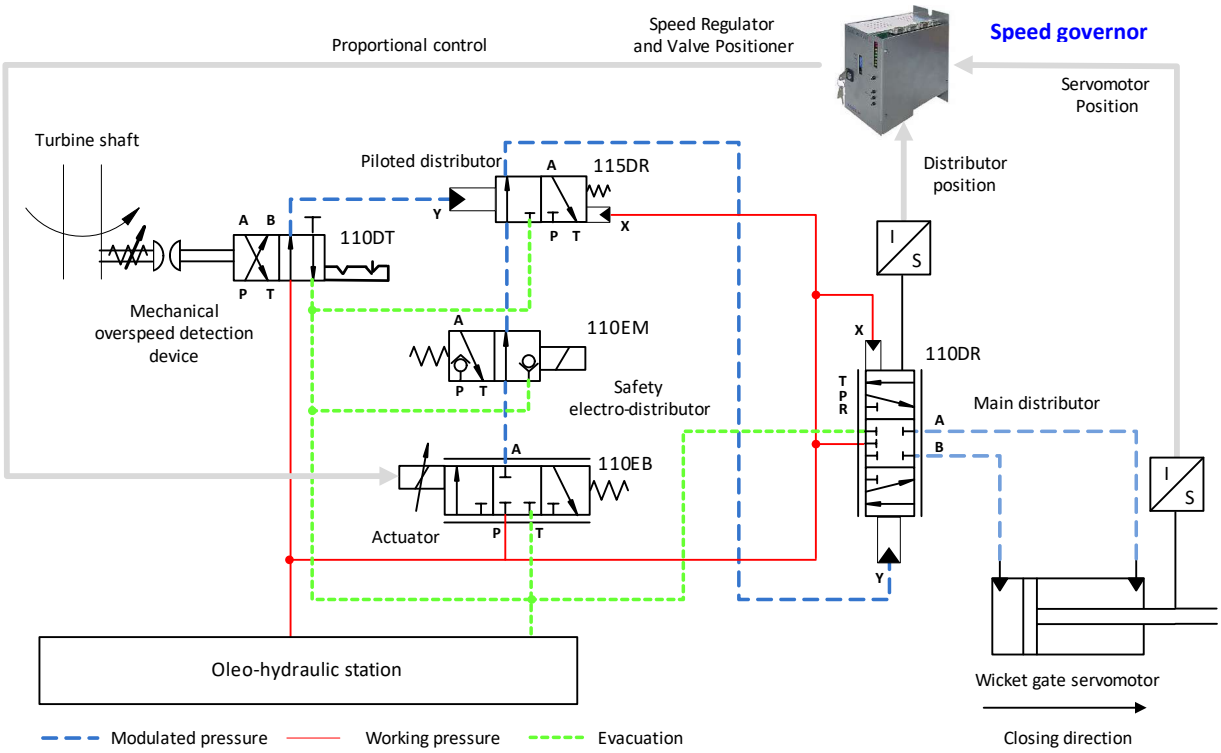


Figure 110 : Simplified oleohydraulic diagram for controlling the adjustment device – Copying system [10]

The SLG Speed/Position regulator electrically controls a 110EB actuator (Valve), which itself controls a 110DR oleohydraulic preamplifier, acting on the chambers of the servomotor to be controlled.

3.12.2 Adjustment diagram

3.12.2.1 Turbines FRANCIS

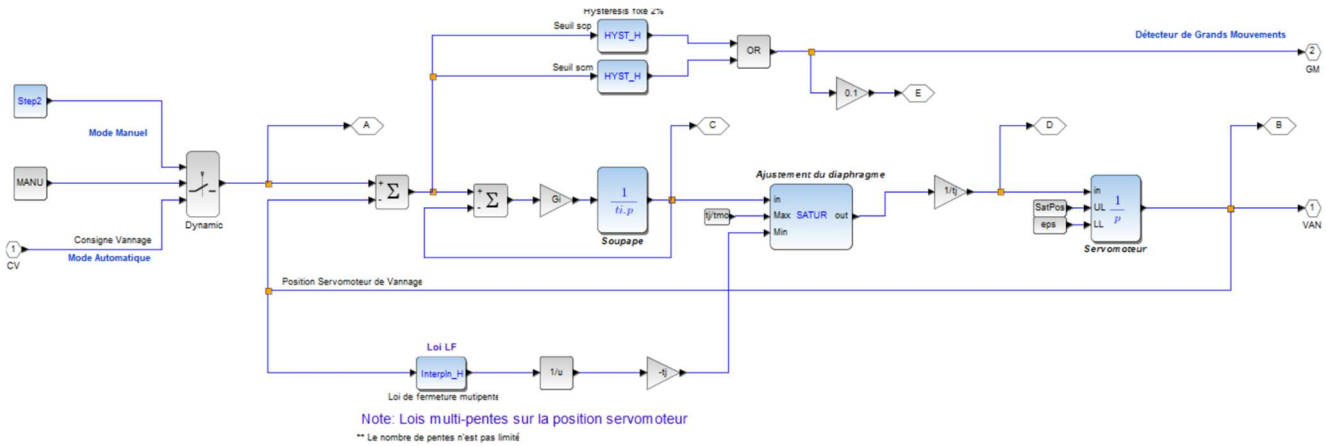


Figure 111 : SYSCOP servomotor positioning block – Valves

3.12.2.2 PELTON turbines horizontal or vertical axis with optional jet dispatcher

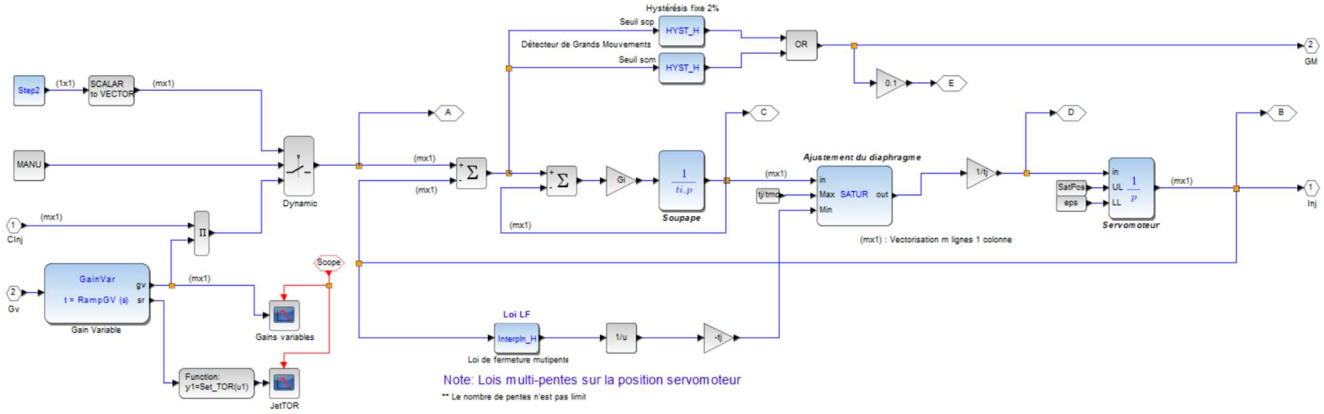


Figure 112 : SYSCOP Servomotor Positioning Block – Injector - Needle

The SYSCOP circuit for PELTON turbines is like the Francis circuit, but includes an additional term called “Variable Gain”, adapting the injector gain according to the orders transmitted by the associated Jet Dispatcher, depending on the power required, for vertical axis turbines.

For 1 or 2 jet **horizontal axis** turbines, systematically disable the distributor function by programming **RepOnOff=0**.

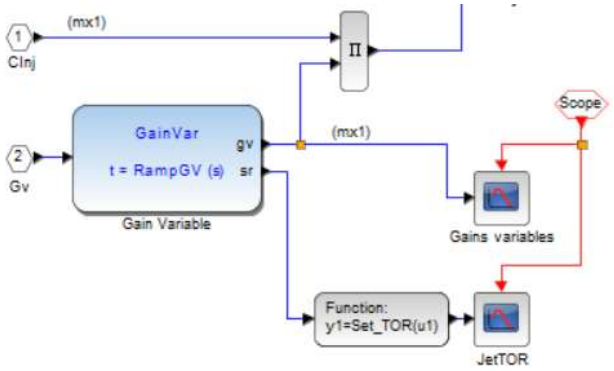


Figure 113 : Variable Gain Adaptation in PELTON Turbines - Vertical Axis

This circuit is common to all PELTON groups of 1 to 6 jets, and is written in vector form (nx1), (n lines 1 column), where n is the number of jets in the machine. There is therefore only one diagram covering all cases.

3.12.3 Francis-Injector Positioner PID Adjustment

tj_	Servomotor Integrator Time Constant (s)	SYSCOP - XLS
ti_	Valve Integrator Time Constant (s)	SYSCOP - XLS
Gi_	Valve Gain (su) (GI=5.0 by default)	SYSCOP - XLS

SatPos	Maximum saturation of the servomotor excursion (pu)	SYSCOP - XLS

SatPos corresponds to maximum saturation of the valve servomotor, therefore to over-opening when the nominal operating point is not positioned at the maximum opening of the servomotor travel (100%).

3.12.4 Adjustment of the operating times of the opening and closing control devices by a multi-slope LF law

tmo	Servomotor operating time when opening (s)	SYSCOP - XLS
LF_	Multi-slope closing law of the control devices (mm or pu/s) – Calculation of closing operating times according to the LF law	SYSCOP - XLS

The operating times correspond to the opening times (① tmo) or closing times (② + ③), calculated from the programmable law **LF**, for a stroke of 100% of the servomotor(s).

The diaphragm is automatically adjusted according to the position of the servomotor, and the direction of movement to be considered.

The machine setting in closing corresponds to the best compromise between overspeed and overpressure conducted for a 4/4 load shedding of the machine.

The rapid maneuvering time generally helps to avoid excessive overspeed, while the slow closing time(s) minimize the oscillations in the pipe generated by the closing of the obturator, and therefore of the valve.

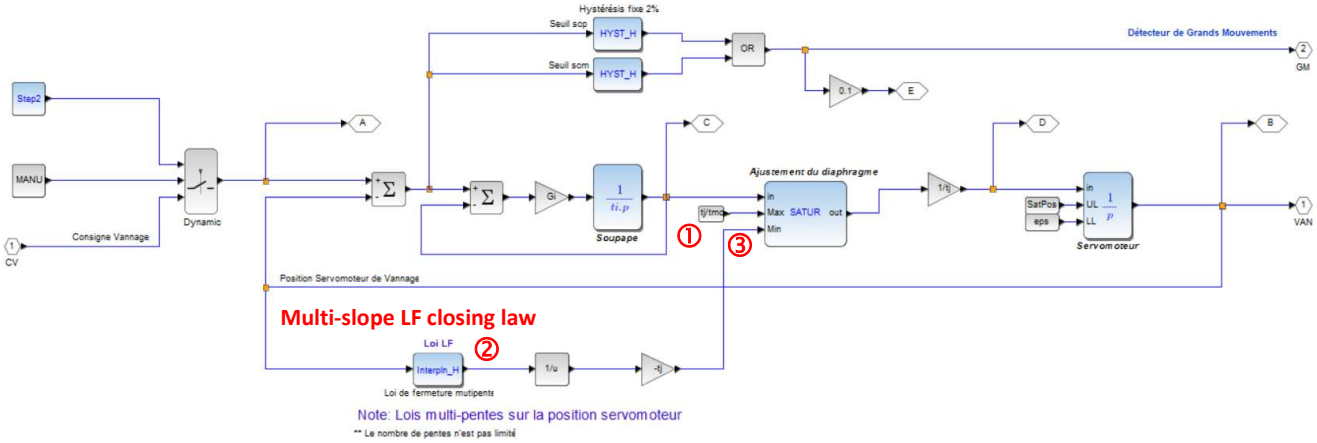


Figure 114 : SYSCOP module for controlling the valve copying system in HydroSim

The **LF** closing law to be programmed is a two-dimensional law with the closing time (s) on the abscissa, from the full opening of the servomotor at time t=0, to the complete closing time of the servomotor. The abscissas are expressed in seconds.

The ordinates represent the slope break points. They can be expressed in millimeters of servomotor travel, or in a standardized 0-1 representation.

From the programmed **LF** law, the remarkable instruction "**Generateur_Loi_fermeture** ", automatically called in the .CTX files, automatically generates the two vectors **xLF** and **yLF** used in the SYSCOP modules, as indicated in ② *Figure 114*.

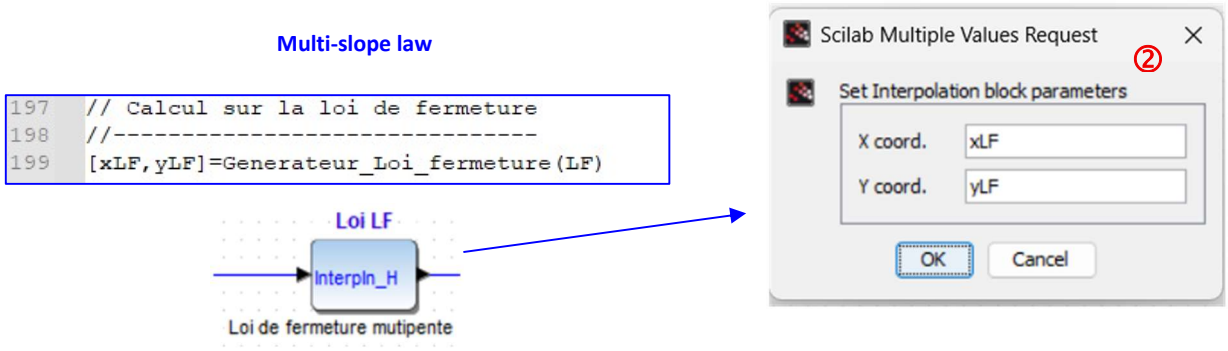


Figure 115 : Calculation of closing maneuverer times on the LF law in CTX files

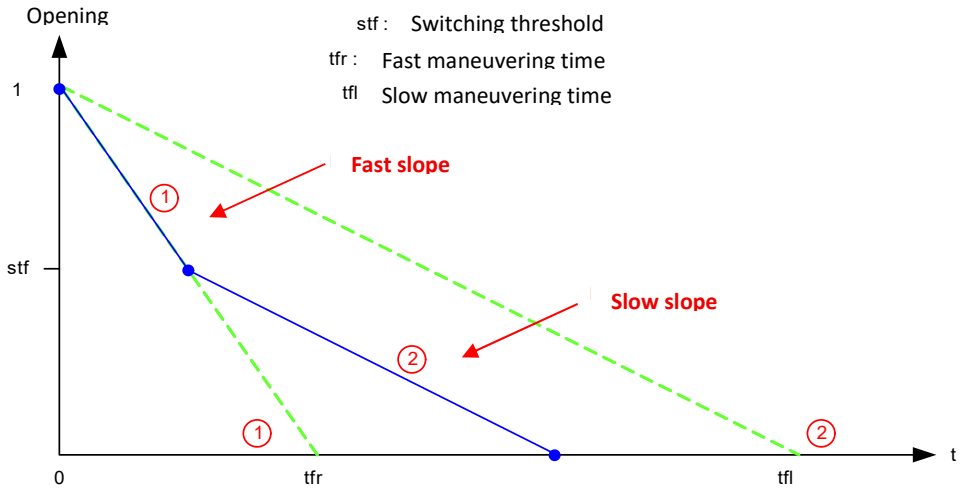


Figure 116 : Principle of parameterization of multi-slope closure laws

The LF law must be programmed in the XLS file of each project, in the Excel sheet named TM

	A	B	C	D	E	F
1	// Temps de manoeuvre et lois de fermeture multi-pentes positionneur SYSCOP					
2	//----------					
3	tmo=10;	// Temps de manoeuvre en ouverture du servomoteur (s)				
4						
5	// Les lois LF et LFP sont traçables en utilisant l'instruction HYDROTUR "PlotLF"					
6	----------					
7	LF=[					
8	0.0	1.0				
9	3.5	0.3				
10	15.5	0.0				
11	];					
12						

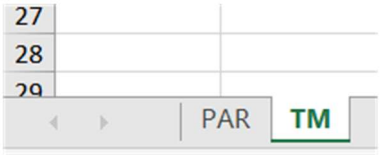


Figure 117 : Multi-slope law in the TM sheet of the HydroSim\FRANCIS\FR2\Standard\FR2c.xls project file

On the other hand, the "**PlotLF**" instruction allows you to visualize the programmed LF manoeuvrer law, as well as the manoeuvrer time law automatically [xLF; yLF] calculated by HydroSim (*Also see Figure 174*).

An error message is displayed if the law is not present in the XLS file:

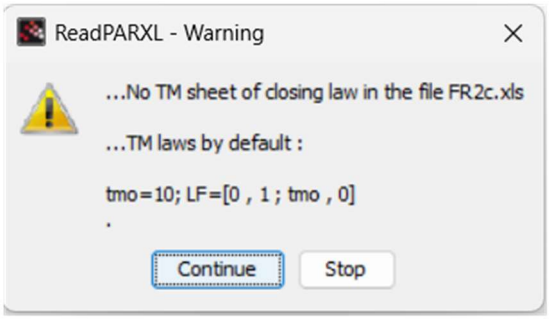


Figure 118 : Default manoeuvrer law if the TM sheet is absent

The example below illustrates the use of the PlotLF instruction in a 4-slope closure law.

The opening and closing laws can also be checked using the manual mode MANU=1 in the SYSCOP modules (*see Figure 127*)

A demonstration of the closure law is carried out by entering the command "**PlotLF demo**" or "**PlotLF démo**" in the Scilab console. (*also see Figure 174*)

```
"LF"

 0.      345.4
 1.      220.
 2.5     212.3
 6.7     163.4
 9.8     83.8
 17.4    0.
```

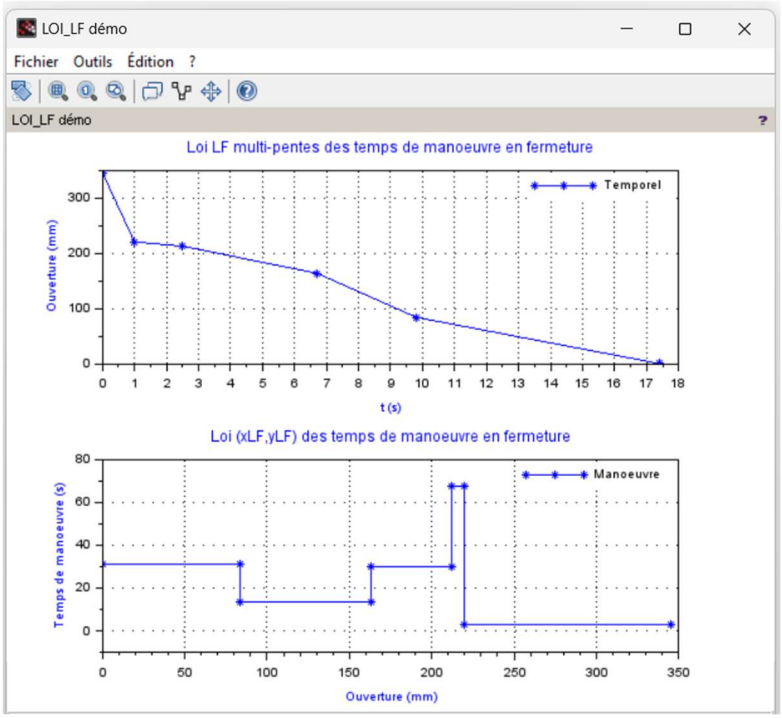


Figure 119 : Example of a multi-slope closure law - Plotting instruction "**Plot LF demo**"

3.12.5 Servomotor large movement tracking thresholds

3.12.5.1 Thresholds for FRANCIS-PELTON Turbines

scp	Large Movement Threshold for Opening Direction (pu) (FRANCIS-PELTON)	SYSCOP/GM - XLS
scm	Large Movement Threshold for Closing Direction (pu) (FRANCIS-PELTON)	SYSCOP/GM - XLS

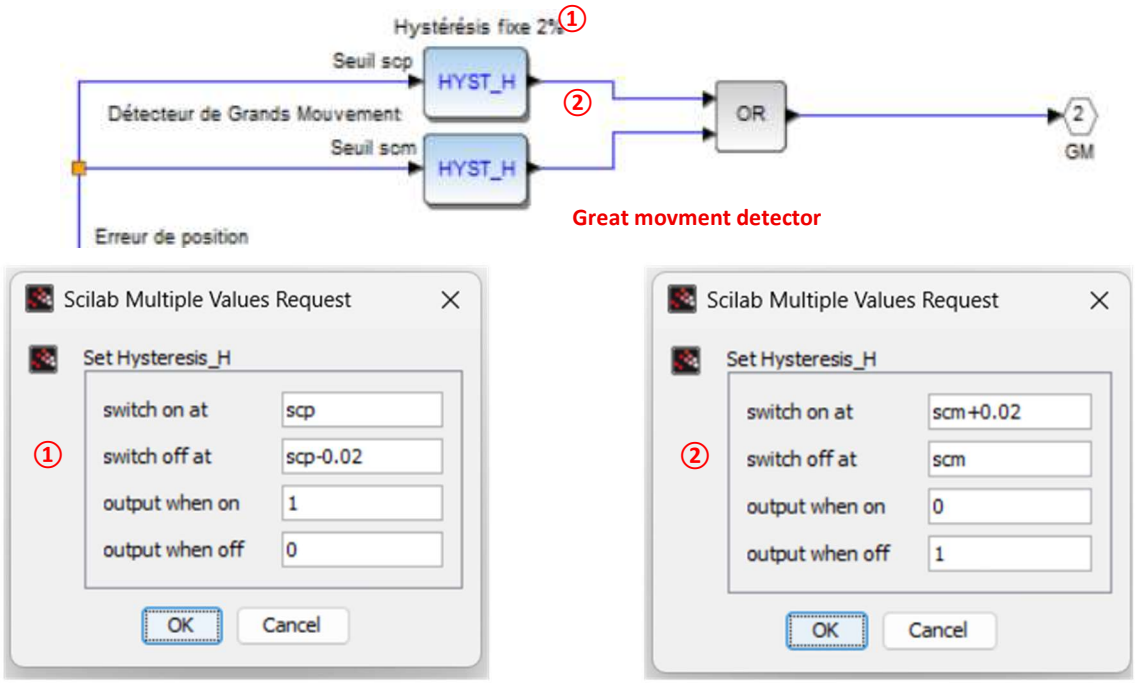


Figure 120 : Large movement detector Valves or Injectors – SYSCOP Module

The **GM** large movement detector, on the valve of a Francis or Kaplan turbine, or on the injectors of a Pelton turbine, makes it possible to inhibit the integral action of the speed regulator, to avoid any saturation of this term, during transients in large movements.

A fixed hysteresis of 2% prevents unwanted triggering of the detection switches.

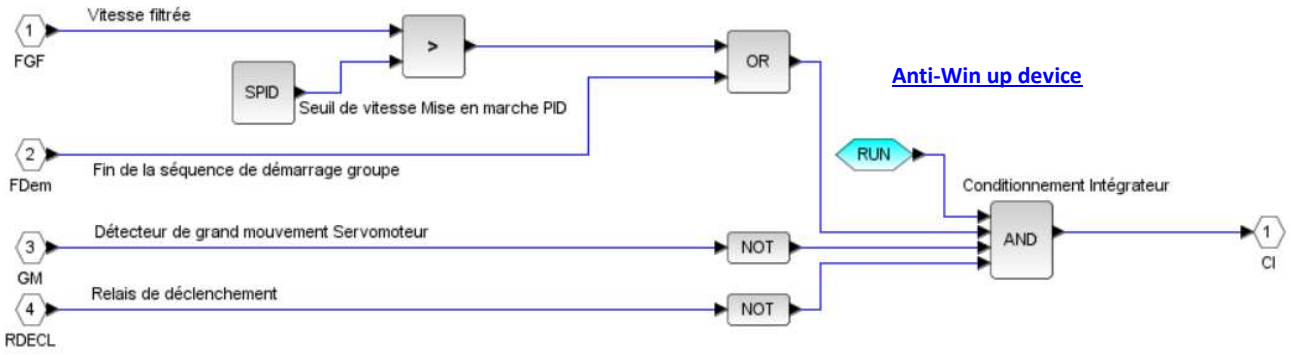


Figure 121 : Speed integrator conditioning block in the CI-REGN module

3.12.5.2 Threshold for KAPLAN Turbines

scv	Large Movement Threshold for Closing Direction (pu) (KAPLAN wicket gate)	SYSCOPV/GM - XLS

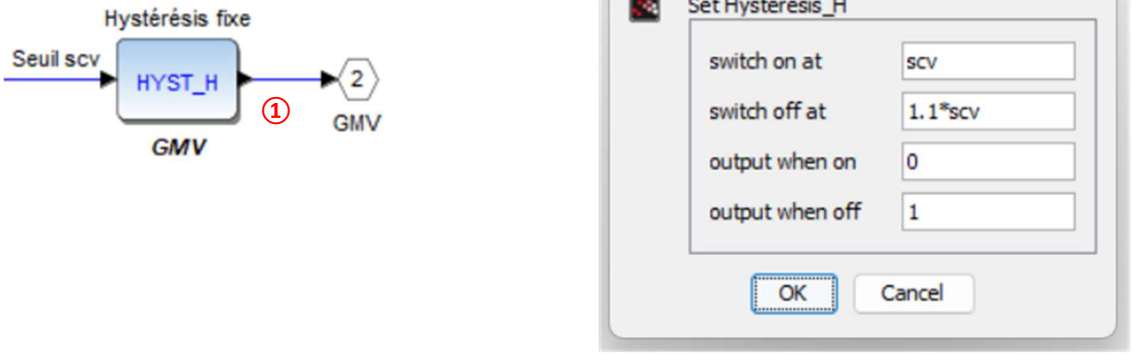


Figure 122 : Large Movement Threshold for Closing Direction (Kaplan Turbine)

☞ By default, program scv=-0.2, unless otherwise specified

3.12.6 Minimum opening of the servomotor when the group is triggered with return to idle operation

PosMini	Minimum opening in RUN mode (see LIN) in the event of group trip and return to noload mode (pu)	LINE -XLS

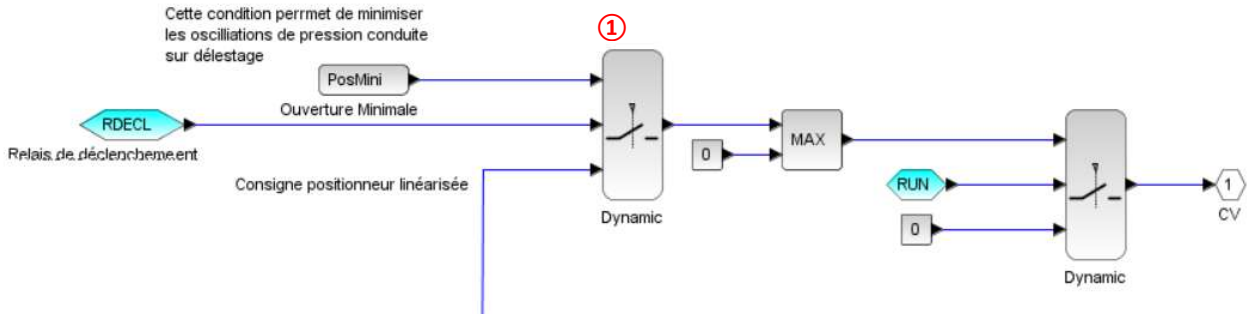


Figure 123 : Prepositioning of the wicket gate servomotor (or Injector) when the group is triggered with Return to noload mode (LINE block)

When the **RDECL** trigger relay is armed (*see Figure 91*), switch ① is in the high position, and imposes a positioning instruction indicated by the **PosMini** parameter.

This device makes it possible to minimize the wave ram generated in a trigger sequence with return to idle running of the machine. (*Voir Figure 40, Figure 41, Figure 42*).

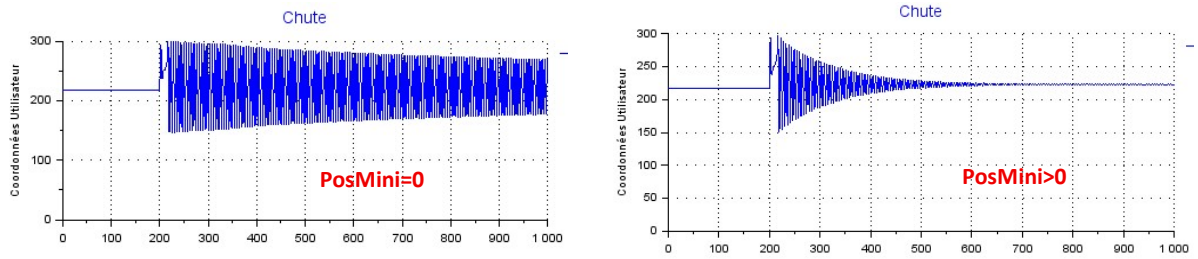


Figure 124 : Damping of penstock oscillations with PosMini

3.12.7 Manual Mode

MANU	Unit in manual mode (su)		SYSCOP - XLS
MANU	**0**	Unit in automatic mode	
	1	Unit in manual mode	
CManu	Manual Wicket gates or Injector Setpoint (pu)		SYSCOP - XLS
EchPos	Disturbance amplitude in manual mode (pu)		SYSCOP - XLS
tDepManu	Start time of the disturbance (s)		SYSCOP - XLS
tManu	Duration of the disturbance in manual mode (s)		SYSCOP - XLS

Manual mode allows you to separate the control of the adjustment components from the speed control loop.

Manual control is understood as a means of adjusting the servocontrol in the position of the turbine opening, using the positioning loop in the electronic regulator or directly via the actuator(s) [10].

Within the HydroSim simulator, Manual mode can optionally be used to record all the system linearities (Power/Opening, Flow/Opening, etc.), to linearize each of these functional quantities as a function of the opening of the servomotor.

☞ In Manual mode, the **TDJF** (Circuit Breaker Closing Time) parameter is not considered, to ensure circuit consistency.

The CManu instruction is applied directly to the input of the copying system positioner, if MANU=1 (*see. Figure 111* :)

From the **CManu** position setpoint, it is possible to generate, via the **STEP2** component integrated into the SYSCOP module, an additional disturbance of amplitude **EchPos,** starting at time **tDepManu,** of duration **tManu**.

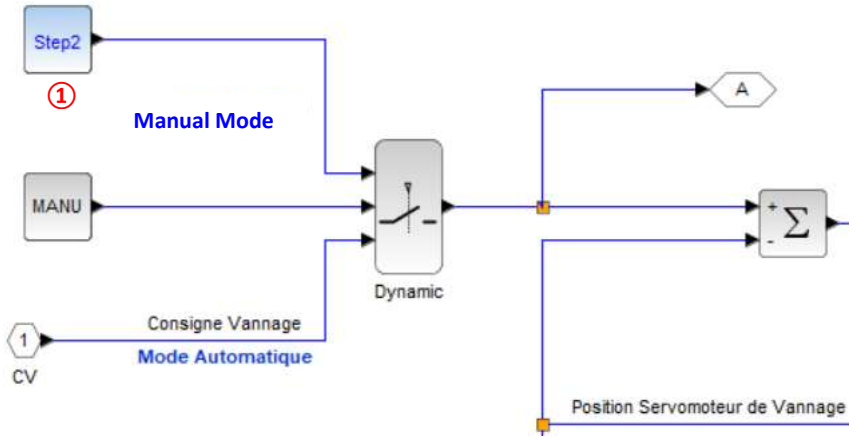


Figure 125 : Manual Mode in SYSCOP blocks (MANU=1)

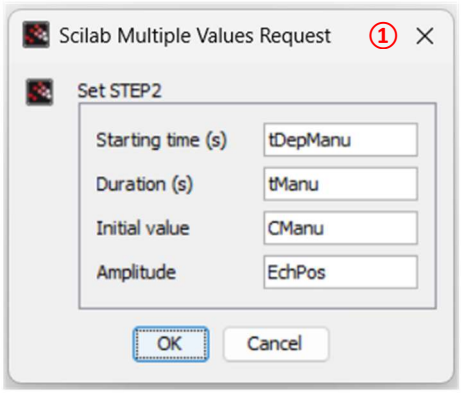
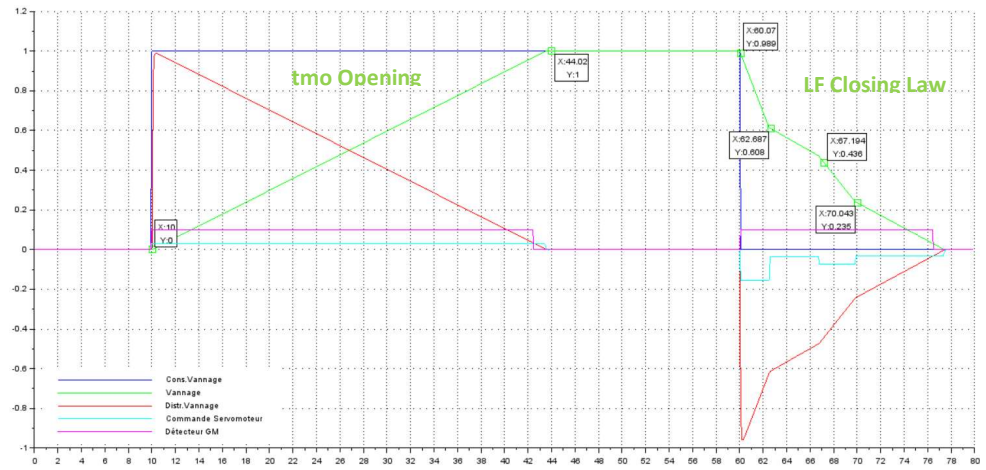


Figure 126 : STEP2 box parameters in a SYSCOP module



CFG file :

TSim=80; // Durée de la simulation (s)

MANU=1; // Régulateur en mode manuel

CManu=0.0; // Consigne de position en mode manuel

EchPos=1.0; // Echelon de perturbation en mode manuel

tDepManu=10 // Instant de départ de la perturbation

tManu=50; // Durée la perturbation en mode manuel

Figure 127 : Verification of a 4-slope LF closure law in manual mode (MANU=1)

3.13 SYSCOPD copying system (PELTON turbines - Deflectors)

3.13.1 Adjustment diagram

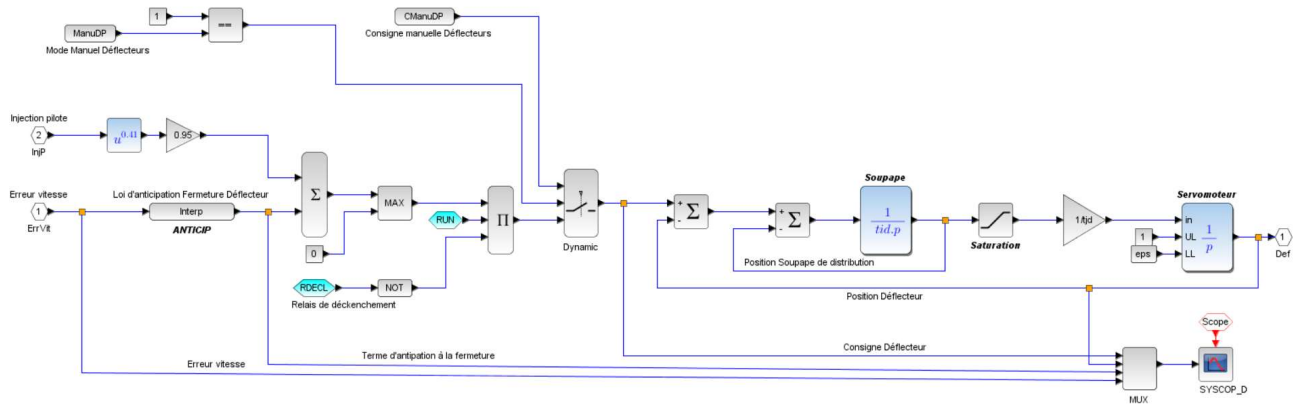


Figure 128 : SYSCOPD deflector copying system

3.13.2 PID Tuning Deflector Positioner

tjd	Servomotor Integrator Time Constant (s)	SYSCOPD - XLS
tid	Valve Integrator Time Constant (s)	SYSCOPD - XLS

3.13.3 Adjusting the manoeuvrer times

tmod	Servomotor operating time when opening (s)	SYSCOPD - XLS
tmfd	Servomotor operating time when closing (s)	SYSCOPD - XLS

The operating time corresponds to the opening time (tmod) or closing time (tmfd) for a stroke of 100% of the servomotor(s)

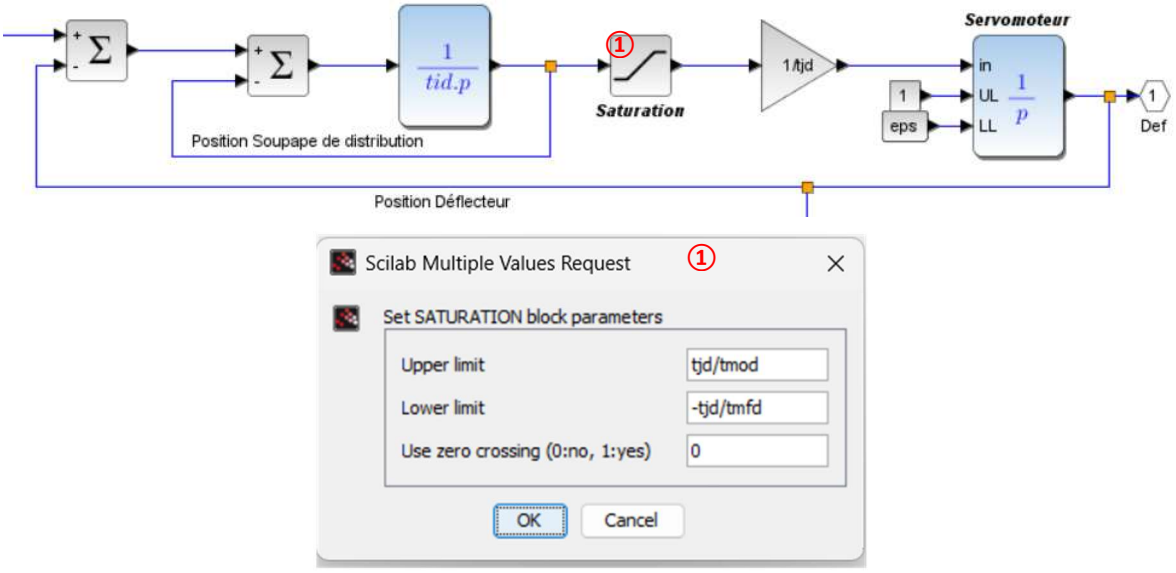


Figure 129 : Action of manoeuvring times on copying systems

3.13.4 Manual Mode Deflectors

ManuDP	Deflectors in manual mode (su)	SYSCOPD - XLS
CManuDP	Manual instruction Deflectors or Blades (pu)	SYSCOPD - XLS

ManuDP allows the safety device to operate in manual mode, the first device being able to remain in automatic mode or not (*see MANU*).

When ManuDP=1, the positioning instruction is indicated by the CManuDP parameter, high position of the switch ①.

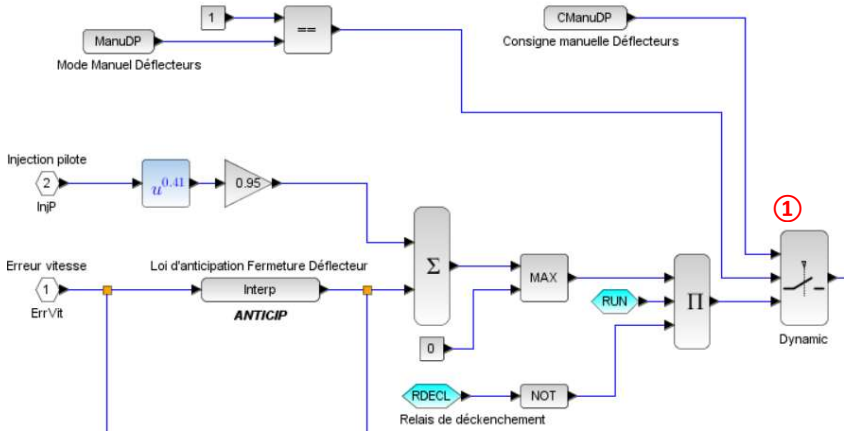


Figure 130 : Manual mode Deflectors in a PELTON turbine

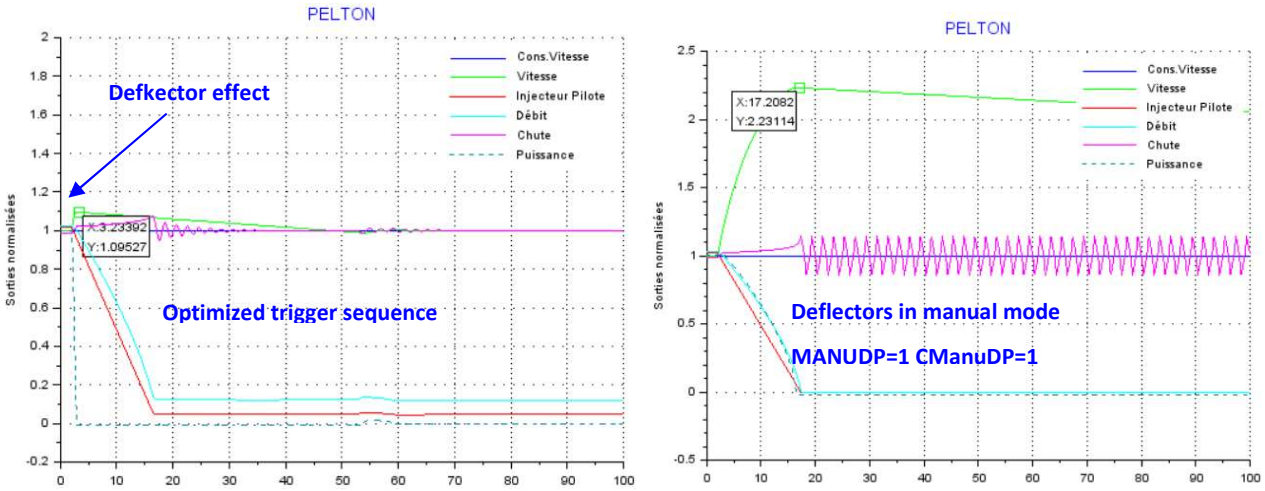


Figure 131 : Cutting effect of the deflectors on a PELTON machine during a machine trip at full load

3.13.5 Law of anticipation of closing of deflectors by anticipation of the speed error

s1a	Anticipation threshold no. 1 (pu)	SYSCOPD - XLS
s2a	Anticipation threshold no. 2 (pu)	SYSCOPD - XLS
ga_	Gain on anticipation of closing (su)	SYSCOPD - XLS

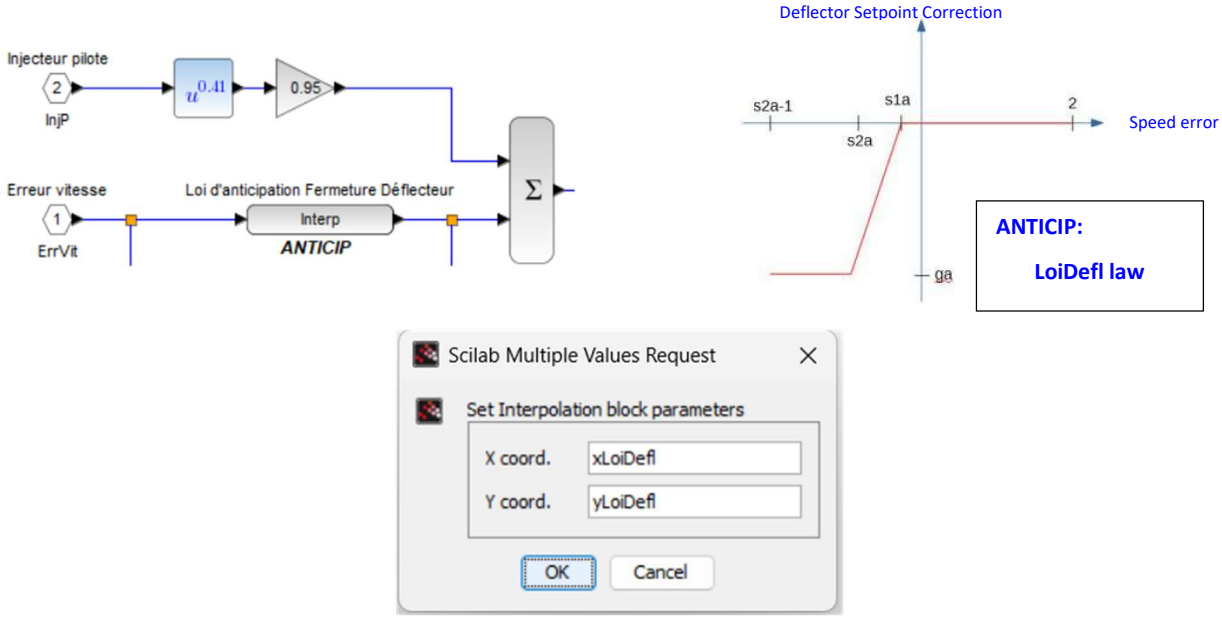


Figure 132 : LoiDefl law for anticipating the closure of deflectors (SYSCOPD block)

In steady state, the deflectors follow the pilot injector according to an empirical tracking law, of the form

$$C_{Def} = 0.95 * C_{Inj}^{0.41}$$

where C_{Def} represents the Deflector setpoint and C_{Inj} the pilot injection setpoint.

During a load discharge on the electrical network, or a group disconnection, the machine undergoes a transient overspeed regime, and to limit the effect of this, an anticipation term applied to the deflector setpoint causes them to penetrate the injector jet, thus instantly cutting off the feed flow in the wheel buckets. The jet is thus deflected.

The Pelton wheel then slows down on its inertia, as long as the speed error remains negative. Then, the deflector resumes its role as follower of the pilot injection, which allows, if necessary, resynchronization of the machine on the network.

In the SYSCOPD scheme, this law is written in matrix form xLoiDefl and yLoiDefl, with

xLoiDefl=[s2a-1. s2a s1a 2.] et yLoiDefl=[ga ga 0. 0.], as shown in the figure above.

Note

Program by default s1a=-0.01 s2a=-0.2 ga=0.5

3.13.6 Analytical law for monitoring the pilot injector

The analytical law for tracking the pilot injector is given by the relation $C_{Def} = 0.95 * C_{Inj}^{0.41}$

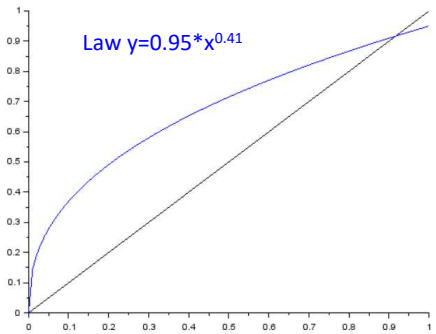


Figure 133 : Analytical law of deflector tracking

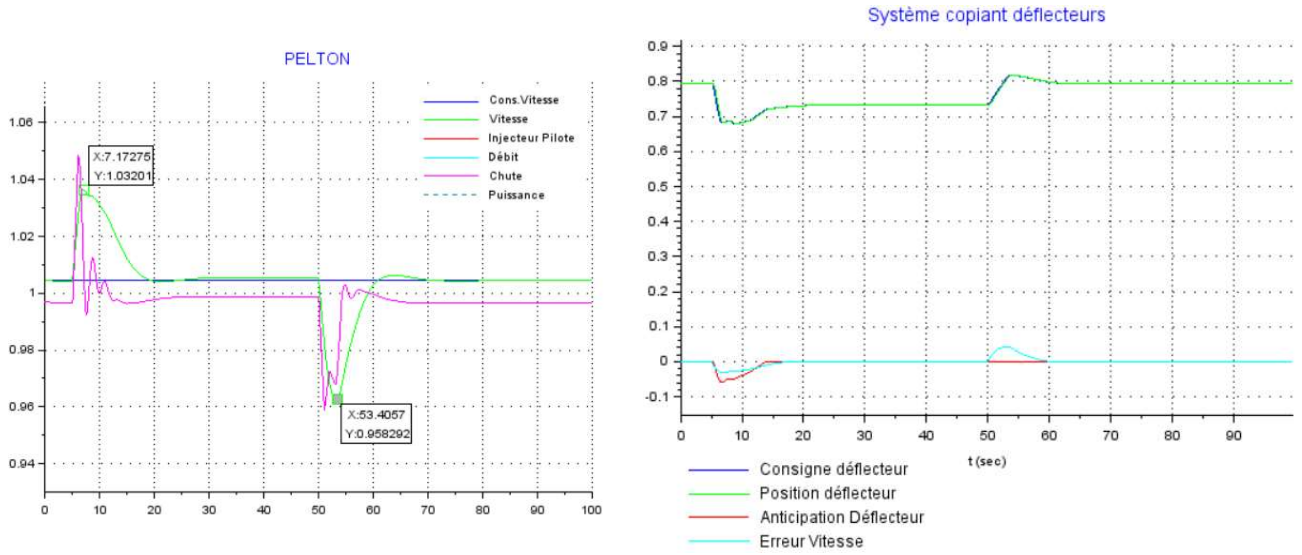


Figure 134 : Step 10% to P=75% - Evolution and anticipation of the PELTON deflector

3.13.7 Power Correction by the Deflector - PU_DEFL Block

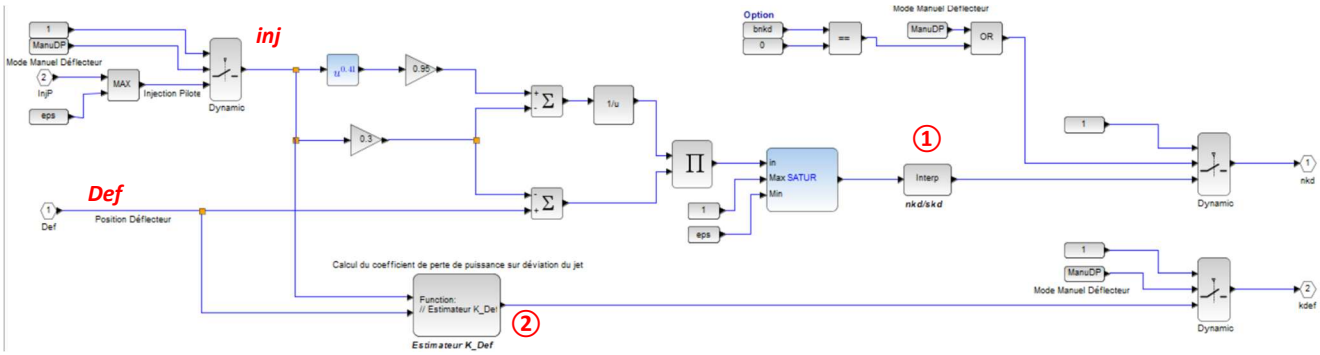


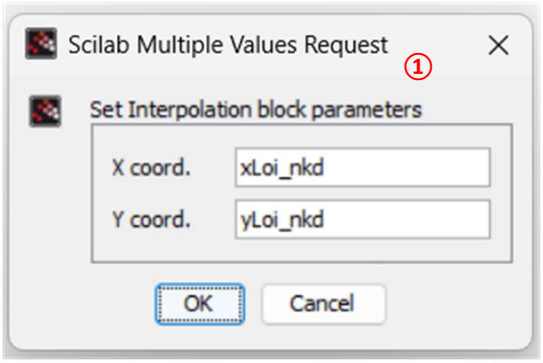
Figure 135 : Power Correction by the Deflector - PU_DEFL Block

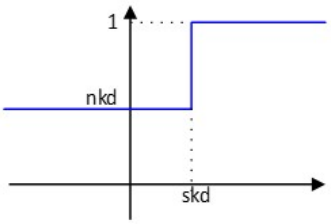
3.13.7.1 Conditioning law of the speed integrator by the deflector ①

The principle is to energize the injector PID when the deflector is in the jet, to avoid significant drag when the system stabilizes and the deflector leaves the jet.

Within the limits of a stability study (maximum load step of 10%) this function is generally not used.

bnkd	Gain on anticipation of closing (su)		PU_DEFL - XLS
bnkd	**0**	Invalidation of the Deflector conditioning algorithm	
	1	Validation of the Deflector Conditioning Algorithm	
skd	Threshold on the coefficient of penetration of the deflector in the jet (pu)		PU_DEFL - XLS
nkd	Threshold on the coefficient of penetration of the deflector in the jet		PU_DEFL - XLS





xLoi_nkd= [0. skd skd+eps 1.];

yLoi_nkd= [nkd nkd 1. 1.];

Figure 136 : Conditioning law of the speed integrator by the deflector

☞ Program by default skd=0.9 et nkd=0.33

The boolean ***bnkd*** invalidates (0) or validates (1) the modulation function of the gain of the speed integral as a function of the position of the deflector.

When the device is disengaged (bnkd=0), the output of the calculation block is 1, so as not to affect the conditioning of the speed integrator.

☞ Program by default bnkd=0, unless otherwise stated.

3.13.7.2 Evaluation of the K_Def coefficient of penetration of the deflector in the PELTON jet ②

The **PU_DEFL** module calculates the **K_Def** coefficient, the deflector's participation in the deflection of the injector needle jet, in overspeeds linked to the PELTON machine sequences. The jet deviation thus indicates a relative and proportional loss of hydraulic power, depending on the operating point.

This calculation is performed in the "**K_Def Estimator**" function indicated in ②.

```
// Estimateur K_Def
//-------------------
Sinj=0       // Seuil de prise en compte de l'action du  Déflecteur

inj=max(u1,0);
if inj<Sinj then inj=0; end;
def=max(u2,0.);

a=0.9*inj^0.41;
b=0.4*inj;

y=0;

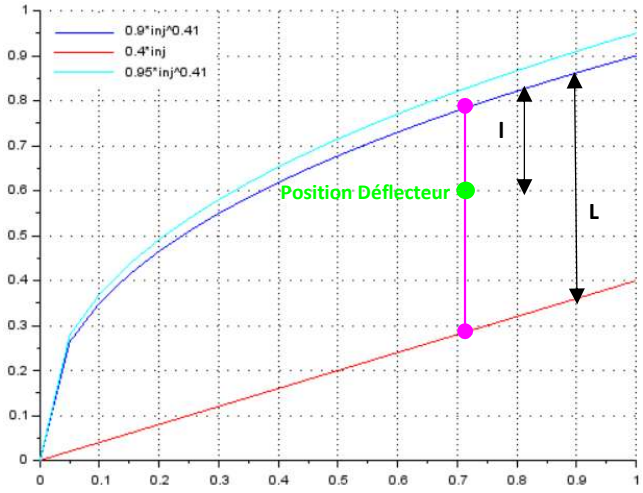
if a<>b then
  y=(def-b)/(a-b);
end

if y>1 then y=1; end

if y<0 then y=0; end

y1=y
```

Figure 137 : K_Def Estimator Algorithm for Deflector - PELTON Machines




```
// Programme Scilab
//-----------------
inj=0:0.05:1;

a=0.9*inj^0.41;     // Curve 1 – Deflector tangent to the jet
b=0.4*inj;          // Curve2 – Deflector cuts off the entire jet
n=0.95*inj^0.41 ;   //Curve 3 – Pilot Injector Tracking Law

plot2d(inj,a,2);
plot2d(inj,b,5)
plot2d(inj,n,4)

h=gcf();
axes = h.children;
axes.grid = [1,1];
axes.grid_style = [9,10];

Xlegend=["0.9*inj^0.41";"0.4*inj" ;"0.95*inj^0.41"];
legend(axes(1),Xlegend,2,%f);
```

Figure 138 : Evaluation of the K_Def coefficient of penetration of the deflector in the PELTON jet

Apart from any disturbance, the deflector follows the injector by the law indicated in curve no. 3 (*see §3.13.6*).

- If the position of the deflector is below curve no. 2, the expression (def-b) is negative, then K_Def=0 and the deflector completely cuts the jet
- If the expression (def-b)/(a-b) is greater than or equal to 1, then K_Def=1, and the deflector does not deflect the jet.
- Otherwise, the jet is partially deflected according to the relationship $K_Def = \frac{l}{L}$

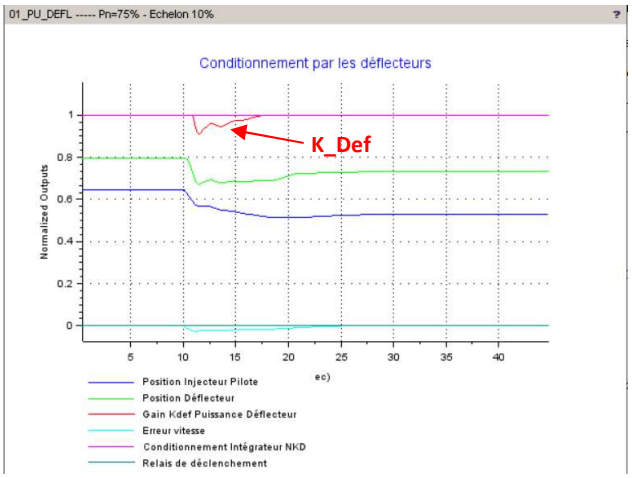


Figure 139 : K_Def - Steps 10% à Pn=75%

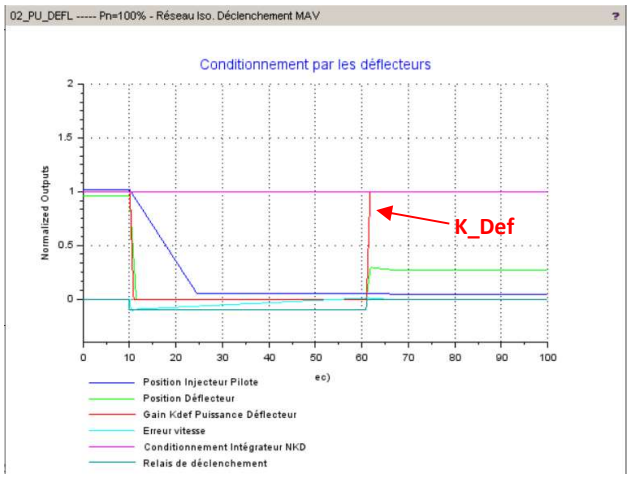


Figure 140 : K_Def Trigger with return to noload mode

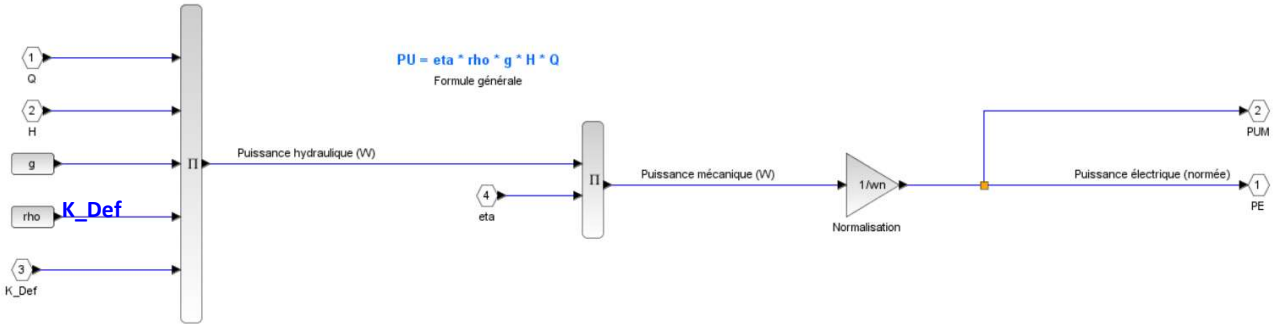


Figure 141 : Power block – PELTON Turbines

3.14 SYSCOPP copying system (KAPLAN turbines - Blades)

3.14.1 Adjustment diagram

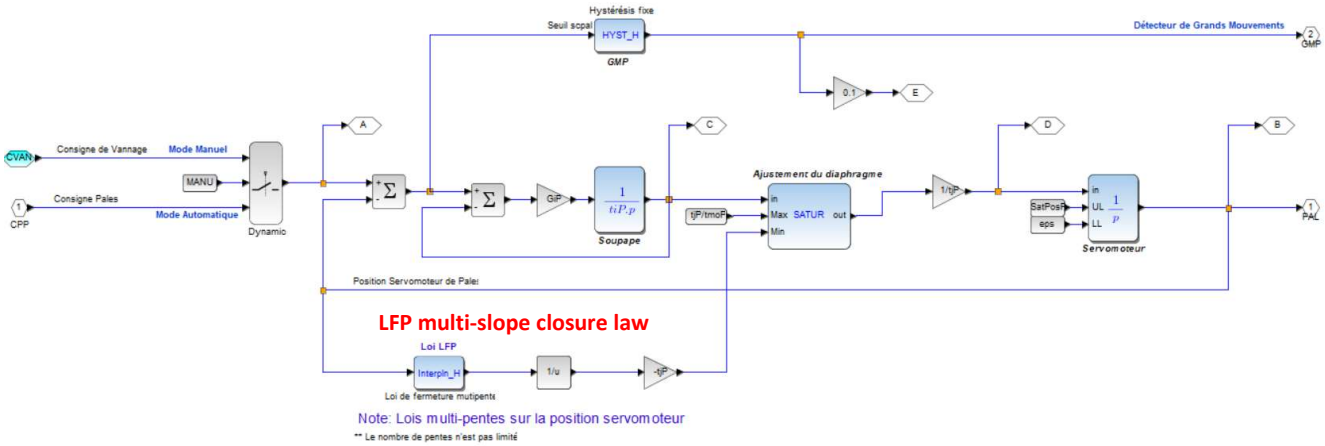


Figure 142 : Blade Copying System (SYSCOPP block)

3.14.2 PID Blade Positioner Tuning

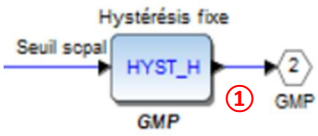
tjP	Time Constant Integral Servomotor Blades (s)	SYSCOPP - XLS
tiP	Time Constant Integral Valve Blades (s)	SYSCOPP - XLS
GiP	Gain Loop Valve Blades (su) (GI=5.0 by default)	SYSCOPP - XLS

SatPosP	Maximum saturation of servomotor excursion Blades (pu)	SYSCOPP - XLS

☞ The operation of these parameters is identical to that already described in the paragraphs on Adjusting SYSCOP Positioners (*see § 3.12.4 as example*)

3.14.3 Large Blade Movement Detection Thresholds

scpal		Large Movement Threshold Conditi



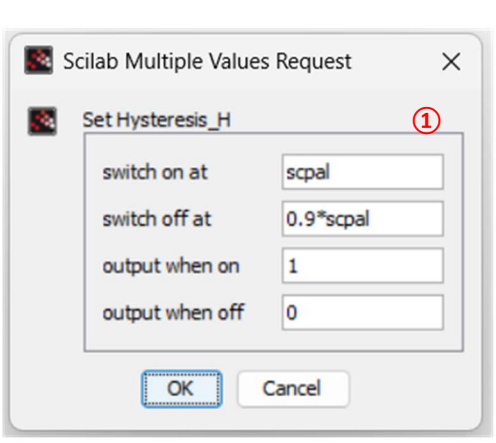


Figure 143 : GMP large blade movement detector (SYSCOPP block)

☞ By default, program scpal=+0.05, unless otherwise specified.

3.14.4 Manual Blade Mode

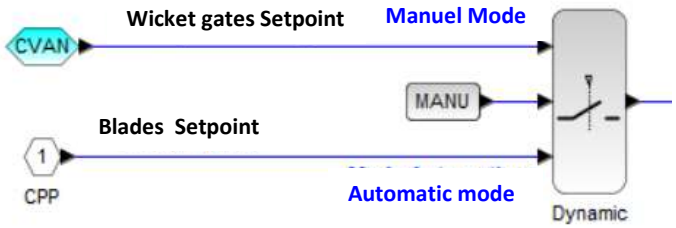


Figure 144 : Operation in Blade Positioner mode - SYSCOPP Module

In the new version 3.xx of HydroSim, the **MANU** manual mode conditions the passages in manual mode of the wicket gates **AND** the blades.

In this mode, the manual blade setting follows the valve setting.

This device can be used to check the operating times and the large movement detection switches of the valve and blade servomotors.

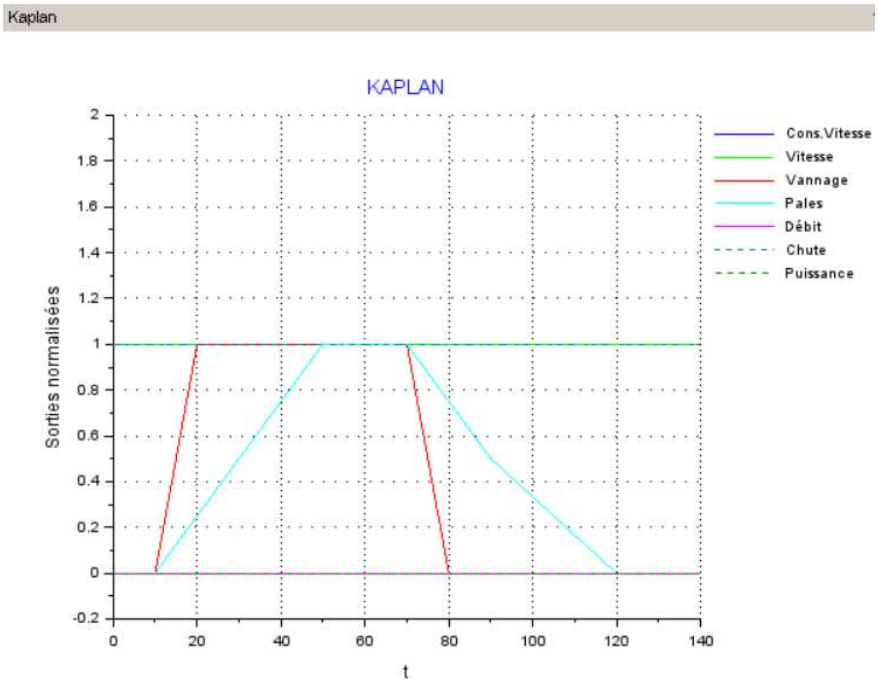


Figure 145 : Checking the operating times of the valve and the blades in manual mode MANU=1

3.14.5 Adjusting the blade manoeuvrer times

tmoP	Operating time when opening the servomotor Blades (s)	SYSCOPP - XLS
LFP_	Multi-slope blade closure law (mm or pu / s) – Calculation of closing operating times according to the LFP law	SYSCOPP - XLS

In a similar way to the LF law for sluicing, the LFP law for closing, and the tmoP parameter for opening are programmable in the TM sheet of the XLS file.

	A	B	C	D	E	F	G	H	I
1	// Temps de manoeuvre et lois de fermeture multi-pentes positionneur PALES SYSCOP								
2	//----------								
3	tmo=10;	// Temps de manoeuvre en ouverture du servomoteur de Vannage (s)							
4	tmoP=40;	// Temps de manoeuvre en ouverture du servomoteur Pales (s)							
5	;								
6	// Les lois LF et LFP sont traçables en utilisant l'instruction HydroSim "PlotLF"								
7	----------								
8	LF=[		// Loi de manoeuvre multipentes de fermeture du Vannage (t en s , ouverture en mm ou normée pu)						
9	0.0	1.0							
10	tmo	0							
11	;								
12	;								
13	LFP=[		// Loi de manoeuvre Pales multipentes de fermeture (t en s , ouverture en mm ou normée pu)						
14	0.0	1.0							
15	20.0	0.5							
16	50.0	0.0							
17	];								
18									

PAR | TM | REND

Figure 146 : Programming of the blade manoeuvring times in the **HydroSim\demos\KAPLAN\KB1\Standard\KB1c.xls** file

Laws can be plotted by entering the **PlotLF** command in the Scilab console.

☞ **See also *§3.12.4 :* Adjustment of the operating times of the opening and closing control devices by a multi-slope LF law**

3.14.6 Blade Pre-positioning Instructions

3.14.6.1 RDVS – PREPAL diagram

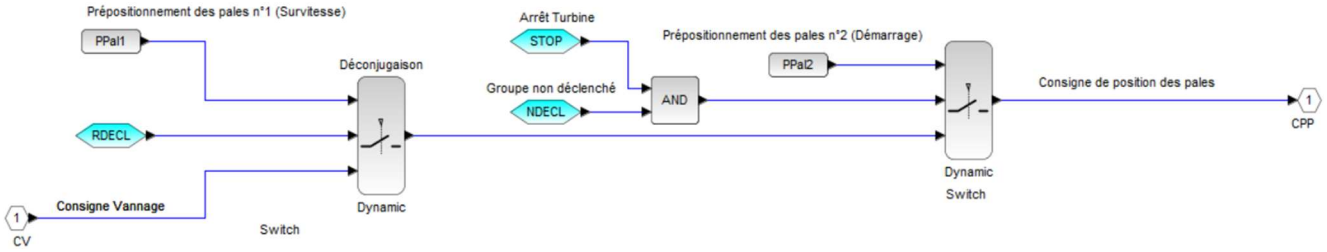


Figure 147 : Pre-positioning of blades - PREPAL module

3.14.6.2 PREPAL settings

PPal1	Pre-positioning of blades no. 1 (pu)	PREPAL - XLS
PPal2	Blade Pre-positioning #2 (Start-up Sequence) (pu)	PREPAL - XLS

3.14.6.3 Blade deconjugation coefficient

KDecP	Blade deconjugation coefficient (su)	TurbAdduc KB - XLS

This coefficient is used in the calculation of the mechanical power PMEC of the group.

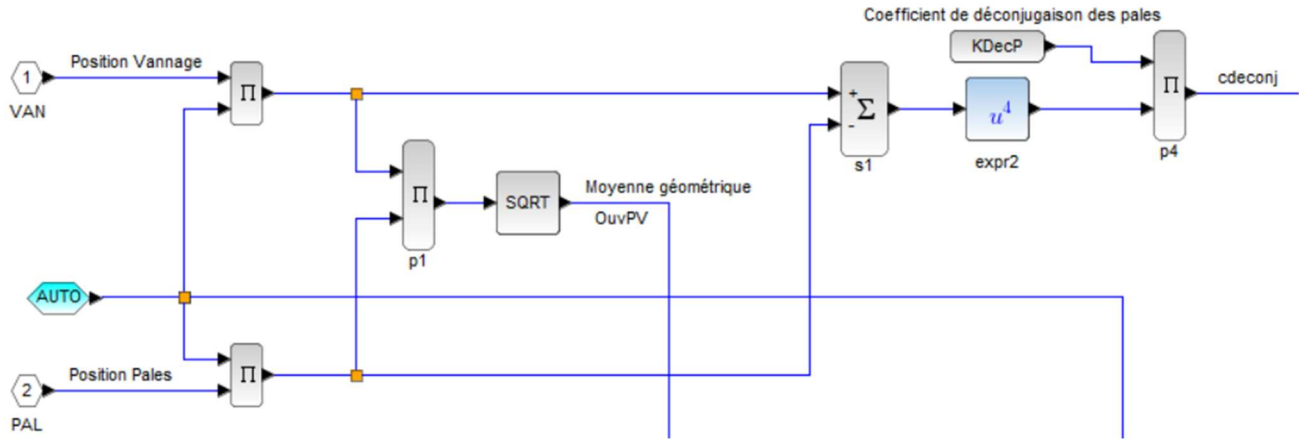


Figure 148 : KDecP coefficient of blade deconjugation

4 LAWS OF LINEARIZATION

4.1 Introduction

To carry out simulations without any bumps at the start of the process, and to guarantee homogeneous data in their interpretations, HydroSim integrates a series of laws considered to guarantee the correspondences of the functional quantities manipulated.

The linearizations of the simulated circuit to be implemented can be carried out in several ways, to specify the relationships between the opening of the valve, and the values of power, flow, efficiency, drop, pressure loss, to be programmed in the simulator.

These laws are listed later in this chapter.

4.1.1 Considering experimental linearity relationships

	A	B	C	D	E	F	G	H	I	J
1	Cote aval (m)	Cote amont (m)	Hb (m)	Hn (m)	CE (Kwh/m3)	Q (m3/s)	Ouv (mm)	Pdc (m)	Puissance (MW)	Rendement (%)
2	267.0	723.0	456.0	444.21	1.0443	73.211	275.00	11.79	275.226	86.25
3	267.0	723.0	456.0	444.74	1.0561	71.539	265.83	11.26	271.987	87.12
4	267.0	723.0	456.0	445.27	1.0681	69.831	256.67	10.73	268.501	88
5	267.0	723.0	456.0	445.81	1.0791	68.048	247.50	10.19	264.346	88.8
6	267.0	723.0	456.0	446.36	1.0888	66.203	238.33	9.64	259.499	89.5
7	267.0	723.0	456.0	446.96	1.0976	64.088	229.17	9.04	253.241	90.1
8	267.0	723.0	456.0	447.72	1.1015	61.362	220.00	8.28	243.32	90.26
9	267.0	723.0	456.0	448.28	1.1043	59.237	210.83	7.72	235.484	90.38
10	267.0	723.0	456.0	448.76	1.1065	57.364	201.67	7.24	228.504	90.46
11	267.0	723.0	456.0	449.44	1.1075	54.616	192.50	6.56	217.749	90.41
12	267.0	723.0	456.0	450.16	1.106	51.514	183.33	5.84	205.101	90.14
13	267.0	723.0	456.0	450.65	1.1039	49.301	174.17	5.35	195.92	89.87
14	267.0	723.0	456.0	451.12	1.1013	47.089	165.00	4.88	186.696	89.57
15	267.0	723.0	456.0	451.72	1.0984	44.124	155.83	4.28	174.483	89.22
16	267.0	723.0	456.0	452.32	1.0917	40.919	146.67	3.68	160.82	88.55
17	267.0	723.0	456.0	452.78	1.0808	38.241	137.50	3.22	148.787	87.57
18	267.0	723.0	456.0	453.18	1.0671	35.787	128.33	2.82	137.479	86.39
19	267.0	723.0	456.0	453.63	1.0493	32.841	119.17	2.37	124.056	84.87
20	267.0	723.0	456.0	454.07	1.0262	29.639	110.00	1.93	109.49	82.91
21	267.0	723.0	456.0	454.16	1.0199	28.883	107.80	1.84	106.044	82.39

Figure 149 : Example of linearity copy on a hydroelectric site (file **HydroSim\demos\FRANCIS\FR2\K2_c\DATA K2.xls**)

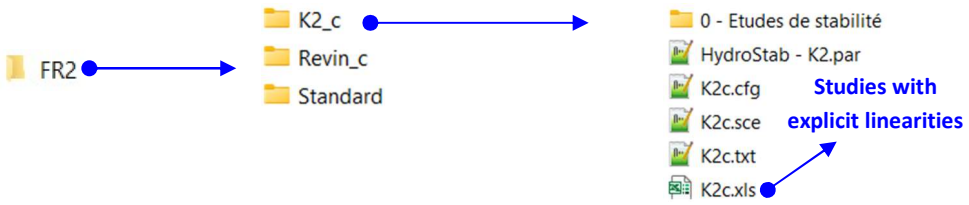
The experimental data must then be entered by the operator, directly into the ".XLS" parameterization file, in a sheet named **LINE** to be created.

In the K2_c study, the reader will consult the file **HydroSim\demos\FRANCIS\FR2\K2_c\K2c.xls.**

	A	B	C	D	E	F
1	// Ouverture en mm	// Débit (m^3/s)	// Puissance (MW)	// Chute nette en m	// Rendement (%)	// Pertes de charge en m
2	O=[	Q=[	P=[	H=[	Rend=[	PDC=[
3	275;	73.211;	275.226;	444.21;	86.2692;	11.79;
4	265.83;	71.539;	271.987;	444.74;	87.1425;	11.26;
5	256.67;	69.831;	268.501;	445.27;	88.0248;	10.73;
6	247.5;	68.048;	264.346;	445.81;	88.8257;	10.19;
7	238.33;	66.203;	259.499;	446.36;	89.5166;	9.64;
8	229.17;	64.088;	253.241;	446.96;	90.1197;	9.04;
9	220;	61.362;	243.32;	447.72;	90.2823;	8.28;
10	210.83;	59.237;	235.484;	448.28;	90.3962;	7.72;
11	201.67;	57.364;	228.504;	448.76;	90.4839;	7.24;
12	192.5;	54.616;	217.749;	449.44;	90.4265;	6.56;
13	183.33;	51.514;	205.101;	450.16;	90.1585;	5.84;
14	174.17;	49.301;	195.92;	450.65;	89.8907;	5.35;
15	165;	47.089;	186.696;	451.12;	89.589;	4.88;
16	155.83;	44.124;	174.483;	451.72;	89.236;	4.28;
17	146.67;	40.919;	160.82;	452.32;	88.5728;	3.68;
18	137.5;	38.241;	148.787;	452.78;	87.595;	3.22;
19	128.33;	35.787;	137.479;	453.18;	86.4115;	2.82;
20	119.17;	32.841;	124.056;	453.63;	84.8849;	2.37;
21	110;	29.639;	109.49;	454.07;	82.9314;	1.93;
22	107.8;	28.883;	106.044;	454.16;	82.4073;	1.84;
23	0;	0;	-0.1*Pnom;	Hnom;	0;	0;
24	]	]	]	]	]	]
25						
26	Interpoler("o=44, p=35");					
27	Interpoler("o=Omav, p=0");					
28						
29						

PAR | TM | LINE

Figure 150 : Entering linearization readings into the file HydroSim\demos\FRANCIS\FR2\K2_c\K2c.xls



The table below lists the variables [O, Q, P, H, Rend, PDC] used in HydroSim concerning the conjugation laws:

HydroSim Variable	Meaning	Unit
xLPO / yLPO	Abscissa / Ordinate of law Opening / Power	Reduced
xLQO / yLQO	Abscissa / Ordinate of law Opening / Flow	Reduced
xLHO / yLHO	Abscissa / Ordinate of law Opening / Head	Reduced
xRend / yRend	Abscissa / Ordinate of law Opening / Efficiency	Reduced
xPdC / yPdC	Abscissa / Ordinate of law Opening / Pressure losses	Reduced
O	Opening column vector	mm
Q	Flow column vector	m^3/s
P	Power column vector	MW
H	Head column vector	m
Rend	Efficiency column vector	Reduced
PDC	Pressure losses column vector	m

Figure 151 : Global variables used in linearization laws

4.1.2 Analytical simulation and linearity calculations

In this case, bLOQ=0 (*see corresponding parameter*)

The principle integrated into HydroSim consists of rewriting several parts of the diagrams in literal form (TURBADDUC for example) and repeating a calculation loop until a point of convergence is obtained, guaranteeing with finesse, an equivalence between the opening of the servomotor and the data to be optimized.

The reader can, for example, follow the routine *LinePQH_1(),* and its subroutines, concerning the FR2 and PELTON circuits.

4.2 Power/Opening Linearization Law LPO

LPO	Power/Opening Linearization Law (pu)	LINE - XLS

The LPO law is present in the LINE linearization modules ① or in the DC load logging module ②; this block is positioned in the general view of the simulated circuit. It makes it possible to obtain an identity relationship between the requested power CReseau and the electrical power supplied by the hydraulic machine.

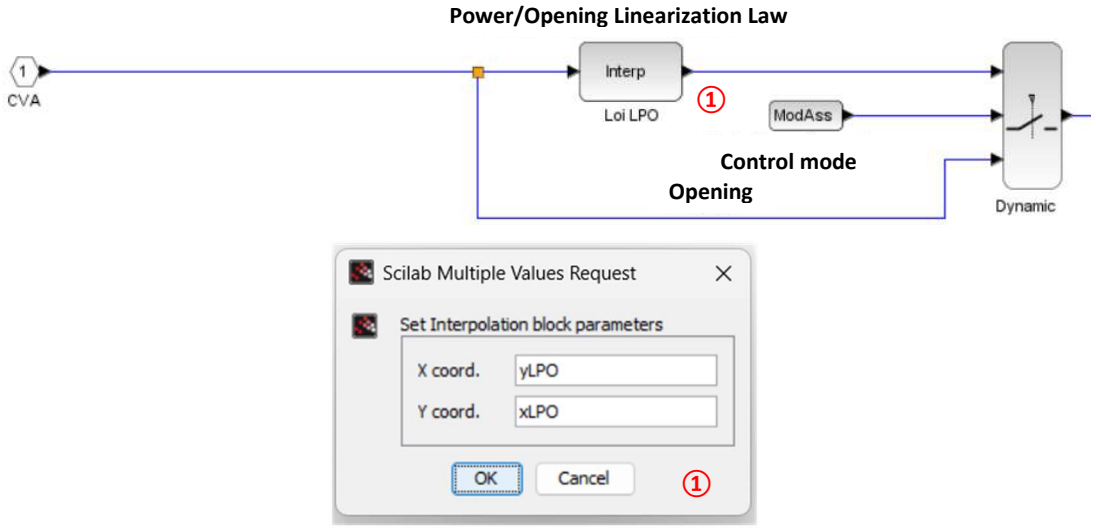


Figure 152 : LPO Power/Opening Linearization Law in the FR2 Circuit – LINE Module

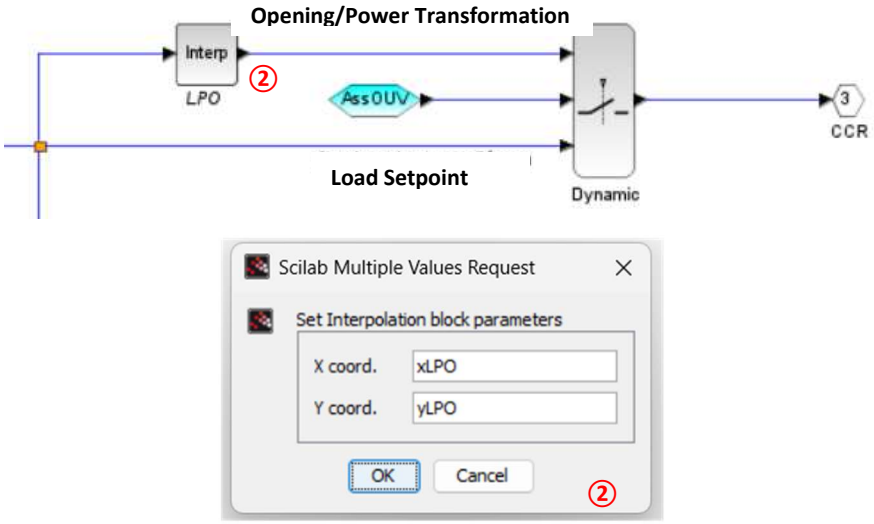


Figure 153 : LPO Power/Opening Linearization Law in FR2 Circuit – Load Recorder - CC Module

☞ **Note that the "X coord" and "Y coord" representations are crossed in modules ① and ②.**

4.3 Linearization Law Flow/Opening LQO

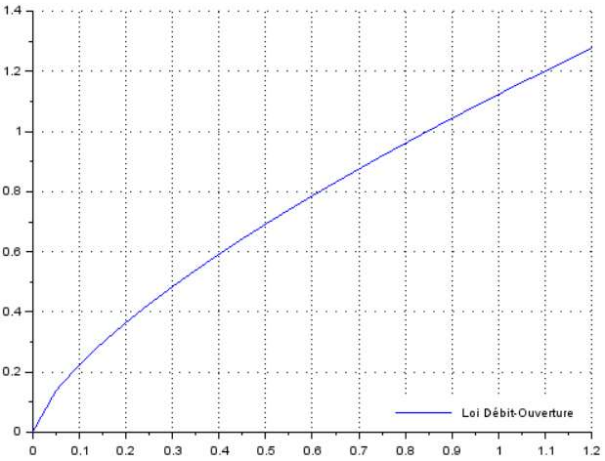
LQO	Linearization Law Flow/Opening LQO (pu)	Preliminary Calculations « .CTX », CC - XLS

The **LQO** law gives an image of the Flow / Opening relationship of the hydraulic machine, and allows, depending on the conditions programmed in the simulation sequence, to calculate the initial flow **Qini** of the hydraulic unit:

```
42  Qini=interpln([xLQO;yLQO],VAN_0)*Qnom;
```

Figure 154 : Calculation of the initial flow rate Qini in the FR2.CTX file

, where **VAN_0** is the initial position of the valve, expressed in reduced coordinates at the start of the simulation, and **Qnom** the nominal flow rate.



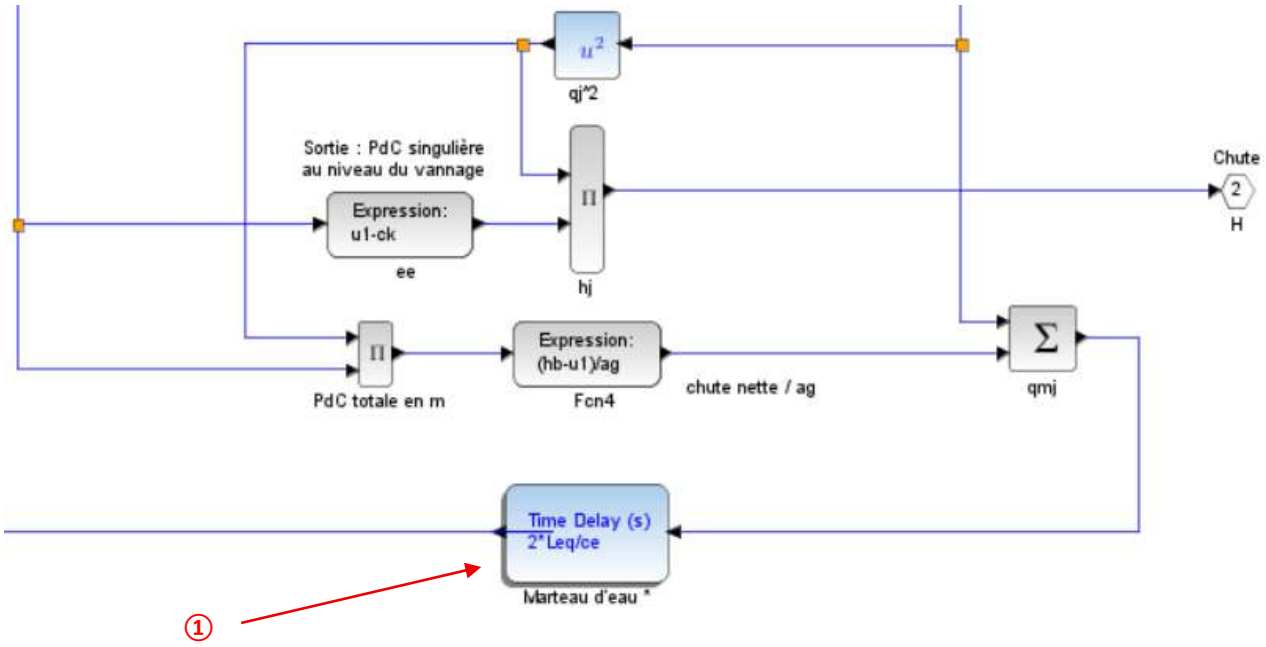

```
// Programme Scilab - Loi LQO
//------------------------------
scf(11) ;
plot2d(xLQO,yLQO,2);

h=gcf();
axes = h.children;
axes.grid = [1,1];
axes.grid_style = [9,10];

Xlegend=["Loi Débit-Ouverture"];

legend(axes(1),Xlegend,4,%f);
```

Figure 155 : Plotting the LQO law under Scilab



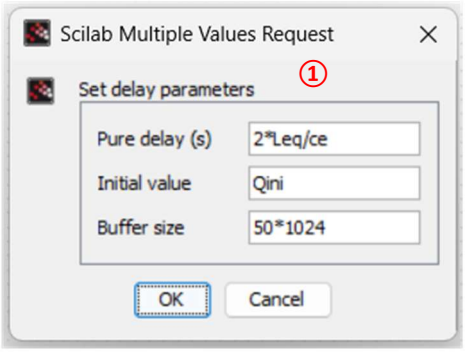


Figure 156 : Using the calculated variable Qini in the FR2 circuit TurbAdduc module

, where **Leq** denotes the equivalent length of the hydraulic circuit, and **ce** the speed of the water.

bLOQ	Interpolation mode of the Flow/Opening LQO law	TurbAdduc - XLS
Display_LINE	Display of recalculated linearization laws (1) or not (0) (for recovery in Excel)	TurbAdduc - XLS

- If **bLOQ=0** :

  The flow rate is simulated by an analytical and hypothetical law $Q = O^{nq}$, where $nq = 0.7$.

- If **bLOQ=1** :

  he flow rate is calculated from an experimental linearization law Q=f(O), obtained from the readings of the linearities measured experimentally on the production site, and provided in an Excel file.

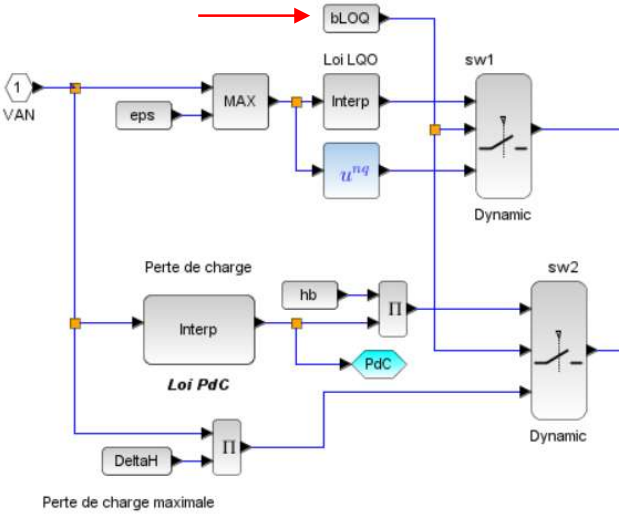


Figure 157 : Actions of the bLOQ switch in the FR2 TurbAdduc module

The Display_LINE parameter allows you to plot all the laws when launching the simulation.

```
Débit réduit yLQO
    0.
    0.1241885
    0.2017425
    0.2679485
    0.3277119
    0.3830949
    0.4352141
    0.4847607
    0.5322002
    0.5778646
```

…etc

Numerical display of all laws in the Scilab console.

Ability to retrieve data via Copy/Paste to copy it into an Excel spreadsheet

Figure 158 : Displaying the laws in the Scilab console if Display_LINE=1

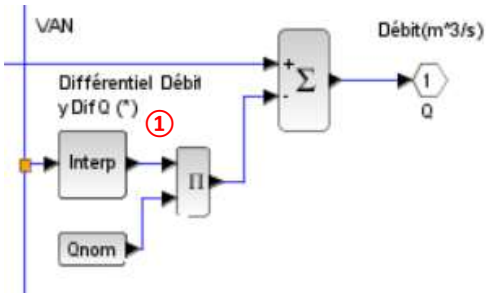
☞ **Program bLQO=0 by default, except for special studies**

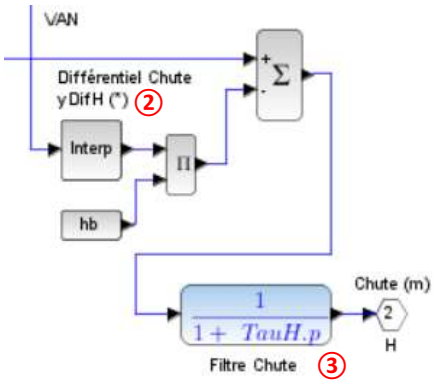
☞ **Set Display_LINE=0 by default**

4.4 Differential Laws in Flow and Fall DifQ-DifH

DifQ	Differential between model flow and experimental flow	TurbAdduc
DifH	Differential between model head and experimental head	TurbAdduc
TauH	Low-pass filter time constant of the head sign (s)	TurbAdduc

These two laws are present in the TurbAdduc component (FR2, PELTON).





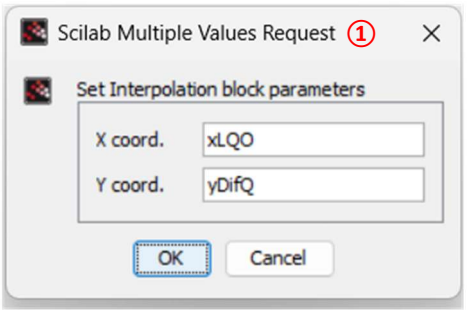


Figure 159 : Differential Flow Circuit

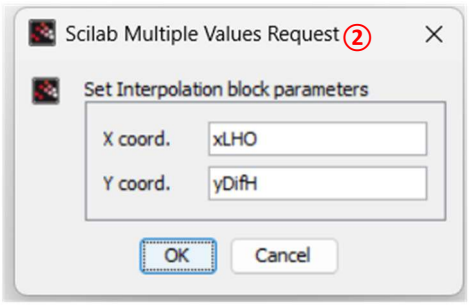


Figure 160 : Differential Head Circuit

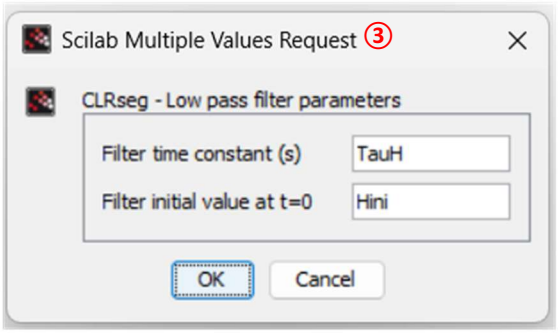


Figure 161 : Initializing the Head Filter

The initialization **Hini** value of the Fall filter, expressed in m, is calculated automatically in the CTX file, depending on the initial position of the valve:

```
//-----------------------------
// Calcul de la chute initiale
//-----------------------------
Hini=interpln([xLHO;yLHO],VAN_0)*hb
```

4.5 Linearization Law Flow/Power LQP

LQP	Linearization Law Flow/Power LQP (pu)	Preliminary Calculations « .CTX », CC

When you want to achieve flow control (**CC module**), and given the presence of the LINE law for linearizing Power/Opening of the machine, it is necessary to linearly transform the flow setpoint into a power setpoint.

This artifice is achieved by the **LQP** law allowing this operation. It is deduced from the **LPO** and LQO laws, and considers the abscissa the **yLPO** data of the **LPO** law, and on the ordinate the **yLQO** data of the Power/Opening **LQO** law.

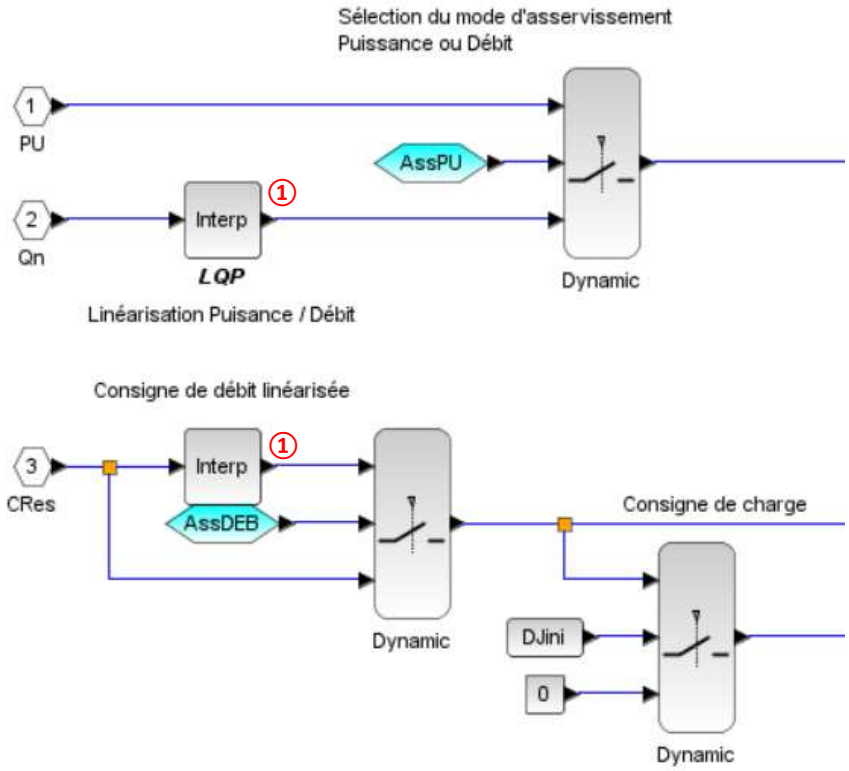


Figure 162 : Flow control in the CC module

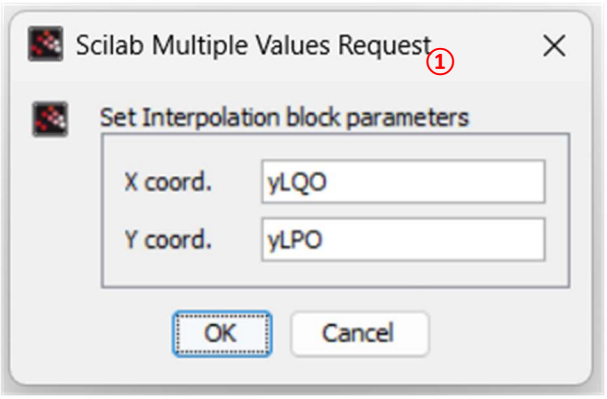
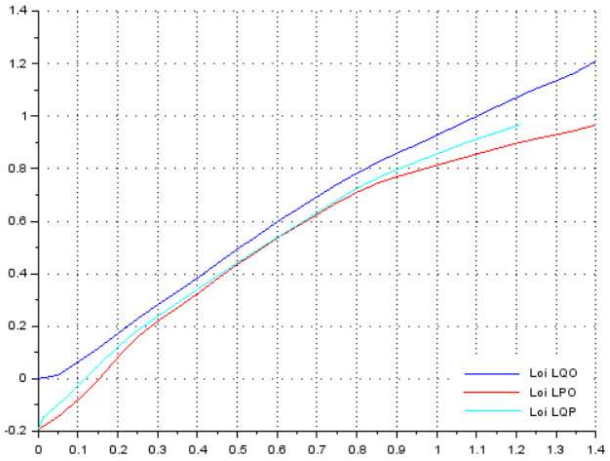


Figure 163 : LQP Law - CC Module




```
// Programme Scilab - Loi LQP
//-----------------------------
scf(12);
plot2d(xLQO,yLQO,2);      // LawLQO
plot2d(xLPO,yLPO,5);      // Law LPO
plot2d(yLQO,yLPO,4);      // Law LQP

h=gcf();
axes = h.children;
axes.grid = [1,1];
axes.grid_style = [9,10];

Xlegend=["Loi LQO", "Loi LPO" , "Loi LQP"];

legend(axes(1),Xlegend,4,%f);
```

Figure 164 : Plot of the LQP law under Scilab

4.6 Linearization Law Head/Opening LHO

LHO	Linearization Law Head/Opening LHO (pu)	Preliminary Calculations « .CTX », « .XLS »

The Head/Open law is used in circuits with Machine hills, type FR5 for example.

It allows you to calculate the initial head **H0** used when launching the simulation:

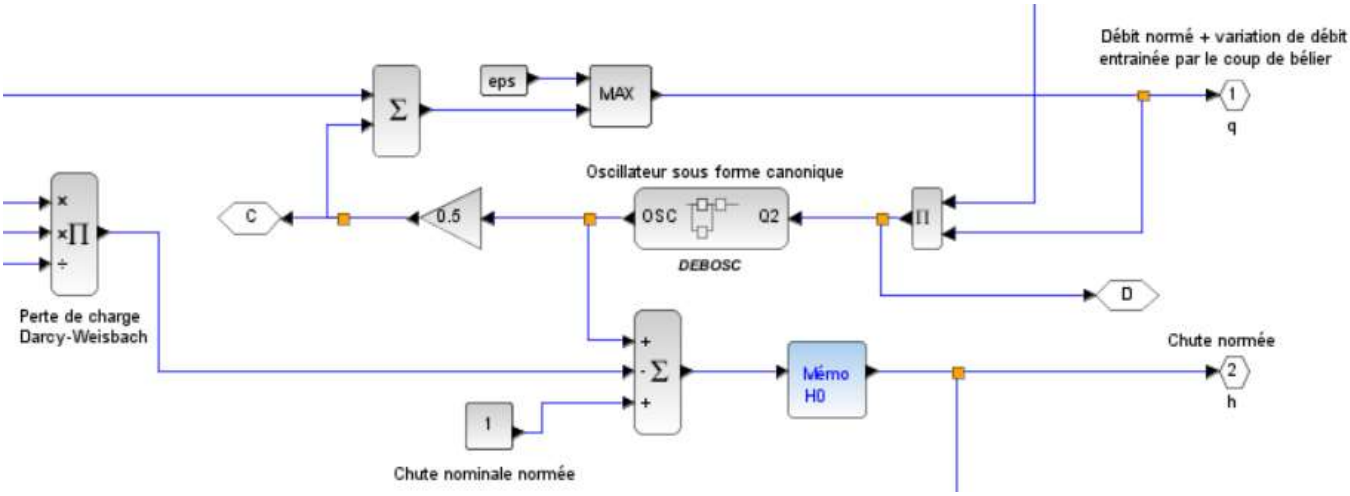
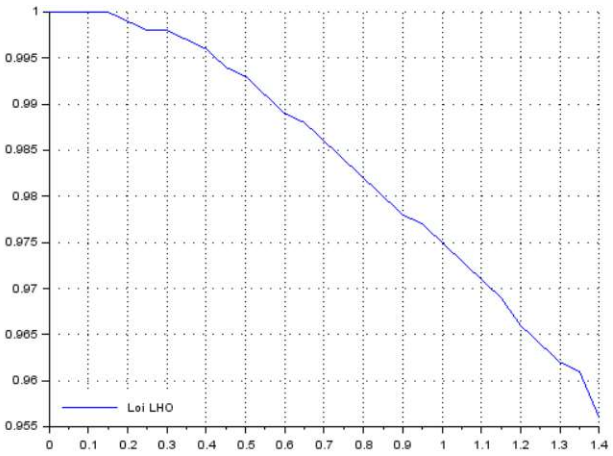


Figure 165 : Calculation of the initial head **H0** in the Water Hammer/TurbAdduc module of the **FR5** circuit

```
120  // Calcul de la chute initiale
121  //----------------------------
122  H0=interpln([xLHO;yLHO],VAN_0)
```

Figure 166 : Calculation of the initial head **H0** in the **FR5**.CTX file




```
// Programme Scilab - Loi LHO
//-----------------------------
scf(15);
plot2d(xLHO,yLHO,2);          // Law LHO


h=gcf();
axes = h.children;
axes.grid = [1,1];
axes.grid_style = [9,10];

Xlegend=["Loi LHO"];
legend(axes(1),Xlegend,3,%f);
```

Figure 167 : Plotting the LHO law under Scilab

4.7 Pressure losses – PdC Law

DeltaH **Law PdC**	Estimated maximum pressure drop (mce) (if data available) Law of linearity of pressure losses as a function of the opening	Contexte

DeltaH denotes the maximum head loss, used in the TURBADDUC turbine supply circuit, and calculated in the CTX file.

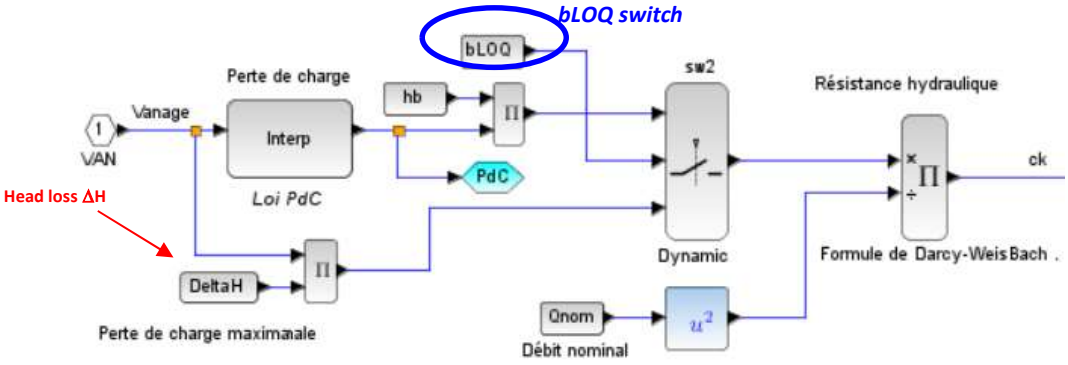


Figure 168 : Evaluation of dynamic head losses in the TURBADDUC circuit of the FR2 model.

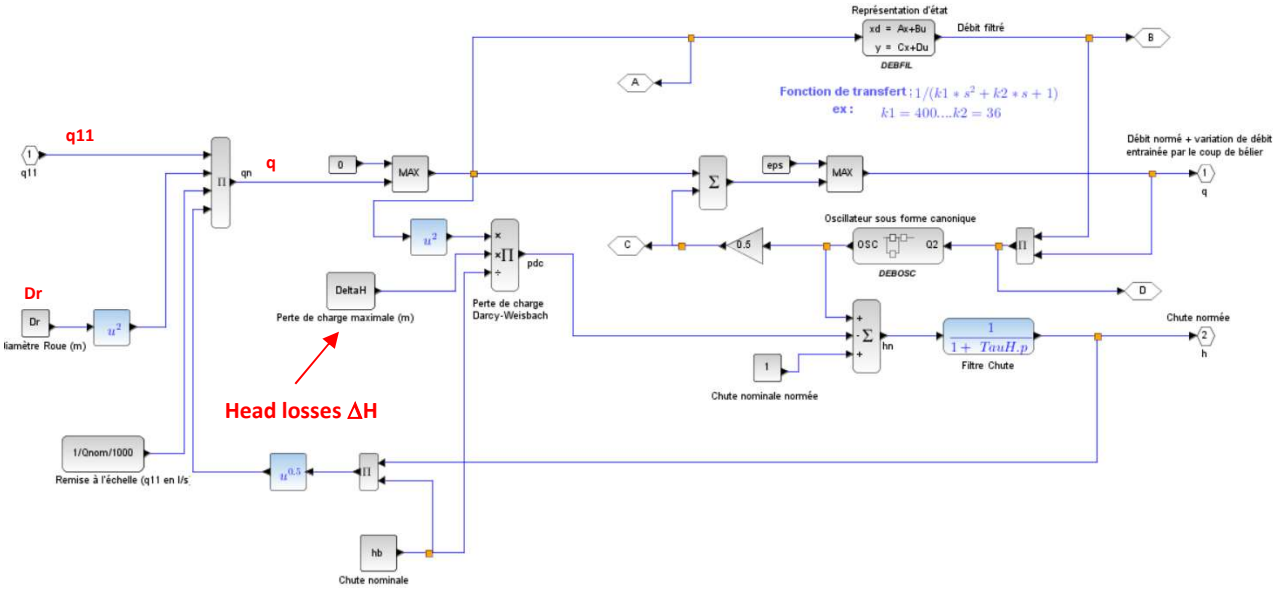


Figure 169 : Evaluation of dynamic head losses in the TURBADDUC-Water hammer circuit of the FR5 model

Two scenarios are provided, depending on the programmable bBLOQ selection parameter.

1. **If bLOQ=1**, the operator has previously entered in the model programming, in the .XLS files, the linearities noted on the site for different falls obtained according to the operating points at opening.

   ☞ ***The reader should consult the chapter 4.1.1 to find out how to incorporate this data***

   The **PdC head loss** law then makes it possible to calculate by linear interpolation the dynamic value of the pressure loss, as a function of the VAN opening of the valve.

2. **If bLOQ=0,** the maximum head drop is evaluated from **Darcy-Weisbach Formula** :

$$\Delta H = f_D \cdot \frac{L_{eq}}{D_h} \cdot \frac{V^2}{2g}$$

,where ΔH Head loss (m), f_D Darcy pressure drop coefficient, L_{eq} Equivalent pipe length (m), D_h hydraulic pipe diameter (m), V average fluid velocity (m.s^{-1}), g acceleration of gravity (m.s^{-2})

Then the simulator calculates the hydraulic resistance **ck** of the process by $ck = \frac{\Delta H}{Q^2}$, where Q is the nominal flow rate (m^3/s)

This parameter **ck** is used in the simulation of the Turbine+Adduction TURBADDUC part.

```
// Calcul du nombre de Reynolds
//-----------------------------
V=Qnom/Seq;                                          // Vélocité moyenne de l'eau
Re=V*rho*Dh/mu

// Calcul du coefficient de frottement de Darcy avec la corrélation de Colebrook-White
//-------------------------------------------------------------------------------------
fd=fsolve(0.01,Colebrook);                           // Appels récursifs à la fonction Colebrook

// Calcul de la perte de charge à 100% d'ouverture
//------------------------------------------------

if bLOQ then
        DeltaH=interpln([xPdC;yPdC],1.)*hb;          // Perte de charge en mètres, calculée à 100% d'ouverture
else
        DeltaH=(fd*Leq*V^2)/(Dh*2*g);                // Perte de charge en mètres - Formule classique de Darcy-WeisBach
end

// Calcul de la résistance hydraulique (équation de Darcy-Weisbach)
//-----------------------------------------------------------------
ck_nom=DeltaH/(Qnom^2);                              // Résistance hydraulique de la conduite
```

Figure 170 : Calculation of the head losses coefficient in the FR2.CTX context of the FR2 circuit

f_D coefficient is pre-calculated from Scilab standard fsolve function, and uses the Colebrook.sci function, provided in the HydroSim suite, and available in the HydroSim\macros\Colebrook.sci directory

This function evaluates the head loss coefficient from **Colebrook-White formula** :

$$\frac{1}{\sqrt{\lambda}} = -2log(\frac{2,51}{Re\sqrt{\lambda}} + \frac{k}{3,7D})$$

Figure 171 : ColeBrook-White Formula - Evaluation of the Head Loss Coefficient

with $\lambda = f_d$, $k = rugo$, and $D = D_h$, Re calculated Reynolds number.

```
function result=Colebrook(x)

        result=1/sqrt(x)+2*log10(2.51/(sqrt(x)*Re)+rugo/(3.7*Dh))

        //result=1/sqrt(x)+2*log10(2.51/(sqrt(x)*Re)+rugo/Dh)          // Ancienne formule

endfunction
```

Figure 172 : Calculation of Darcy's coefficient of friction in the function in the routine "**Colebrook.sci**"

The Scilab **fsolve**[7] function makes the result tend towards 0 from the value fd=0.01, therefore towards the equality indicated in *Figure 171*, where fd=x.

By adding a trace line "mprintf("fd=%f resul=%f\n",x,result)" in the function above, we obtain for example the trace:

[7] fsolve solves the system of nonlinear equations [f(λ)-g(λ)=0]. Type "doc fsolve" in the Scilab console for more information on this function.

```
fd=0.010000000000 resul=-1.570684379166
fd=0.010000000149 resul=-1.570684453675
fd=0.006858799374 resul=0.504115542416
fd=0.007622019018 resul=-0.116400654319
fd=0.007478849079 resul=-0.007278833516
fd=0.007469299109 resul=0.000111418977
fd=0.007469443089 resul=-0.000000105218
fd=0.007469442953 resul=-0.000000000002
fd=0.007469442953 resul=0.000000000000
```

Figure 173 : Colebrook-White Instruction Tracing

☞ **See also the MECAFLUX suite of expert software in Fluid Mechanics**[8] Mecaflux Standard

https://www.mecaflux.com/suite/boutique.php

https://www.mecaflux.com/didacticiels_et_tutoriaux.htm

☞ **The reader should also consult the site for more information on the calculations carried out.:**

https://hydroturbine.info/formules-et-calculs/pertes-de-charge/pertes-de-charge-lineaires/

[8] Cost around €60 - Hydraulics software suite, very high expert quality.

4.8 Plotting linearization laws in the Scilab console – HydroSim instructions

4.8.1 Presentation

New instructions have been developed to visualize the entered linearization curves.

These instructions must be entered in the Scilab console, after first loading the laws (or the first launch of a simulation with a .SCE file).

The source codes for these functions are available in the ***HydroSim\macros\Plot.sci*** file, a file loaded automatically when Scilab is launched.

The reserved HydroSim instruction "**Plot**", entered in the Scilab console, summarizes all the plotters made available:

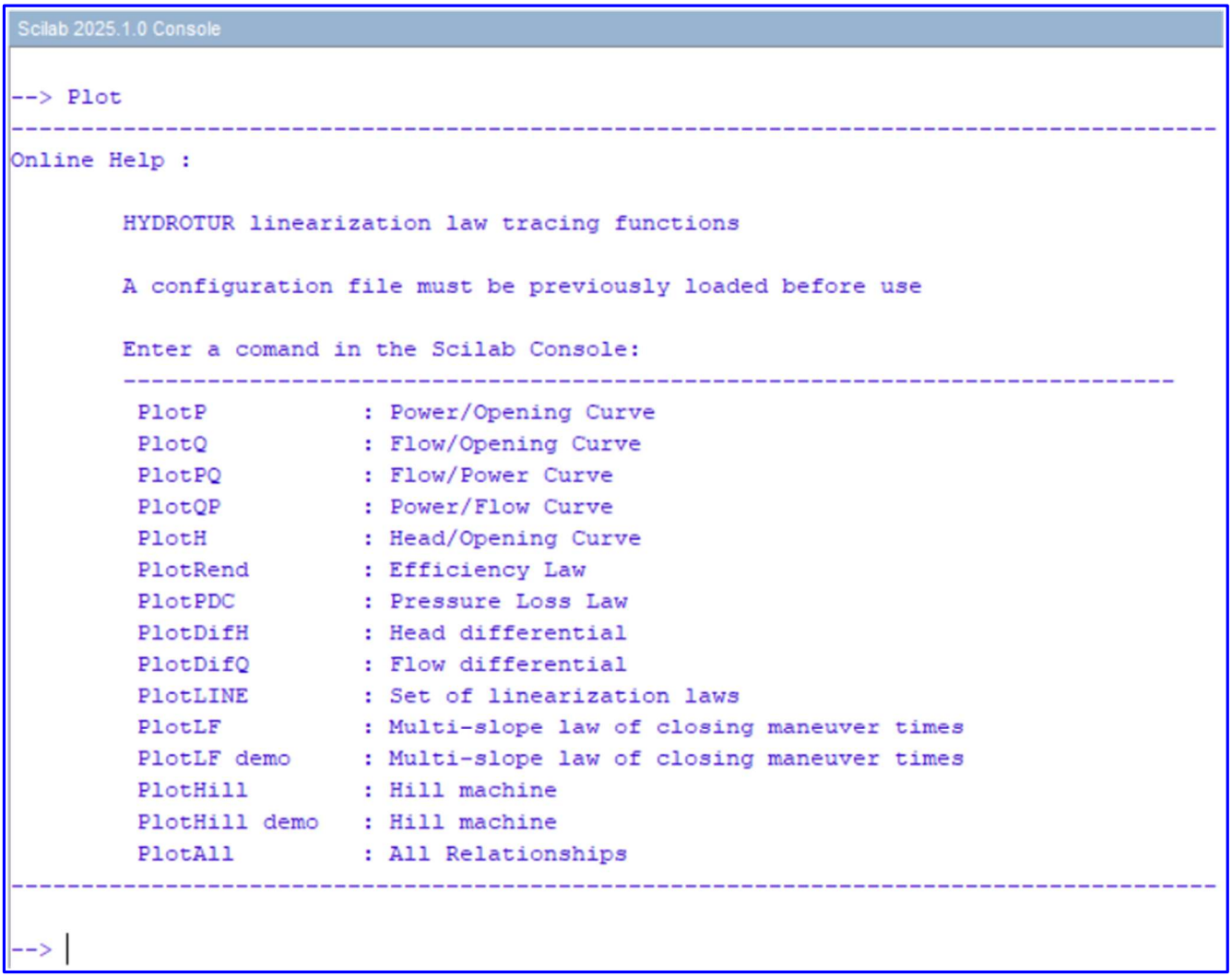


Figure 174 : "**Plot**" instructions in the Scilab console

4.8.2 Examples of law tracing

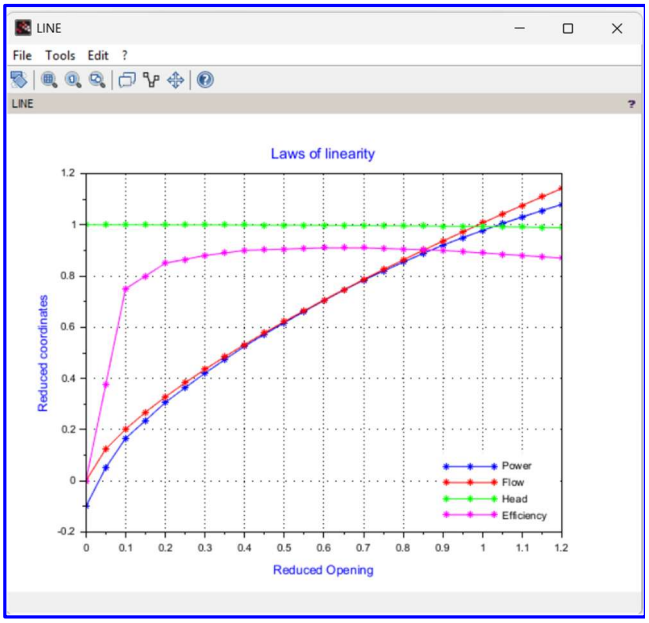


Figure 175 : Example of linearization law plot -"**PlotLINE**"

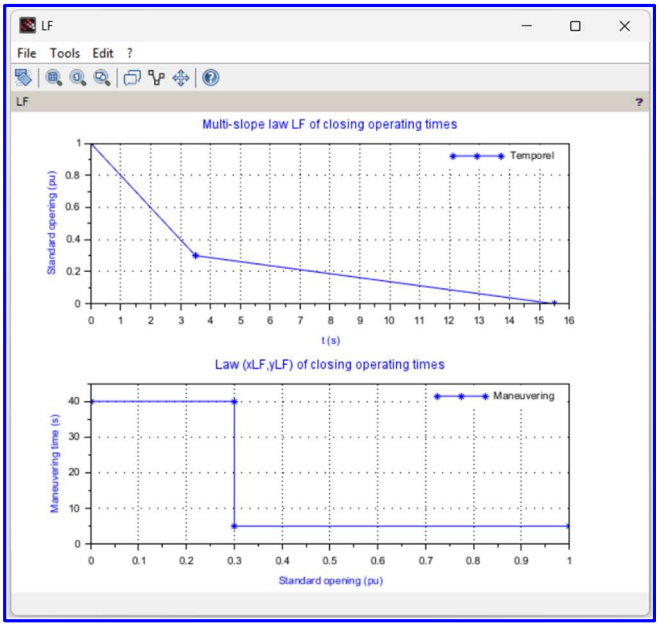


Figure 176 : Example of a plot of the manoeuvring time law "**PlotLF**"

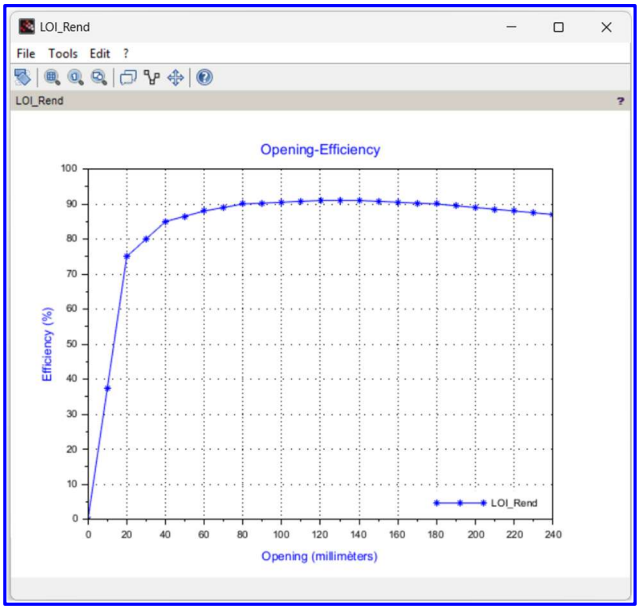


Figure 177 : Example of efficiency law plot "**PlotRend**" -

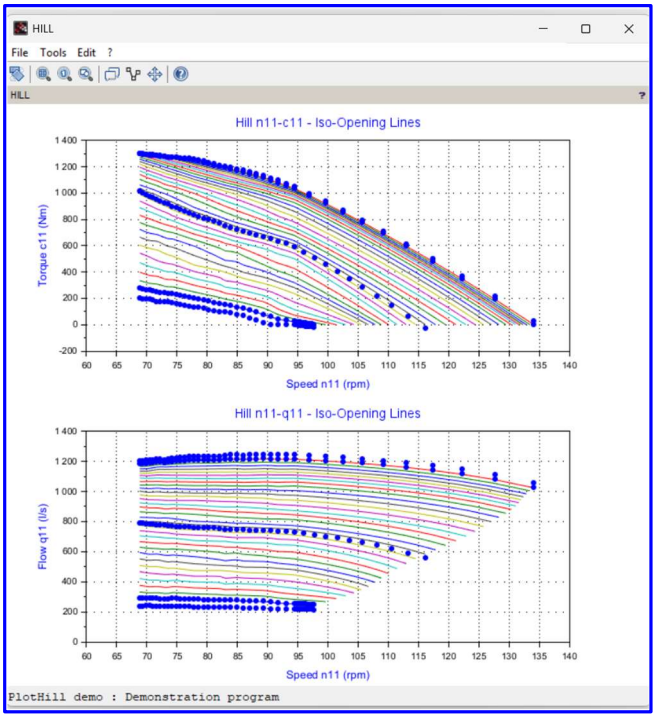


Figure 178 : Example of a hill layout "**PlotHill demo**"

4.9 "Interpoler" instruction: adding interpolation points in the linearization laws

The HydroSim "**Interpoler**" instruction allows you to add points to the linearization laws.

This device is particularly suitable when the experimental laws are only partially known. Extrapolation cannot then be correctly carried out outside the known segments, and it is necessary to add approximate points guaranteeing consistency over the entire servomotor travel.

This instruction is only considered if bLOQ=1.

The reader should refer to the chapter « **Adding interpolation points in linearization laws**» of the "installation and user guide", describing this instruction.

```
//Interpoler("o=183.3, p=210");  // Insertion d'un point à l'ouverture 183.3 mm Puissance 210 MW - Le rendement est recalculé
Interpoler("o=44, p=35");        // Insertion d'un point à l'ouverture 44 mm Puissance 35 MW - Le rendement est recalculé


Interpoler("o=Omav, p=0");       // Insertion du point de fonctionnement en marche à vide (Puissance électrique nulle)
```

Figure 179 : Using the HydroSim 'Interpolate' function

4.10 Analytical calculation of linearization laws

4.10.1 Principle

In the new versions of HydroSim, the linearization laws, if they are not known (bLOQ=0, FR2, PELT1 to PELT6), are carried out from a numerical simulation of the TurbAdduc supply circuit

Then the calculated flow rates and heads are entered into the relationship $P = \eta.\rho.g.H.Q$ to deduce the resulting mechanical power.

This relationship uses the efficiency of the turbo-alternator group. For this reason, HydroSim relies on a default efficiency law. This is defined in the file **VariablesGlobales.sce**, available in the **HydroSim\macros** directory.

```
// Loi Rendement par défaut
//-------------------------------------------------------------------------------------------
Rend=[];
xRend=[0:00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80  0.90 1.00];          //Ouverture
yRend=[0.00 0.75 0.85 0.88 0.9 0.905 0.91 0.91 0.905 0.90 0.89];          //Rendement
```

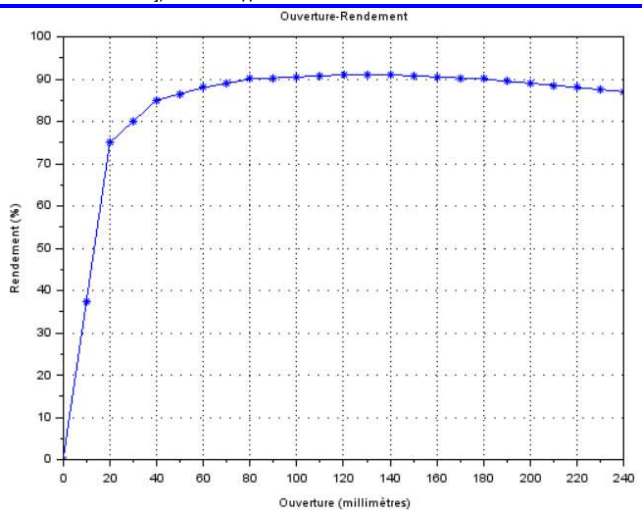


Figure 180 : Default efficiency Law (Tracing Instruction: PlotRend FR2)

☞ The efficiency law can therefore be modified, or overridden in a CFG file, which is preferable. If the linearization laws are known (bLOQ=1), the same procedure is used to calculate the differentials DifQ and DifH concerning the deviations between the simulated circuit and the provided laws.

5 SPECIFIC PARAMETERS FOR PELTON TURBINES – HORIZONTAL OR VERTICAL AXIS – JET DISPATCHER

5.1 Foreword

The new version of HydroSim, developed from Scilab version 6, brings significant simplifications in the design of simulation diagrams for vertical axis PELTON turbines.

Indeed, the vectorization of the SYSCOP model allows its configurable use by any number of adjustment organs (here, the number of injectors).

This therefore results in a single schematic library "**PELTON.zcos**", comprising only one SYSCOP module (instead of a schematic library for 4 needles, 5 needles, 6 needles turbines comprising as many SYSCOP modules).

The direct consequence is that a single PELTON schematic library covers all representations of horizontal or vertical axis machines, if the programming of the jet dispatcher is appropriate according to the number of injectors.

However, we note the paradoxical situation that it is necessary to program a dispatcher for horizontal axis turbines with 1 or 2 jets.

Nevertheless, for these models, the distributor can be inhibited with the RepOnOff=0 programming.

5.2 Principle of the jet dispatcher for PELTON machines.

5.2.1 General description

These parameters mainly concern vertical axis multi-jet PELTON turbines, for the Jet Dispatcher function.

The principle and operation of the jet distributor are described in [10] *page 73 to 81.*

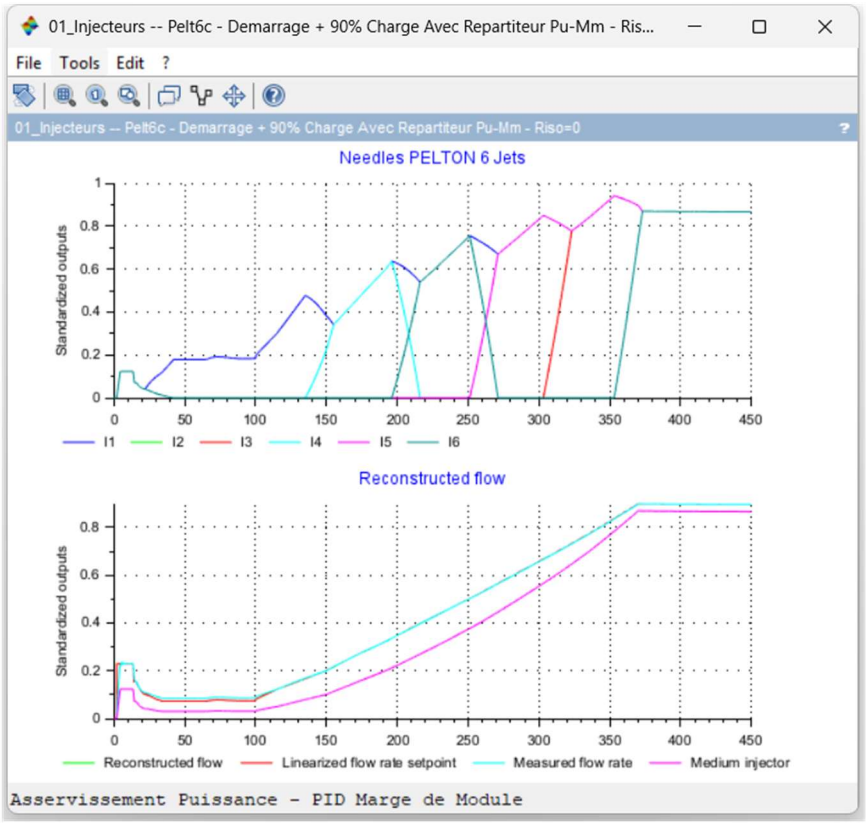


Figure 181 : Jet dispatcher - 90% load intake (File HydroSim\demos\PELTON\Pelt6\Standard\0 - Etudes Stabilité\Démarrage + 90% Charge Avec Répartiteur)

NJets	Number of turbine jets (su)	REPARTITEUR - XLS

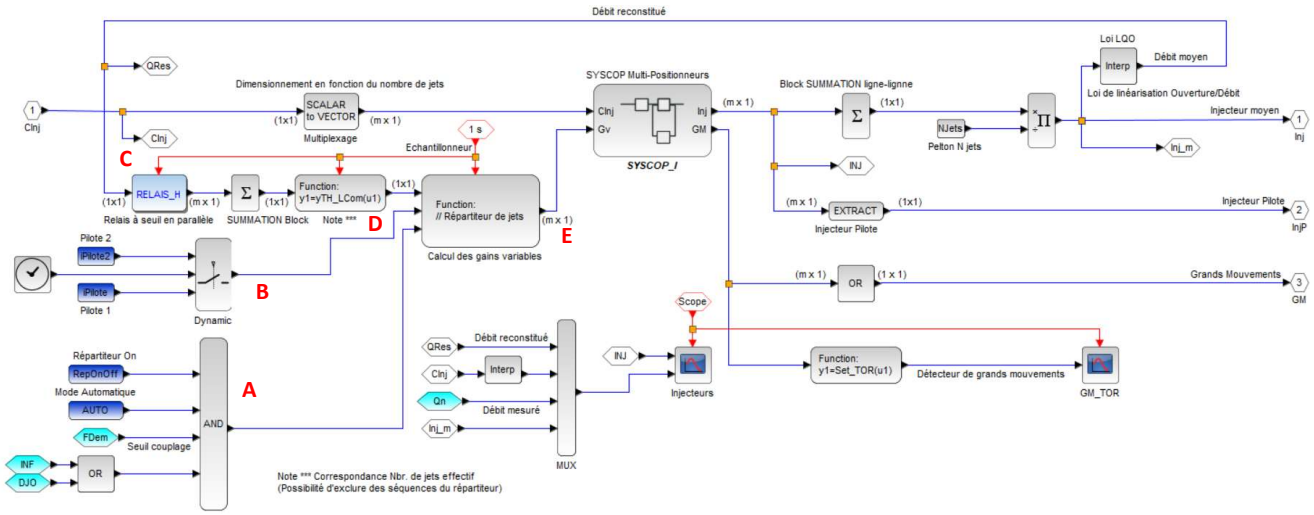


Figure 182 : Jet dispatcher for PELTON machine (*also see Annexe A*)

5.2.2 Configurable validation of the jet dispatcher

RepOnOff	Jet dispatcher On or Off (su)	REPARTITEUR - XLS
RepOnOff	**0**	The jet dispatcher is permanently deactivated.
	1	Activation condition of the jet dispatcher

When RepOnOff=0, the flow dispatcher is inactive. This means that all injectors follow the command signal of the pilot injector.

In **A**, when RepOnOff=1, the jet dispatcher is active if all the conditions listed below are met:

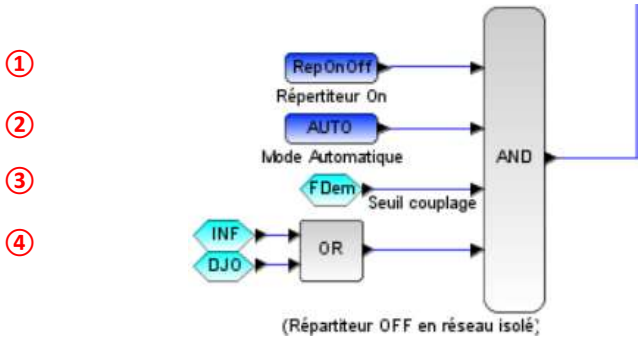


Figure 183 : Conditions for validation and activation of the jet dispatcher (extract from the REPARTITEUR module)

①	The parameter RepOnOff=1
②	The simulator must be in automatic mode, i.e., MANU=0 (therefore AUTO=1)
③	The FDem threshold for the synchronizing phase of the unit has been validated (internal sequence of the speed governor, see SPID).
④	The network on which the machine operates is of the "interconnected network" type, i.e., Riso=0 (Interconnected network operation (0) or isolated network (1)) OR The group circuit breaker is open (see TDJF: Circuit breaker closing time)

These conditions therefore define the start-up sequence for the Pelton turbine:

- Upon receiving the start-up command (see TStart), all injectors participate in bringing the machine up to speed.
- When the synchronization threshold is reached (see SPID threshold and DJO=1), the FDem signal becomes 1 and the dispatcher activates. Under these conditions, all injectors close except for the pilot injector, which is used to synchronize the machine.

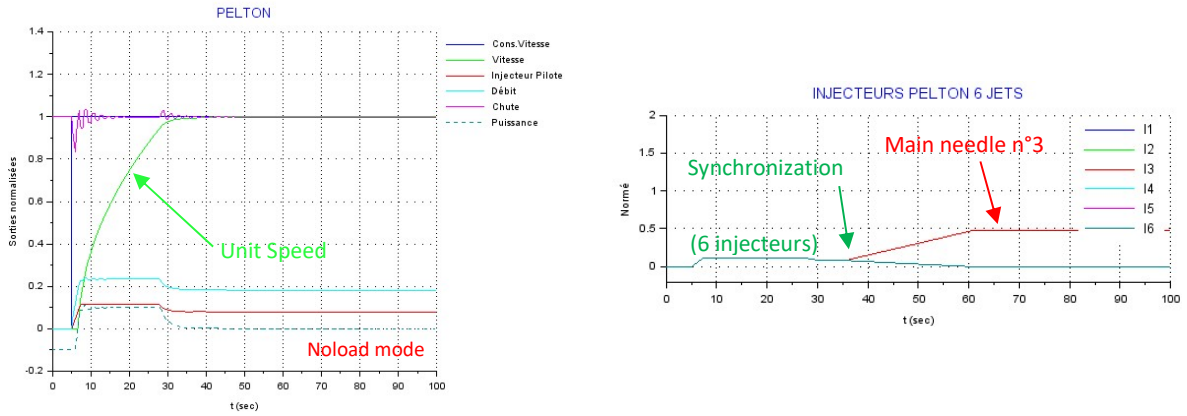


Figure 184 : Start-up sequence of a 6-jet Pelton turbine with pilot injection on needle #3

5.2.3 Select the pilot injection

iPilote	Main pilot injector number (su)	REPARTITEUR - XLS
iPilote2	Secondary pilot injector number (su)	REPARTITEUR - XLS
tPilote	Time required for pilot injector switching (s)	REPARTITEUR - XLS

In **B**, the "dispatcher" circuit enables switching of the pilot injector when the engine is running.

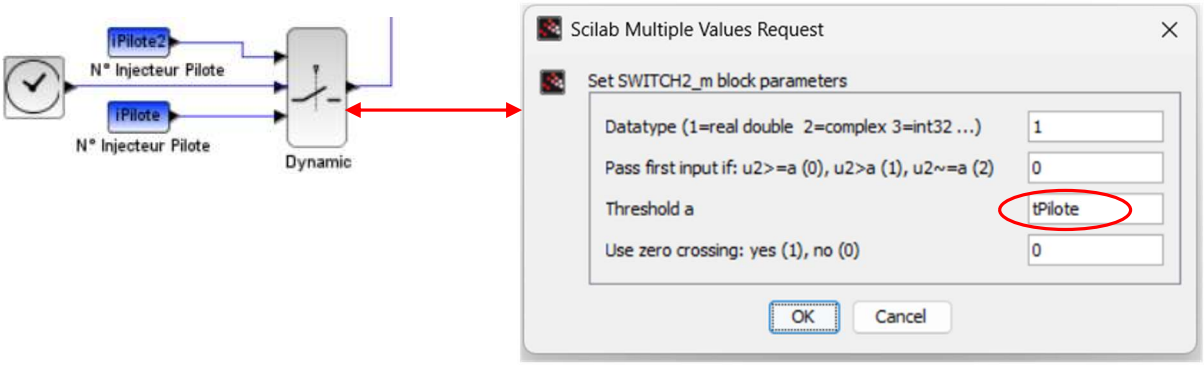


Figure 185 : Procedure for replacing the pilot injector - Engine running (extract from REPARTITEUR diagram)

At time **tPilote**, which is programmable by double-clicking the dynamic switch (threshold value a), the pilot injector number is changed, resulting in a transient operating state of the injectors.

This process is guaranteed to minimize power and flow rate fluctuations when the switch ramp-up time is optimized.

5.2.4 Jets switching thresholds

SLCom1	1 needle switching threshold (pu)	REPARTITEUR - XLS
SLCom2	2 needles switching threshold (pu)	REPARTITEUR - XLS
SLCom3	3 needles switching threshold (pu)	REPARTITEUR - XLS
SLCom4	4 needles switching threshold (pu)	REPARTITEUR - XLS
SLCom5	5 needles switching threshold (pu)	REPARTITEUR - XLS
SLCom6	6 needles switching threshold (pu)	REPARTITEUR - XLS

```
254  // Seuils de commutation des jets
255  //--------------------------------
256  SLCom1=-1;SLCom2=1/NJets;SLCom3=2/NJets;SLCom4=3/NJets;SLCom5=4/NJets;SLCom6=5/NJets;
257  ;
258  //-------------------------------------------------------------------------------
259  // Seuils et Loi de commutation des jets PELTON
260  // Remarque : il est possible de by-passer une séquence en modifiant le nombre
261  // de jets aloués dans la table yTH_LCom
262  //-------------------------------------------------------------------------------
263  ;
264  TH_LCom= [SLCom1 SLCom2 SLCom3 SLCom4 SLCom5 SLCom6];   // Seuils de commulation
265  yTH_LCom=[1      2      3      4      5      6     ];   // Nombre de jets engagés dans la séquence
266
267  TL_LCom=TH_LCom-0.001;                                  // Seuils bas avec hysteresis
```

Figure 186 : Example of programming the jet switching thresholds – File "HydroSim\demos\PELTON\Pelt6\StandardPelt6c.xls"

The jet switching thresholds shown in *Figure 186* are equidistant.

In reality, it is necessary to program these thresholds based on the power/efficiency or flow rate/efficiency relationship to achieve optimal performance.

A jet dispatcher for a Pelton turbine is a feature that optimizes the machine's efficiency based on the required power output, by controlling the number of jets in operation.

As an example, *Figure 187* shows that to meet a production demand of 12.5% of the rated power, the efficiency gain when operating with one engine is as follows:

- 1% compared to operation with 2 jets
- approximately 2% compared to operation with 4 jets

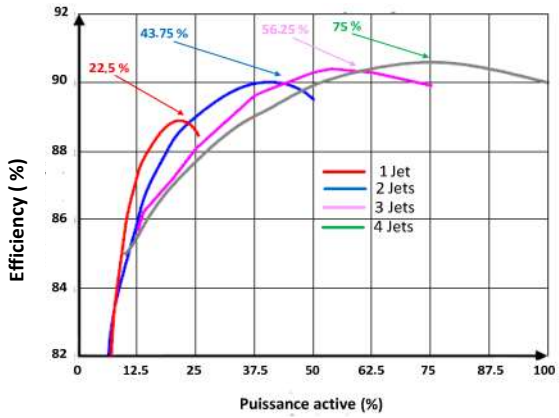


Figure 187 : Efficiency curves of a 4-jet Pelton turbine

5.2.5 Multivariable switching relay with hysteresis RELAIS_H



In **C**, the **Relais_H** component represents a multiple relay system connected in parallel to the input flow (or power) signal.

Its operating principle is described in the document. « **HYDROTUR - SEGPAL - Reference guide version xx** ».

The equivalence of this component can also be considered as shown below:

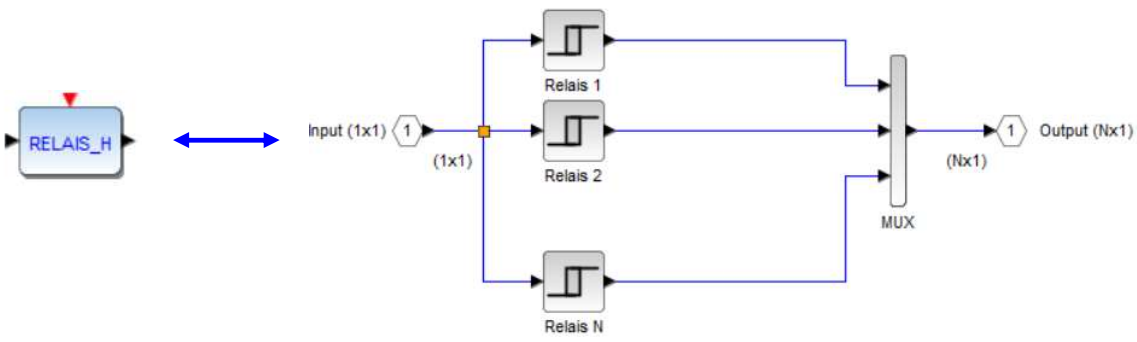


Figure 188 : Principle of the multiple relay RELAIS_H.

The summing circuit downstream of the **RELAY_H** component determines the number of injectors to activate. The figure below illustrates the operation of the multiple relay:

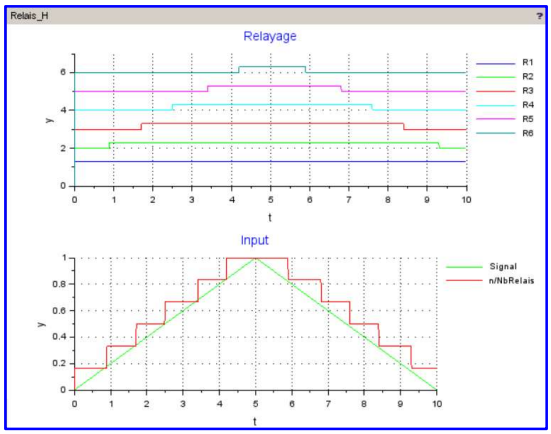


Figure 189 : Test program for the RELAY_H component for a 6-jet Pelton turbine

The switching thresholds are tabulated in two column matrices, **TH_LCom** and **TH_LCom**, in the parameter file "*HydroSim\demos\PELTON\Peltx\StandardPeltxc.xls*", as shown in *Figure 186,* considering programmed hysteresis.

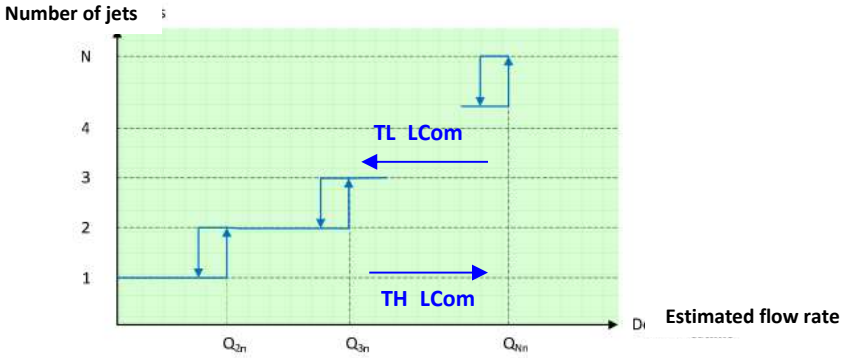


Figure 190 : Switching thresholds for injector jets - Hysteresis is set to TL_LCom=TH_LCom-0.001 by default

Double-clicking on the **RELAY_H** component will display its configuration window:

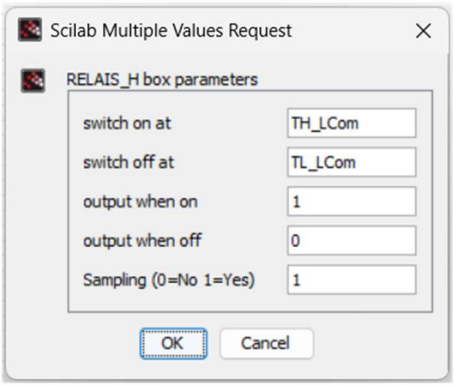


Figure 191 : Programming interface for the **RELAY_H** component

5.2.6 Possible inhibition of specific sequences

In **D**, the function "y1=yTH_LCom(u1)" 

allows you to confirm or modify the number of injectors to be activated. Therefore, it is possible to "bypass" a sequence if operational conditions require it.

This function uses the **yTH_LCom** table shown in *Figure 186*.

For example, to ensure that no sequence is skipped in a 6-jet Pelton turbine, the programmer would typically specify:

yTH_LCom=[1 2 3 4 5 6]; // Number of jets involved in the sequence

To "bypass" the 5-jet sequence, i.e., to go directly from the 4-jet sequence to the 6-jet sequence, the programmer will specify:

yTH_LCom=[1 2 3 4 4 6]; // Number of jets involved in the sequence

Or

yTH_LCom=[1 2 3 4 6 6]; // Number of jets involved in the sequence



5.2.7 Dispatcher function

Finally, in **E**, the "*Repartiteur_Jets.sci*" script function distributes the number of jets to be activated, considering the radial forces exerted on the shaft of the Pelton turbine.

5.2.8 Calculation of radial forces on the Pelton wheel – Asymmetry detection

This paragraph is essential for understanding the selection of injector sequences described in the jet dispatcher function of a PELTON turbine.

The calculation of stresses on a PELTON turbine wheel[9] is sometimes a mandatory requirement in certain specifications. This calculation allows for the detection of any asymmetry in the stresses acting on the turbine shaft.

This asymmetry is due to differences in the positions of the injectors (positioning inaccuracies, servo motor tracking errors, etc.) or possibly to the complete closure of the injectors as instructed by the jet dispatcher algorithm.

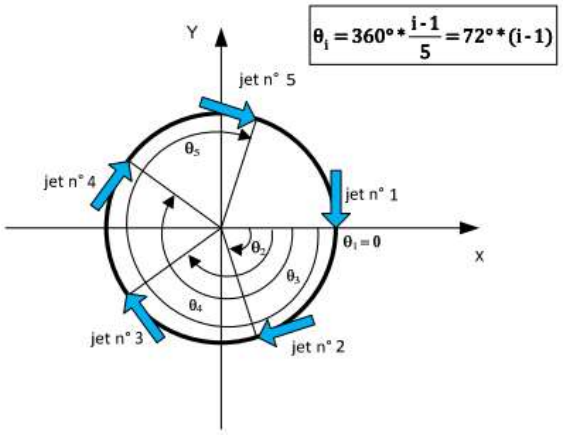


Figure 192 : Detection of radial forces on a 5-jet Pelton turbine

The consequence of detecting an asymmetry is overheating of the machine bearings, which poses a risk of damage to the equipment.

5.2.9 PELTON jet selector

PELTON	Number of injectors in service	A	B	C	D	E	F
4 jets	1	●					
	2	●		●			
	3	●	●	●			
	4	●	●	●	●		
5 jets	1	●					
	2	●		●			
	3	●		●		●	
	4	●	●	●		●	
	5	●	●	●	●	●	
6 jets	1	●					
	2	●			●		
	3	●		●		●	
	4	●	●		●	●	
	5	●	●	●	●	●	
	6	●	●	●	●	●	●

[9] **A calculation note PeltEff.xlsx is available in the HydroSim\TURBINES\PELTON\Utilities\ directory, and presented here in B.3**

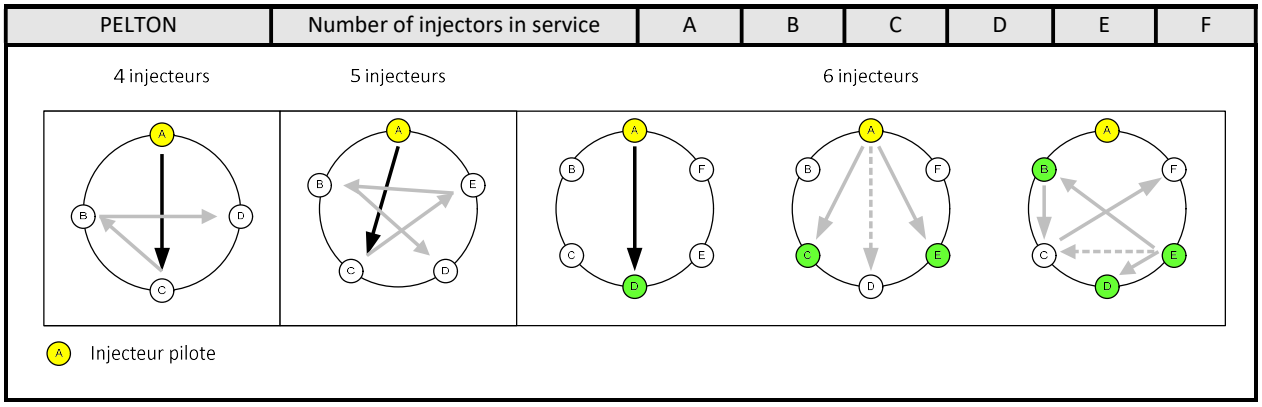


Figure 193 : PELTON jet selector

The table above indicates the injector sequences to be implemented, depending on the number of jets to be opened or closed, to minimize the forces produced on the wheel.

The pilot injector is the reference injector (injector A). The opening sequences of the other injectors (B-C-D, etc.) are thus determined from the pilot injector.

5.2.10 Principle of variable gain in the PELTON injector positioner

RampGV	Variable gain switch ramp time (s)	PELTON.ctx

RampGV sets the switching time of the variable gains, in the jet switch.

As a reminder, whatever the distance to be covered, the final values of the injector positions must be synchronized, to guarantee equality of flow and power during switching, when changing the pilot injector, with the group running.

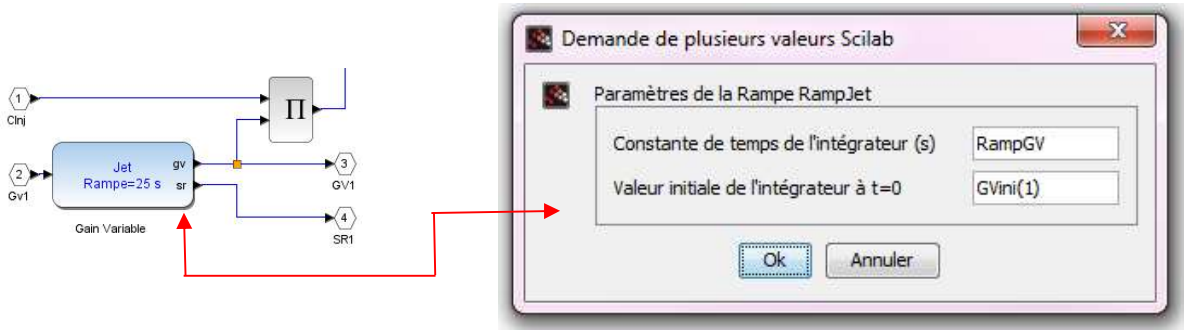


Figure 194 : Multiplication of the Injector setpoint by a variable gain - Extract from the SYSCOP Injector diagram

The switching transient is ensured by linearly modifying the variable gain of the positioning loop of each injector, as a function of time.

Although the switching time T can be optimized according to the stroke to be performed by the cylinder of each servomotor, it is preferable to set a single switching time, equal to the greatest of the "full opening" and "full closing" operating times of the injectors, these two pieces of information being programmable by the operator interface.

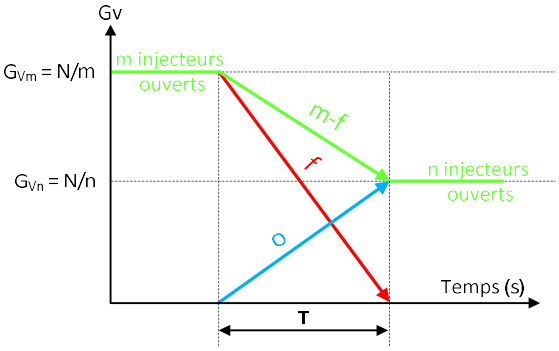


Figure 195 : Switching of injectors of a PELTON wheel

We thus obtain the following table of transient gains:

Needles	m open needles	Transition m➔n	n open needles
Staying open (m-f)	$G_{Vm} = \frac{N}{m}$	$G_{Vm\to n}(t) = \frac{\frac{N}{n} - \frac{N}{m}}{T}t + \frac{N}{m}$	$G_{Vn} = \frac{N}{n}$
Closing (f)	$G_{Vm} = \frac{N}{m}$	$G_{Vf\to 0}(t) = \frac{-\frac{N}{m}}{T}t + \frac{N}{m}$	0
Opening (o)	0	$G_{Vo\to n}(t) = \frac{\frac{N}{n}}{T}t$	$G_{Vn} = \frac{N}{n}$

Figure 196 : Variable Gains Table

5.3 Economic interest of a jet distributor

The interest of the dispatcher seems certain from an economic point of view. From the general formula:

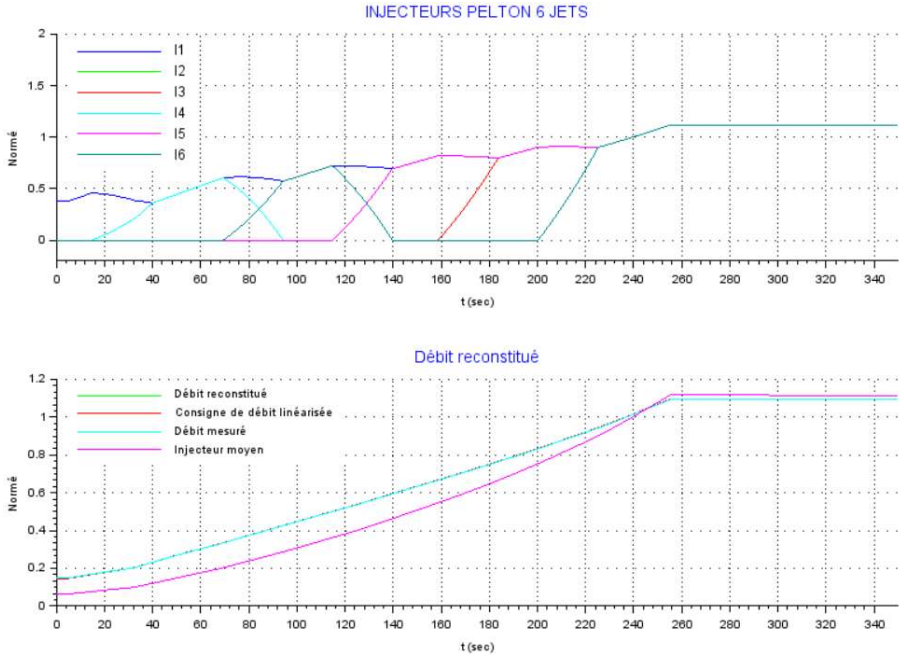
$$P = \eta.\rho.g.H.Q$$

For example, we obtain

$$Q_5 = \frac{\eta_4}{\eta_5} Q_4$$

, where Q_i and η_i designate a flow rate and an efficiency for i injectors put into service.

In other words, if $\frac{\eta_4}{\eta_5} < 1$ the same power is produced by increasing the number of jets and reducing the volume of water passed through the turbine (*see* [10] *page 176 to 178, or B.2*)



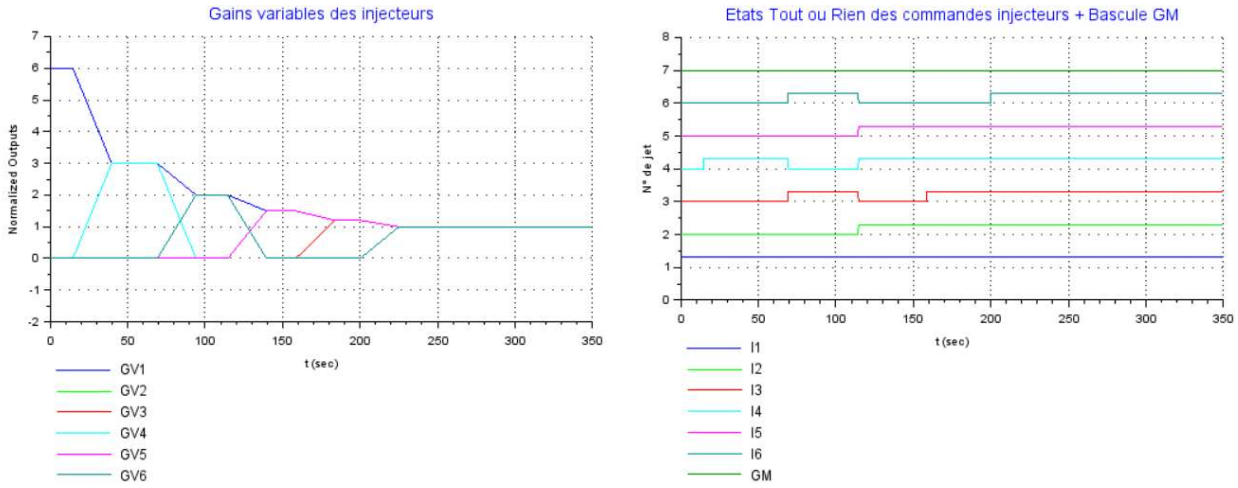


Figure 197 : Principle of the jet switch for PELTON turbine 6 injectors – 100% PU load intake[10]

10

6 HILLS MACHINE

6.1 General - Variable speed characteristic curves

To control the behaviour of a turbine during transient regimes (start-up, sudden discharge and runaway), it is useful to know its characteristic curves at variable speed.

To do this, turbine manufacturers use tests on scale models to establish charts that are valid for a specially machined turbine, designed to achieve the best wheel efficiency.

These characteristic curves are measured on a test bench in an Expert Hydraulic Laboratory, generally on models with a 1 m diameter wheel, under a 1 meter head, hence the "11" indices found in the formula indices.

These tests are carried out under constant head, constant turbine opening, variable flow rate and rotation speed.

The parameters obtained are as follows, depending on the rotation speed "n":

– flow rate Q (useful for calculating water hammer during runaway);

– efficiency η (eta) ;

– torque C on the turbine shaft (useful for calculating the acceleration of the group and sizing the flywheel).

Like the Q - H curves, these curves are combined in the form of an abacus with a hill of efficiencies.

To make these curves usable for any turbine size and any head, the scales are converted into a unitary form:

- The flow rate Q becomes unit flow rate Q 11 (or q11)
- The speed n becomes unit rotation speed n11
- The torque C becomes the unit couple C11 (or c11)

Indeed, homothety rules then make it possible to move from the characteristics of the scale models to the characteristics of the real machine.

The standardized quantities in the modelling are:

✓ n_{11} : Unit rotation speed of a 1 m diameter turbine operating under 1 m head ($m^{1/2}.tr/min$)

$$\boxed{n_{11} = \frac{n.D}{\sqrt{H}}}$$ where n is the speed in rpm, D the diameter of the wheel, and H the net head in m.

✓ q_{11} : Unit flow rate of a 1 m diameter turbine operating under 1 m head ($m^{1/2}/s$)

$$\boxed{q_{11} = \frac{Q}{D^2.\sqrt{H}}}$$ where Q is the flow rate in m^3/s

✓ c_{11} : Unit torque of a 1 m diameter turbine operating under 1 m head (N/m^3)

$$\boxed{c_{11} = \frac{C}{D^3.H}}$$, where C is the torque in $N.m$

✓ p_{11} : Unit power of a 1 m diameter turbine operating under 1 m head

$$\boxed{p_{11} = \frac{P}{D^2.H^{3/2}}}$$, where P is the power in W

☞ **These calculations and their representations will be found in the TurbAdduc modules, for the circuits concerned.**

Machine hills allow to simulate the behaviour of the group, considering the main diagram indicated below:

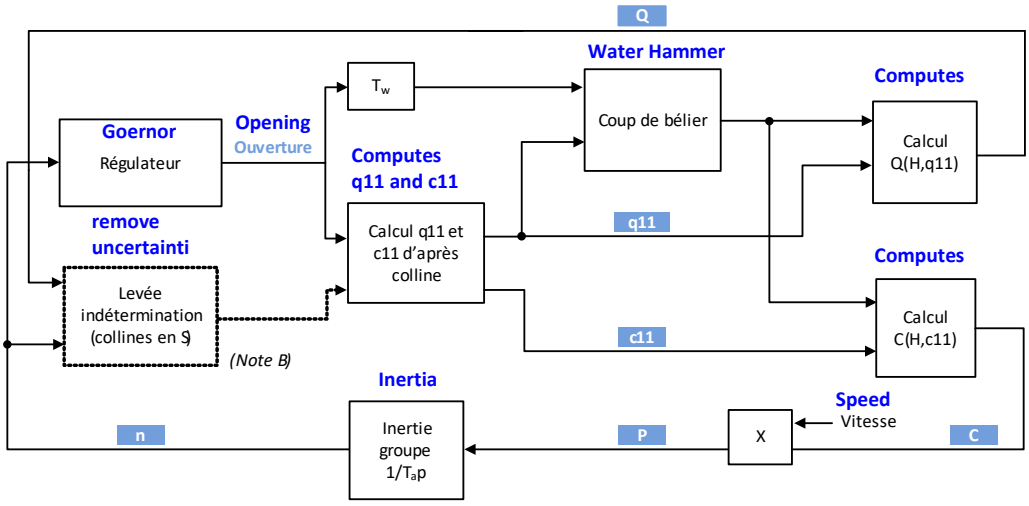


Figure 198 : Modeling principle with characteristic hills

6.2 Organization

Machine hills are loaded when launching the model's "SCE" files taking this data in, or in a "**Replay**" sequence of a recording in the corresponding directory.

Machine hill interpolation routines, and their loaders, are available in the **HydroSim "macros"** directory.

Currently, three models are available; they can be extended and improved in studies:

Model	Loader	Interpolator
FR4 for FRANCIS machine	ChargeurColline4.sci	Intercol4.sci
FR5 for FRANCIS machine	ChargeurColline5.sci	Intercol5.sci
KB1 for Kaplan machine	ChargeurCollineKB_STD.sci	IntercolKB.sci

In these modules, the interpolators on the hills have the following common points, in their resolutions in the SCILAB SOLVERS; the outputs of these boxes depend on the embedded algorithm:

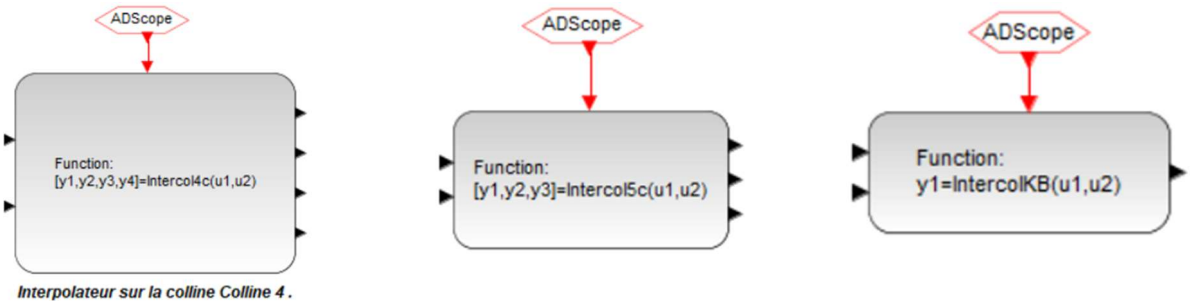


Figure 199 : Hill functions in Xcos TurbAdduc FR4-FR5-KB1 modules

- Interpolators are sampled at the **ADScope** period 

. This implementation constraint is because in the absence of sampling, the XCOS calculation and run-time unit is saturated, and blocks all calculations in a prohibitive manner.
- The ADScope period can be modified in the "System" component, common to all circuits, and is currently set to 2 ms.

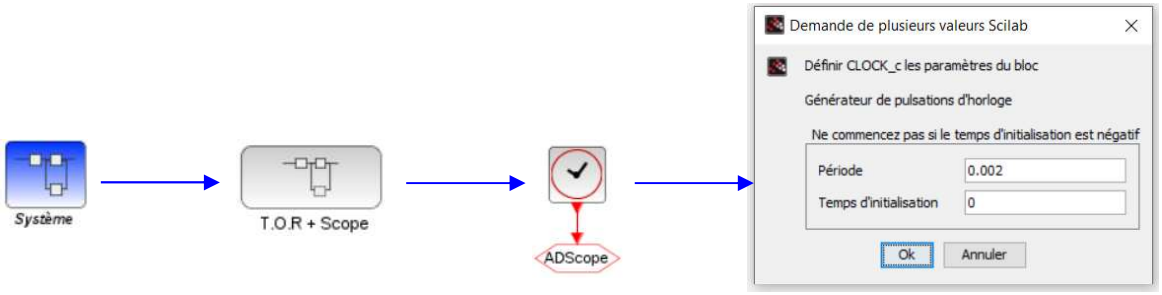


Figure 200 : Interpolator Sampling - Hill Machine

- Xcos interpolators are created using the standard block "**scifunc_block_m**" accessible in the "User-defined functions" subgroup of the standard XCOS palette:

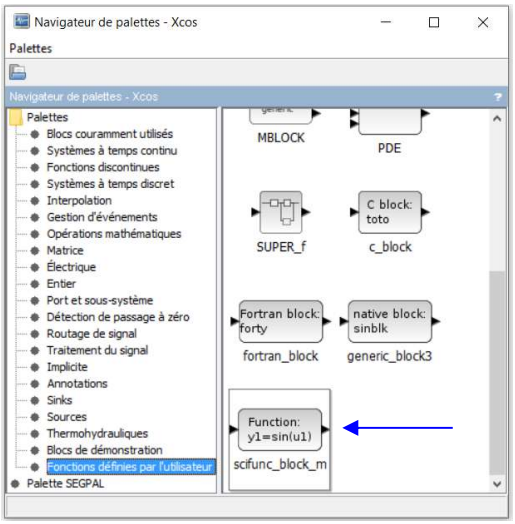


Figure 201 : Function "**scifunc_block_m**" in the Xcos standard palette

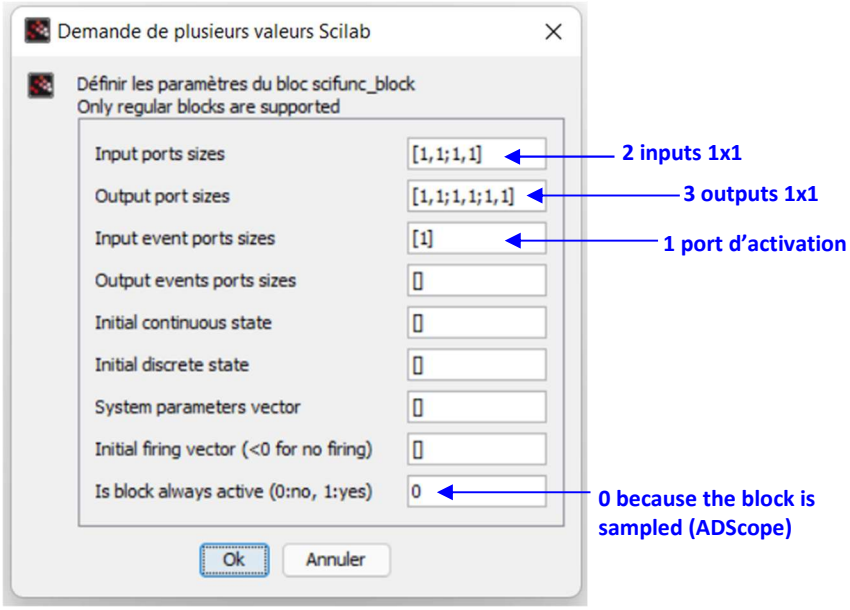


Figure 202 : Functional box of the **Intercol5c** interpolator – FR5 circuit (box 1/2)

6.3 Demonstrator of an interpolator on a hill machine

By entering the command "**PlotHill demo**" in the Scilab console, it is possible to visualize the general interpolation principle on machine hills.

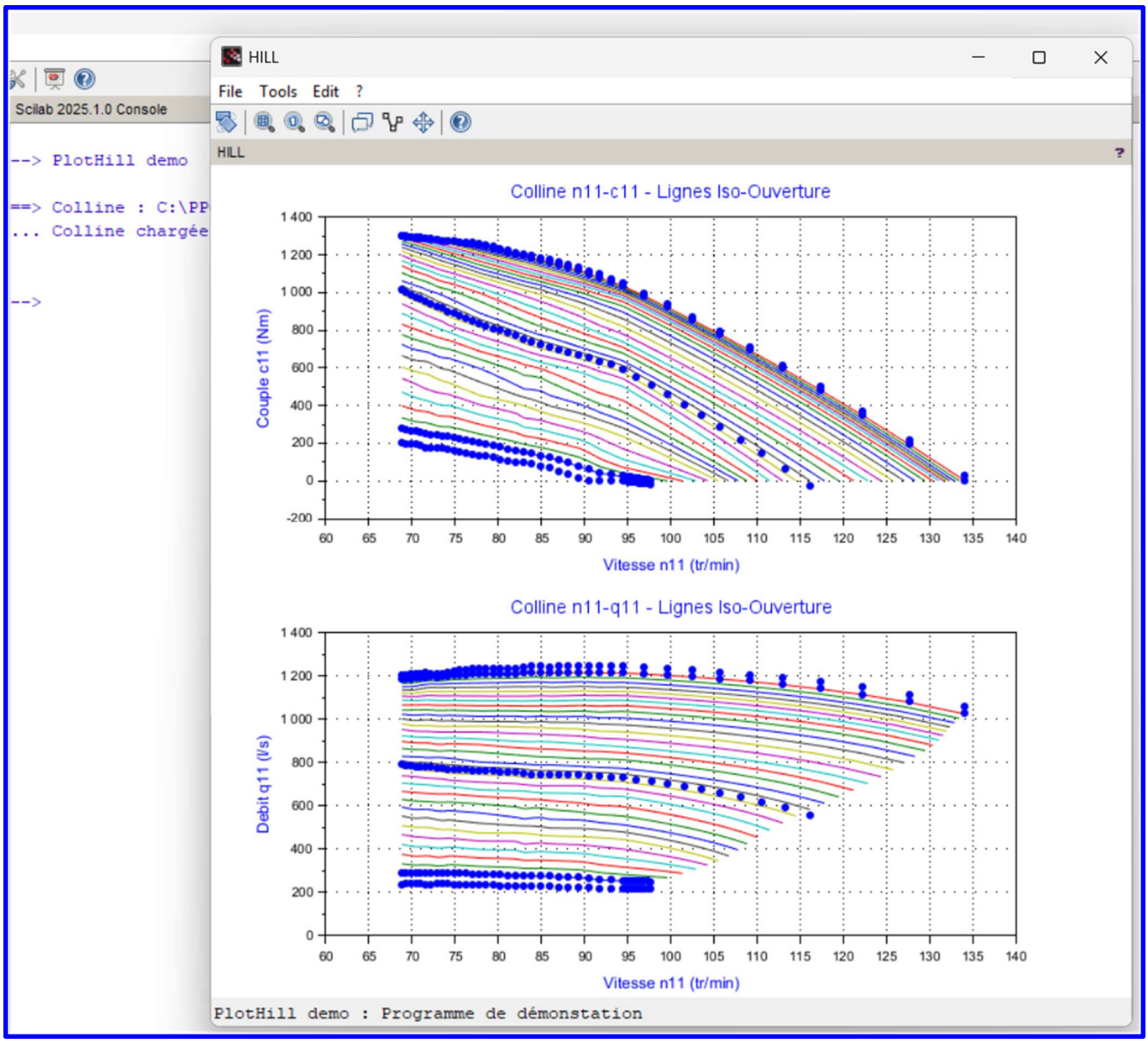


Figure 203 : Demonstrator of an interpolator on a hill machine

6.4 Hills for Francis Machine type FR4

6.4.1 Representation in the TurbAdduc circuit

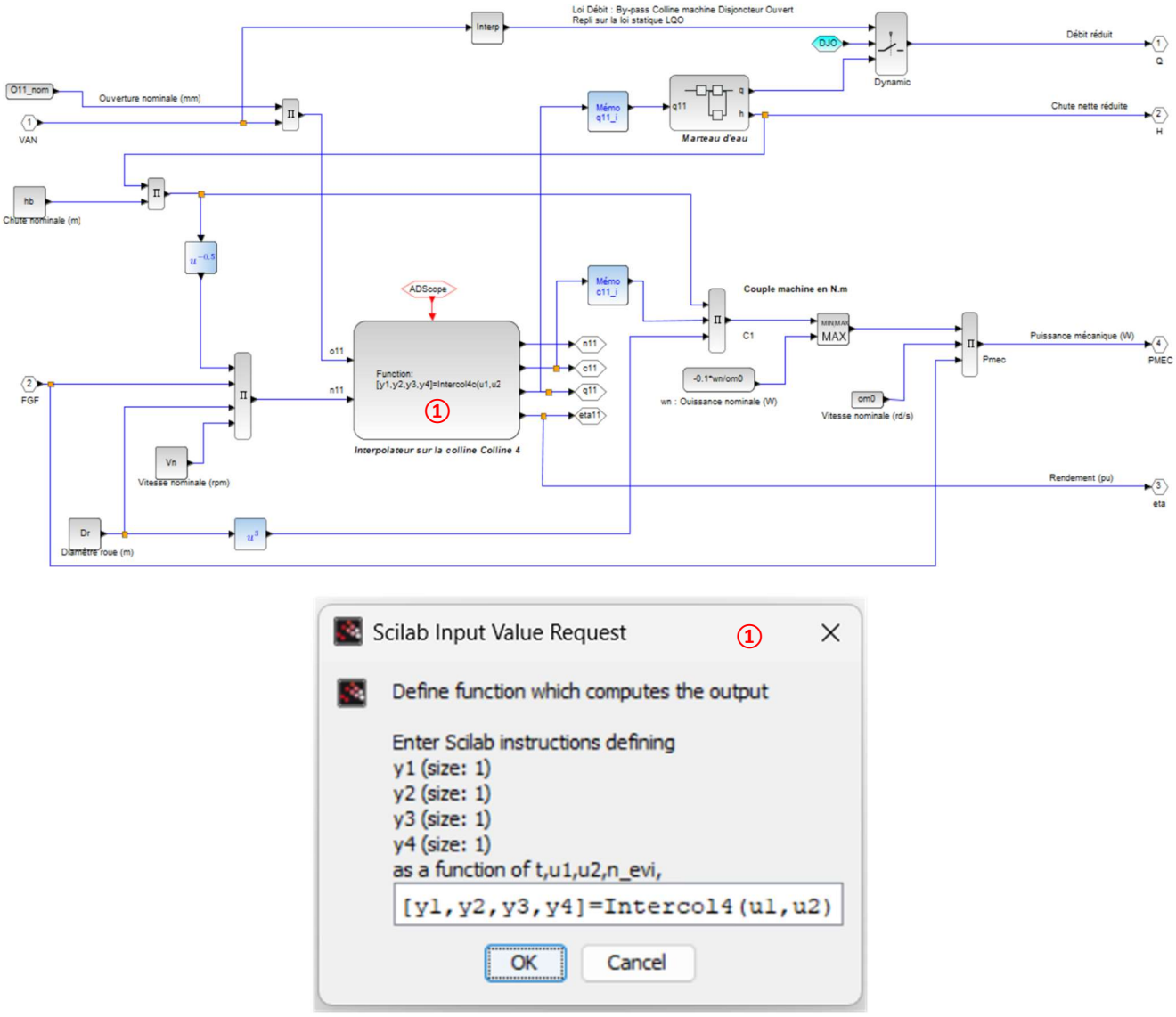
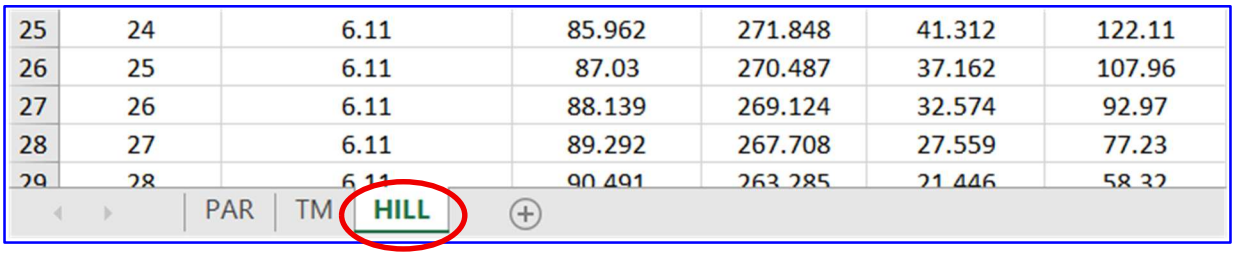


Figure 204 : Hill for FRANCIS Type FR4 Machine – Interpolator **Intercol4.sci** (box 2/2)

6.4.2 Loading Hills FR4

The hill to be loaded must be present in a sheet named "**HILL**" in the Excel parameterization file, in **XLS** format



25	24	6.11	85.962	271.848	41.312	122.11
26	25	6.11	87.03	270.487	37.162	107.96
27	26	6.11	88.139	269.124	32.574	92.97
28	27	6.11	89.292	267.708	27.559	77.23
29	28	6.11	90.491	263.285	21.446	58.32

PAR | TM | HILL

Figure 205 : Declaration and insertion of the FR4 machine hill in the XLS parameterization file

It is then loaded by the loader "FR4_Loader".

At the end of the script execution, if all the formats have been respected, a message in the Scilab console indicates the successful execution of the operation:

```
-------------------------------------------------------------------
Machine :         FRANCIS
Xcos Model :      FR4c.zcos
Project :         FR4c
-------------------------------------------------------------------

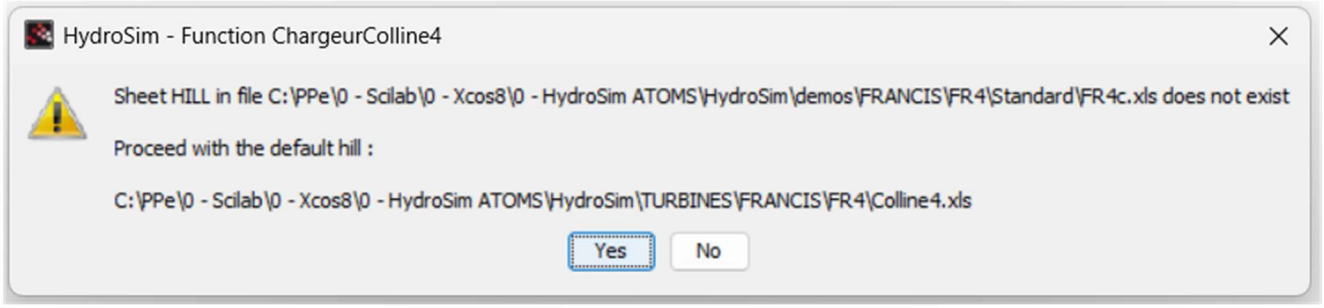
==> Hill : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR4\Standard\FR4c.xls
... Loaded Hill

Xcos Model : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\TURBINES\FRANCIS\FR4\FR4c.zcos

==> Hill : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR4\Standard\FR4c.xls
```

Figure 206 : Loading diagnosis of an FR4 hill in the Scilab console

An alert message is reported if the "HILL" sheet does not exist:



In this case, HydroSim uses a default hill located in the **HydroSim\TURBINES\FRANCIS\FR4\Colline4.xls directory:**

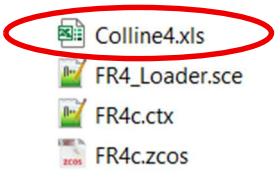


Figure 207 : Default Hill Hill4.xls

6.4.3 FR4 Hills Format

The Colline FR4 file (e.g. Collin4.txt) is a text file containing a set of lines. The lines are separated by a Carriage Return ("\n" in C language or hexadecimal ASCII code (0Dh 0Ah)

Each line consists of a set of 6 fields: N_{11} Q_{11} η_{11} C_{11}

1	Indice	Ouverture (mm)	N (rpm)	Q (l/s)	ETA (%)	C (N.m)

Figure 208 : FR4 Hills Format

Fields are separated by a tab character ("\t" in C language or ascii code 09h)

The table must be sorted:

- **First by increasing openness (Opening)**
- **Then, for each opening, by increasing speed n_{11}**

40	39	6.11	96.956	248.295	1.992	4.77
41	40	6.11	97.29	247.679	1.009	2.4
42	41	6.11	97.628	247.045	0	0
43	1	6.89	68.8	332.177	74.21	334.9
44	2	6.89	69.344	329.763	73.712	327.65
45	3	6.89	69.901	327.291	73.163	320.2
46	4	6.89	70.472	325.813	72.717	314.24
47	5	6.89	71.057	326.52	72.475	311.29
48	6	6.89	71.657	327.245	72.224	308.3

Figure 209 : Ranking extracted from the Colline4.txt file

his gives iso-opening curves.

6.4.4 FR4 Hills Layout

At the end of a sequence simulation, it is possible to visualize a hill using the **PlotHill** instruction in the Scilab console:

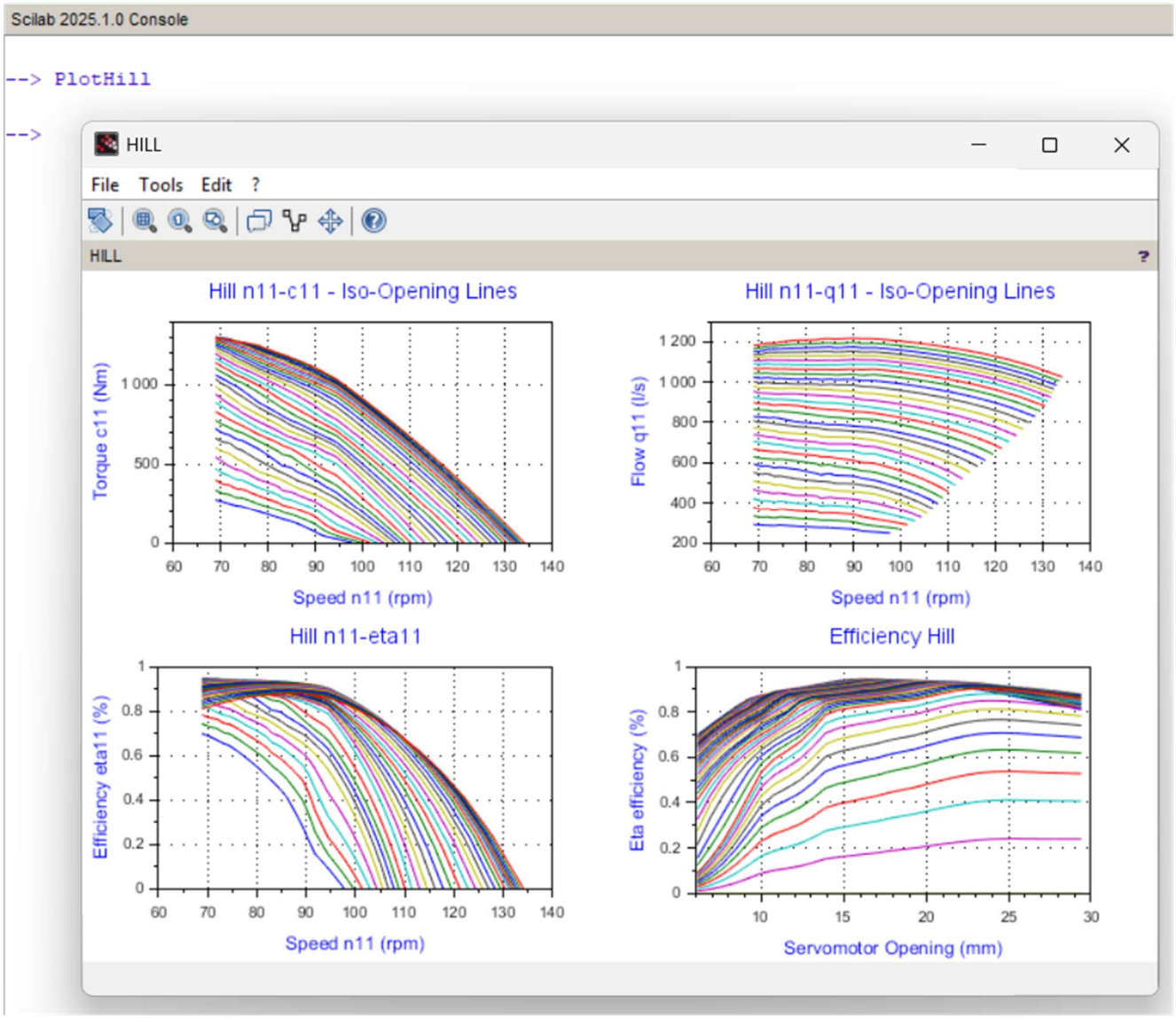


Figure 210 : Plotting the FR4 hill in the Scilab console

6.5 Hills for Francis Machine type FR5

6.5.1 Representation in the TurbAdduc circuit

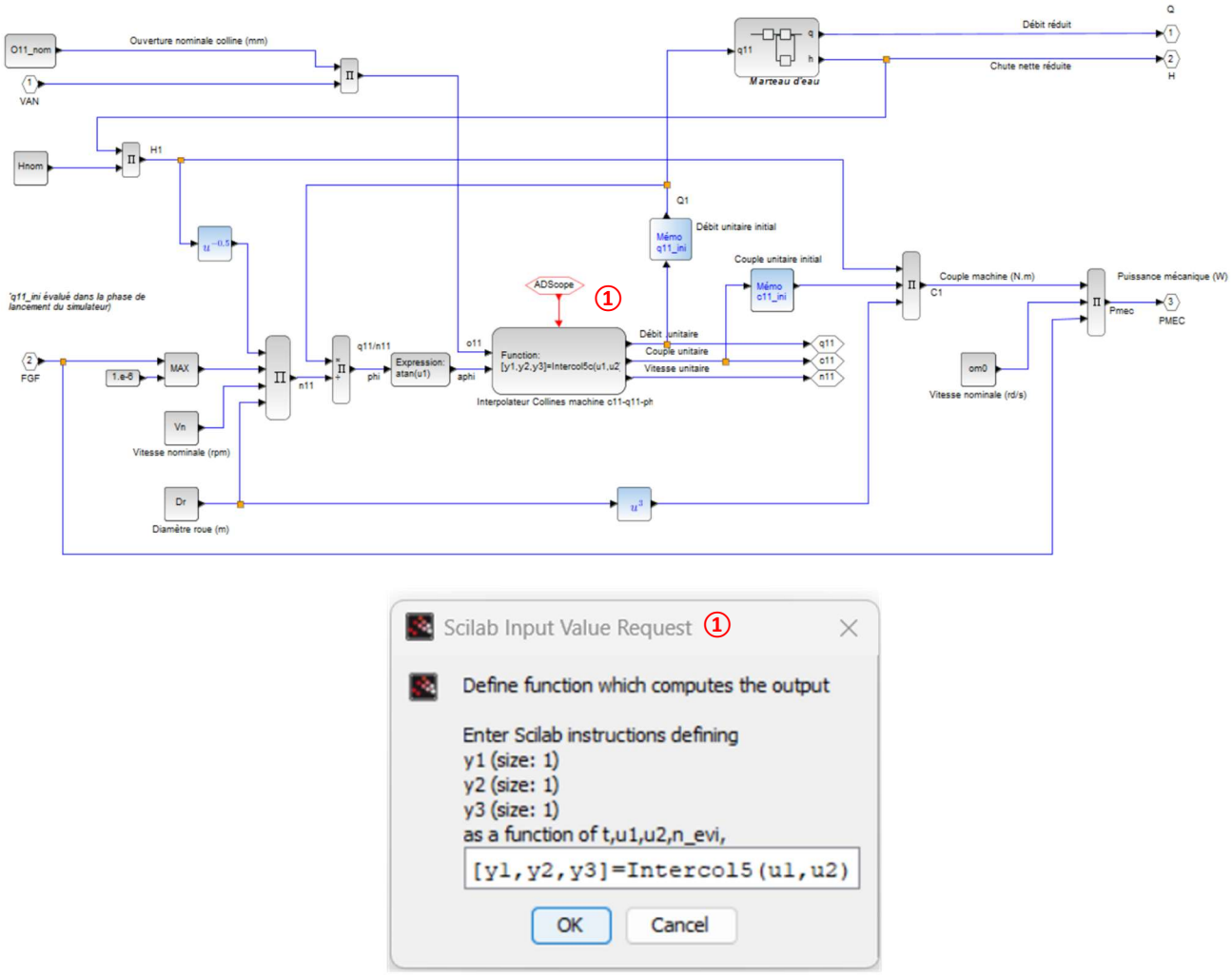


Figure 211 : Hill for FRANCIS Type FR5 Machine – Interpolator **Intercol5.sci**[11] (box 2/2)

6.5.2 Loading Hills FR5

The hill to be loaded must be present in a sheet named "**HILL**" in the Excel parameterization file, in **XLS** format

23	6.95	77.284	271.901	174.61	1.154105528
24	6.95	76.192	273.106	184.32	1.178819146
25	6.95	75.144	274.273	193.57	1.200503003
26	6.95	74.139	276.156	202.54	1.219898565
27	6.95	73.173	278.132	210.98	1.236953397
28	6.95	72.243	279.457	218.86	1.251969656
29	6.95	71.348	280.446	225.13	1.263890585

PAR | TM | HILL

Figure 212 : Declaration and insertion of the FR5 machine hill in the XLS parameterization file

It is then loaded by the loader "FR5_Loader".

[11] *See also Figure 27*

At the end of the script execution, if all the formats have been respected, a message indicates, in the Scilab console, the successful execution of the operation: ».

```
-------------------------------------------------------------------
Machine :         FRANCIS
Modèle Xcos :     FR5c.zcos
Projet :          FR5c
-------------------------------------------------------------------

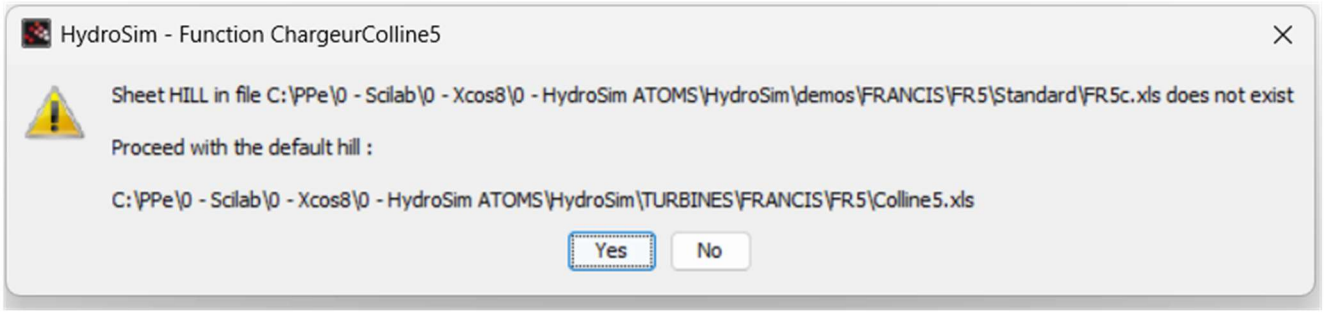
==> Colline : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR5\Standard\FR5c.xls
... Colline chargée

Modèle Xcos : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\TURBINES\FRANCIS\FR5\FR5c.zcos

==> Colline : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR5\Standard\FR5c.xls
```

Figure 213 : Loading diagnosis of an FR5 hill in the Scilab console

An alert message is reported if the “HILL” sheet does not exist:



In this case, HydroSim uses a default hill located in the **HydroSim\TURBINES\FRANCIS\FR5\Colline5.xls** directory:

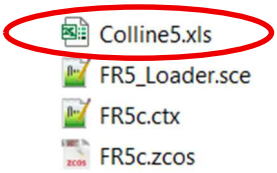


Figure 214 : Default Hill Hill5.xls

6.5.3 FR5 Hills Format

The Colline FR5 file (e.g. Collin5.txt) is a text file containing a set of lines. The lines are separated by a Carriage Return ("\n" in C language or hexadecimal ASCII code (0Dh 0Ah)

Each line consists of a set of 5 fields:

	N_{11}	Q_{11}	C_{11}	φ_{11}
Opening (mm)	Speed (rpm)	Flow (l/s)	Torque (Nm)	Angle (rd)

Figure 215 : FR5 Hills Format

Fields are separated by a tab character (“\t” in C language or ascii code 09h)

On each line we can check the relationship, for a model wheel diameter Dr=1 m:

$$\varphi_{11} = \text{atan}\left(\frac{q_{11}}{n_{11}}\right)$$

, atan represents the mathematical function “ArcTangent.”

The table must be sorted:

- **First by increasing openness (Opening)**
- **Then, for each opening, by increasing angle φ_{11}**

	A	B	C	D	E
1	Ouverture (m	Vitesse (rp	Débit (l	Couple (N	Angle (rd
2	6.95	92.954	251.533	0	0
3	6.95	92.353	252.735	7.63	0.082430573
4	6.95	91.763	253.871	15.07	0.162774414
5	6.95	91.185	254.946	22.32	0.240056985
6	6.95	90.617	255.965	29.39	0.313627669
7	6.95	90.06	256.931	36.29	0.383049976

Figure 216 : Ranking extracted from the Colline5.txt file

This gives iso-opening curves.

6.5.4 FR5 Hills Layout

At the end of a sequence simulation, it is possible to visualize a hill using the **PlotHill** instruction in the Scilab console:

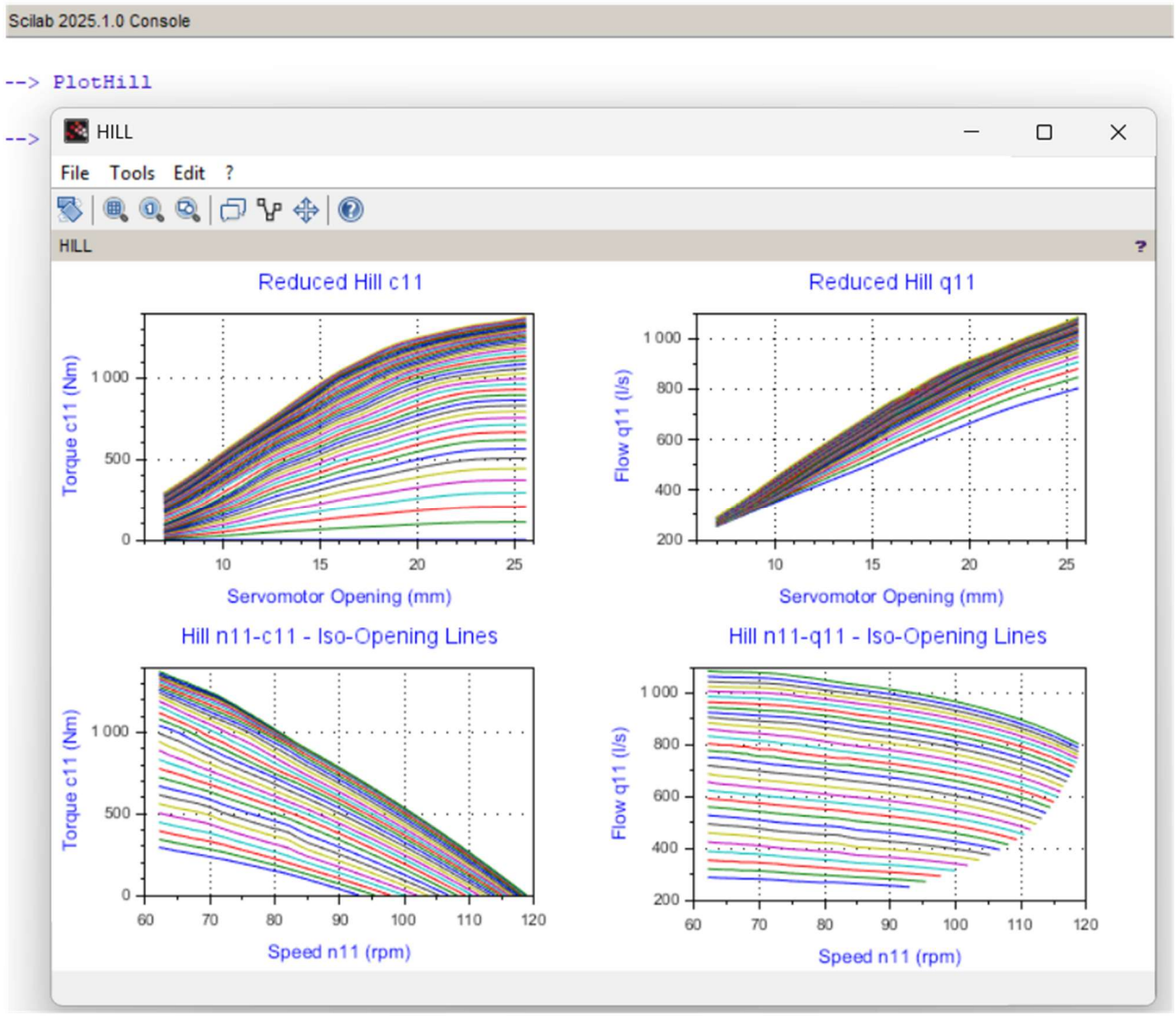
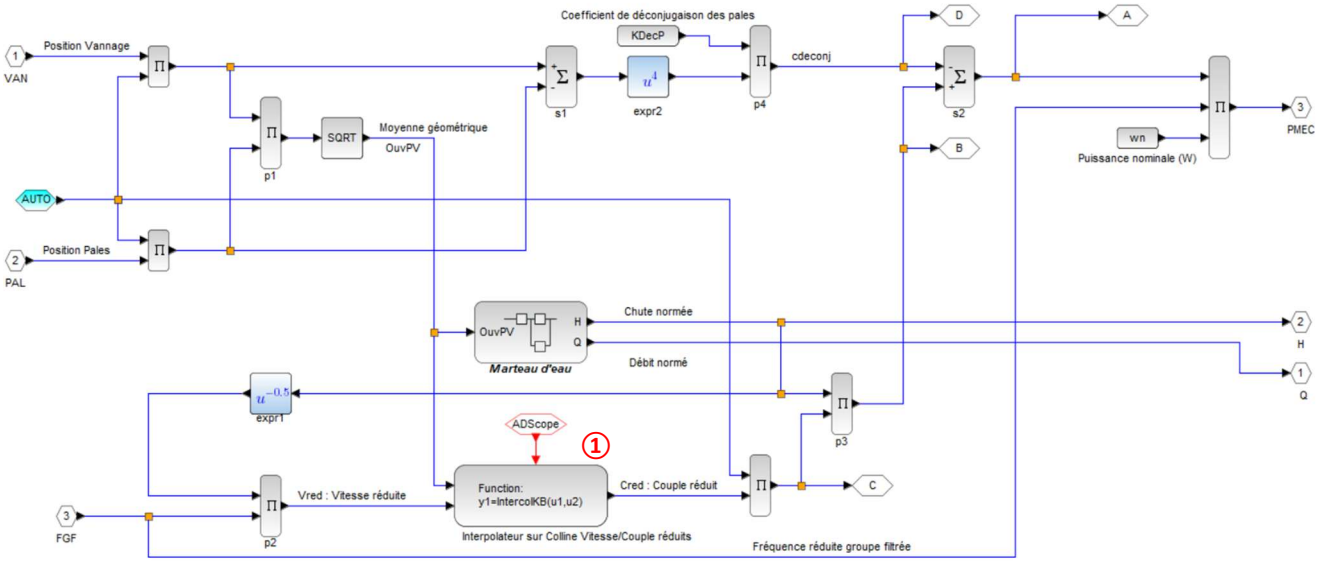


Figure 217 : Plotting the FR5 hill in the Scilab console

6.6 Analytical Computing for Kaplan KB1

6.6.1 Representation in the TurbAdduc circuit



The interpolator is implemented by the **IntercolKB** function.

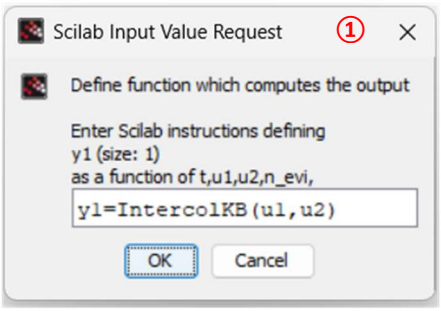


Figure 218 : Hill for Kaplan KB1 Machine – **IntercolKB** Interpolator (box 2/2)

6.6.2 KAPLAN Hill Layout

At the end of a sequence simulation, it is possible to visualize a hill using the PlotHill instruction in the Scilab console:

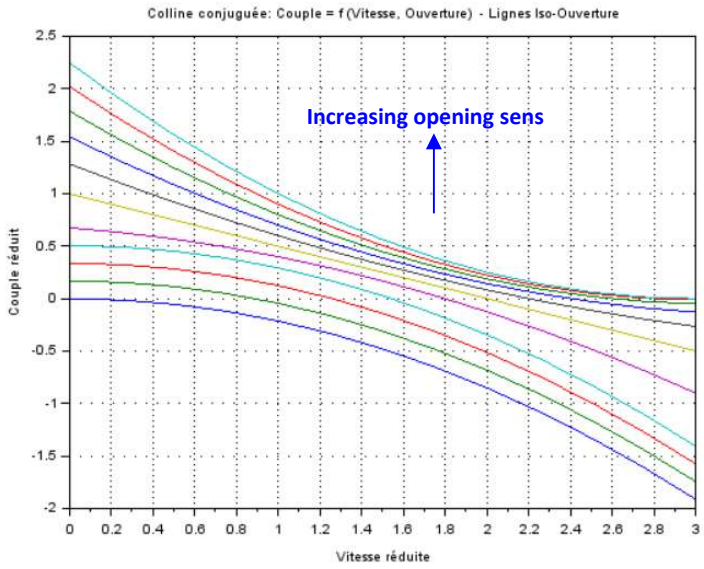


Figure 219 : Analytical Hill KB1 Iso-opening Lines

ANNEX

A. CALCULATION ELEMENTS IN THE HYDRAULIC CIRCUIT – CALTUR EXCEL

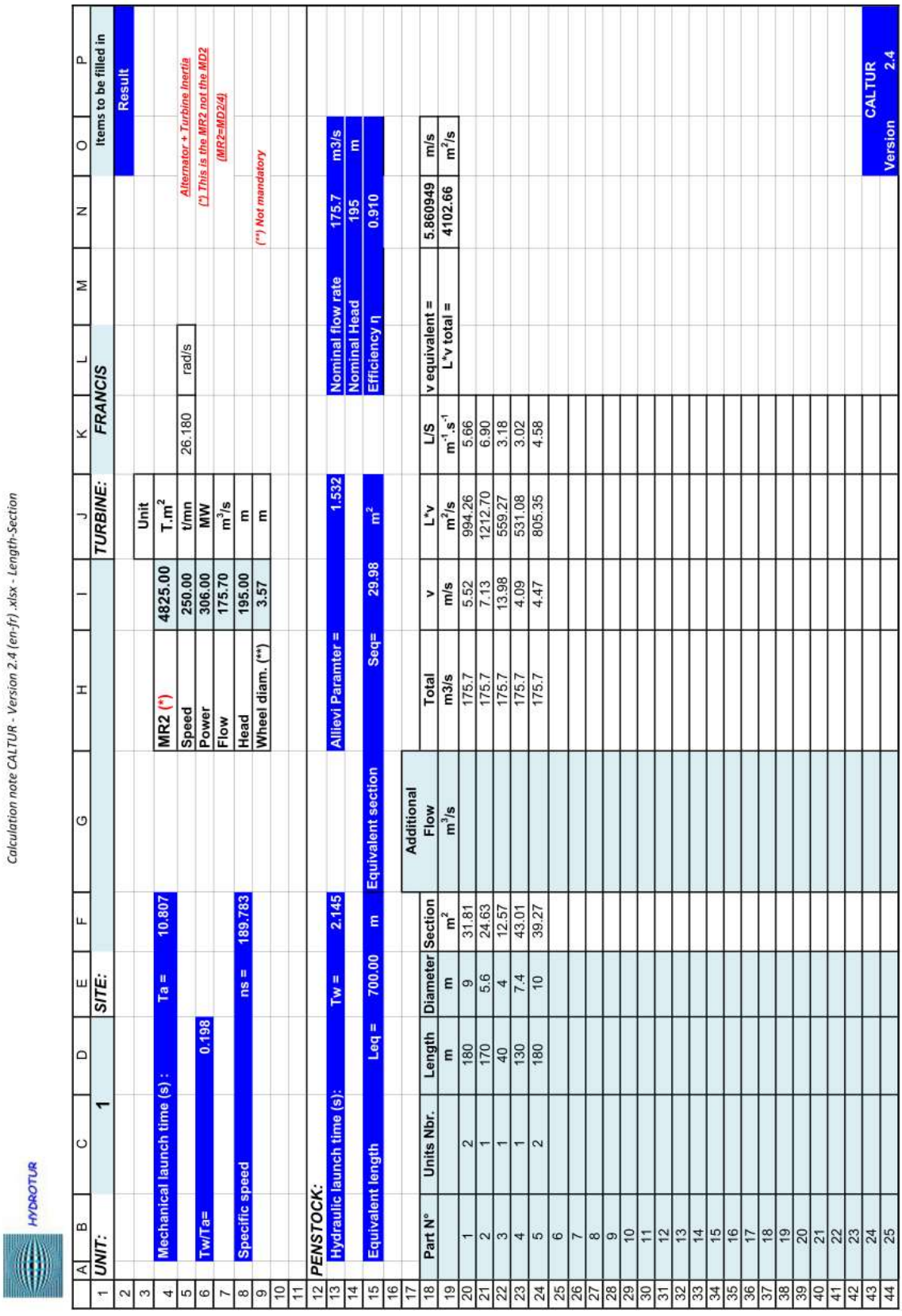


Figure 220 : Calculation note en/fr CALTUR.xlsx

B. JET DISPATCHER

B.1 DISPATCHER module diagram

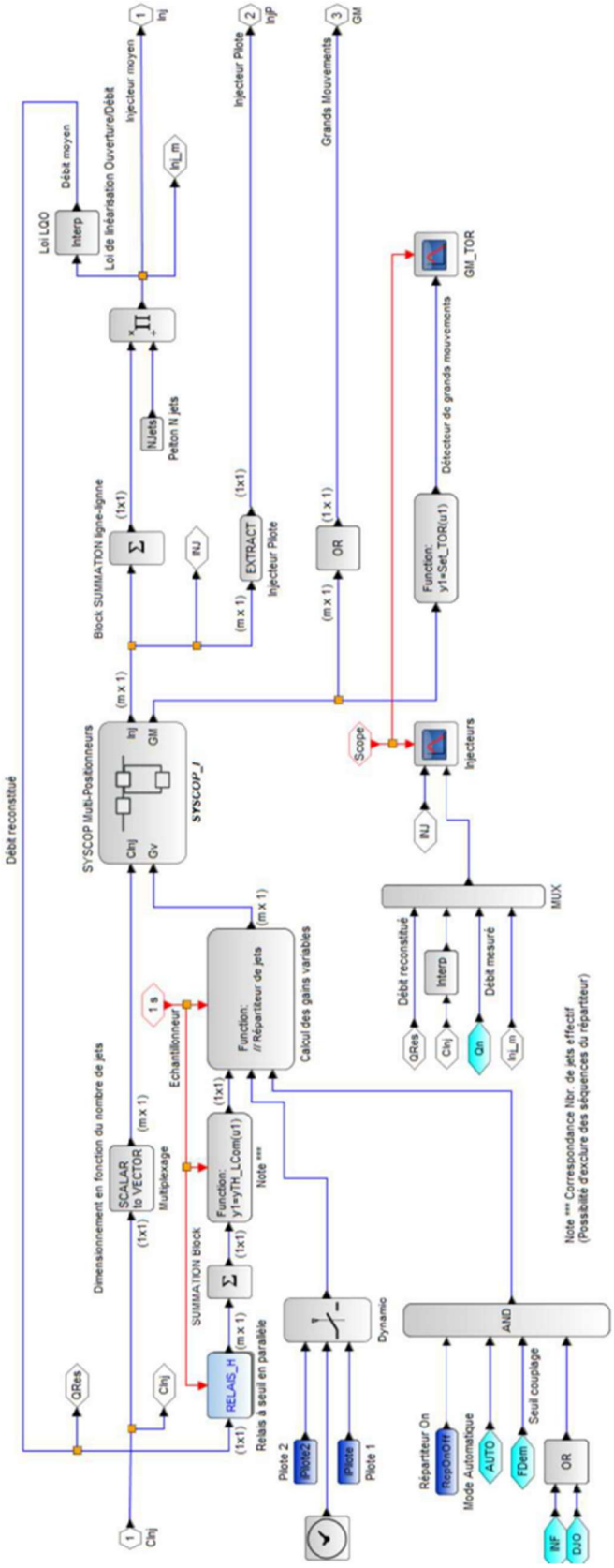


Figure 221 : DISPATCHER module diagram

B.2 Economic study of a jet dispatcher at the San Colombano plant (Italy)

This chapter consolidates, by an example, the study presented in **§ 5.2**

Figure 222 shows the monthly average statistics of a PELTON 5 jet group operated over 7 consecutive years at the San Colombano plant in Italy.

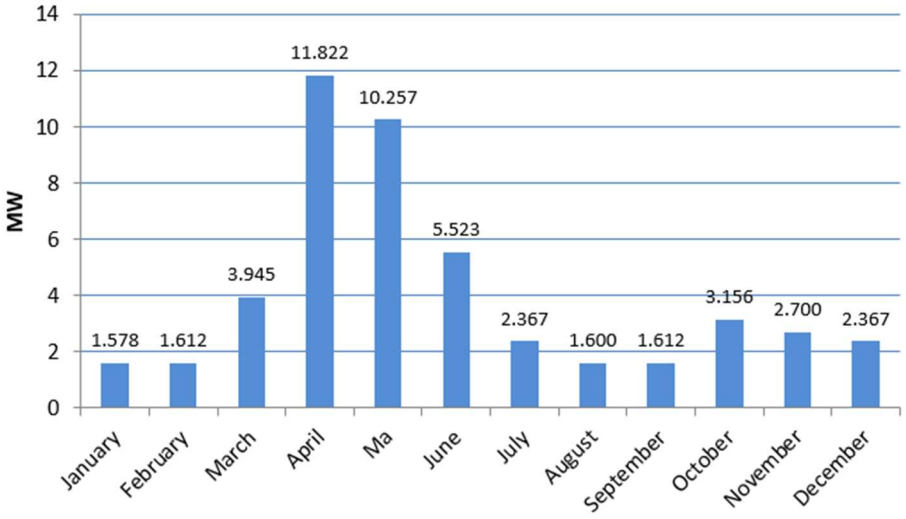


Figure 222 : Average turbine power over 7 years

The unit operates under a head of 382 m and provides a nominal power of 16 MW with a nominal flow rate of 4,787 m3/s.

The power supplied by a needle is therefore $\frac{16MW}{5}=3.2MW$

Figure 224 shows the machine performance curves as a function of the power and injectors to be engaged in the sequences.

In January, the group was operating at a power of 1.58 MW.

The efficiency for 1 jet operation is $\eta_1 = 87\%$, compared to an efficiency $\eta_5 = 78\%$ at the same power with 5 jet operation.

Either an optimized flow rate $Q_{n1} = 0.484 m^3 s^{-1}$ against $Q_{n5} = 0.54 m^3 s^{-1}$, or a water saving equal to approximately $(0.54 m^3 s^{-1} - 0.484 m^3 s^{-1}) * 3600 s * 24 h * 30 j \approx 145000 m^3$ for the month of January.

Figure 223 shows the gain obtained on the average flow rate per month, and the volume(s) of water saved are shown, because of the engagement or not (5 injectors in service) of the jet distributor.

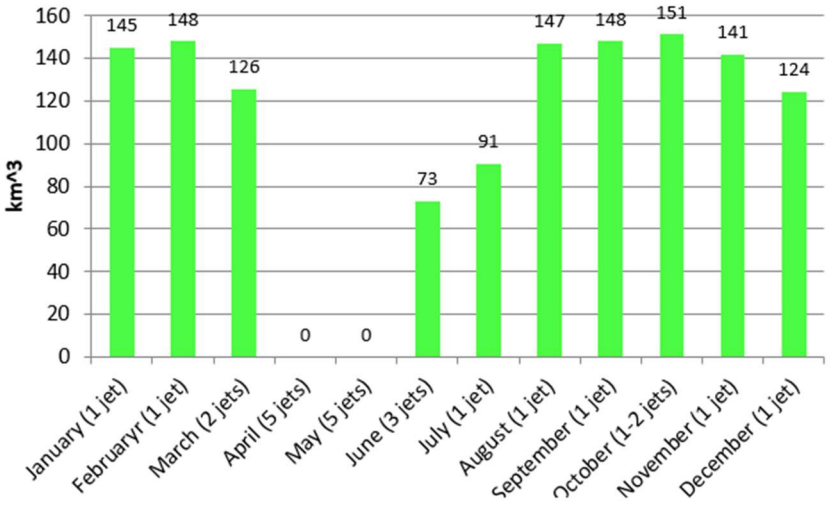


Figure 223 : Volume gains per year

During the spring period (snow melting), the unit is operated at around the nominal power, therefore at 5 jets, and there is of course no water saving in this time slot.

The volume of water saved per year would therefore be 1,294,000 m3, or:

$$\frac{1\,294000\ m^3}{2500\ m^3} \approx 517$$ **Olympic swimming pools**

$$1294000\ m^3 \text{ x } 4\ € \approx 5.2\ M€$$ **economic gain**

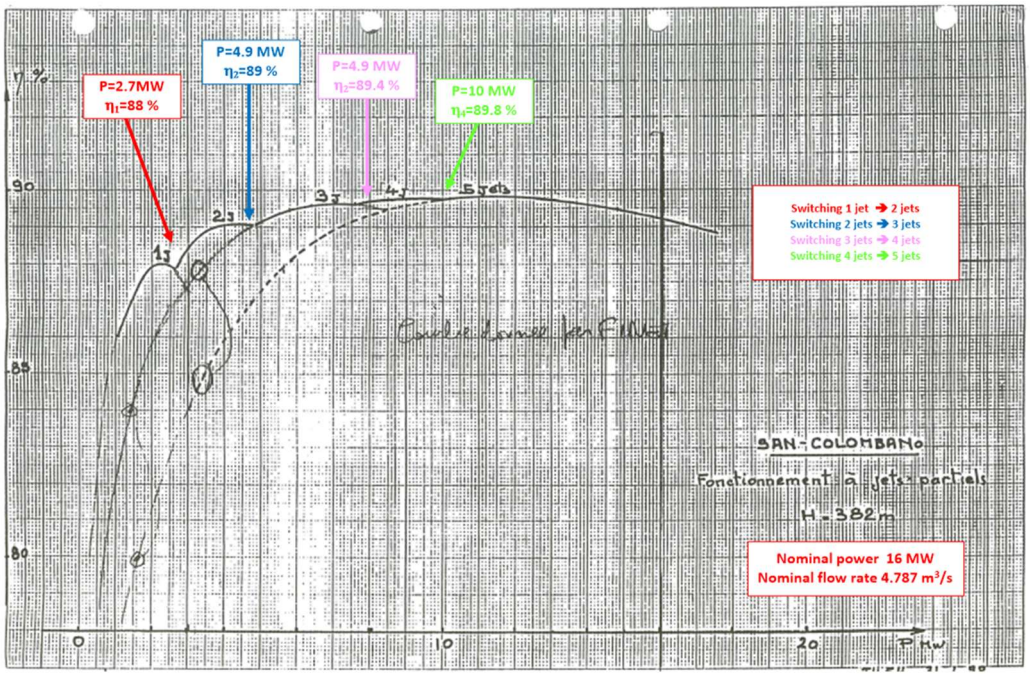


Figure 224 : Efficiency curves for the San Colombano plant (PELTON 5 jets)

Month	Turbine powers (MW)	Optimized flow rates (m^3/s)	Flow rate 5 jets (m^3/s)	Gain month / year (km^3)
January	1.578	0.484	0.540	145 000
February	1.612	0.494	0.551	148 000
March	3.945	1.183	1.231	126 000
April	11.822	3.513	3.513	0
Ma	10.257	3.048	3.048	0
June	5.523	1.647	1.675	73 000
July	2.367	0.726	0.761	91 000
August	1.600	0.491	0.547	147 000
September	1.612	0.494	0.551	148 000
October	3.156	0.962	1.021	151 000
November	2.700	0.819	0.873	141 000
December	2.367	0.718	0.766	124 000
			Total	1294 000

Figure 225 : Annual operating statistics data

B.3 Calculation of forces on a PELTON wheel - Vertical axis

The **PeltEff.xlsx** spreadsheet PeltEff.xlsx, shown below, is available in the **HydroSim\TURBINES\PELTON\Utilities** directory

HYDROTUR - HydroSim

PeltEff.xlsx

	A	B	C	D	E	F	G	H	I
1			Calculation of forces on a PELTON wheel 5 jets - Vertical axis						
2		Data Input				Opening (%)			
3	n	5	Number of jets	Needle 1	Needle 2	Needle 3	Needle 4	Needle 5	
4	Hn	1034	Nominal head (m)	60	0	60	0	60	
5	Qn	21	Nominal flow rate (m^3/s)	o_1	o_2	o_3	o_4	o_5	o_6
6	Vn	428.6	Nominal speed (tr/mn)						
7	D	3.1	Wheel diameter (m)						
8	g	9.81	Acceleration of gravity (m/s^2)		Resultant force ==>		226.964 kN		
9	ro	1000	Density of water (m^3/s)						
10									
11			Calculated constant	K=	612059.667				
12									
13				q_1	q_2	q_3	q_4	q_5	q_6
14			Flow rate per needle (m^3/s)	2.520	0.000	2.520	0.000	2.520	
15			Total flow rate (m^3/s)		qt	7.560			
16									
17				f_1	f_2	f_3	f_4	f_5	f_6
18			Force Fi exerted on the buckets (kN)	367.236	0.000	367.236	0.000	367.236	
19			Fix: Projection Fi in X (kN)	367.236	0.000	-297.100	0.000	113.482	
20			Fiy: Projection Fi in Y (kN)	0.000	0.000	215.856	0.000	-349.262	
21									
22			Fx: Module of X (kN)	183.618	Fx				
23			Fy: Module of Y (kN)	-133.406	Fy				

Figure 226 : PeltEff.xlsx Effort Calculation Excel Sheet

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