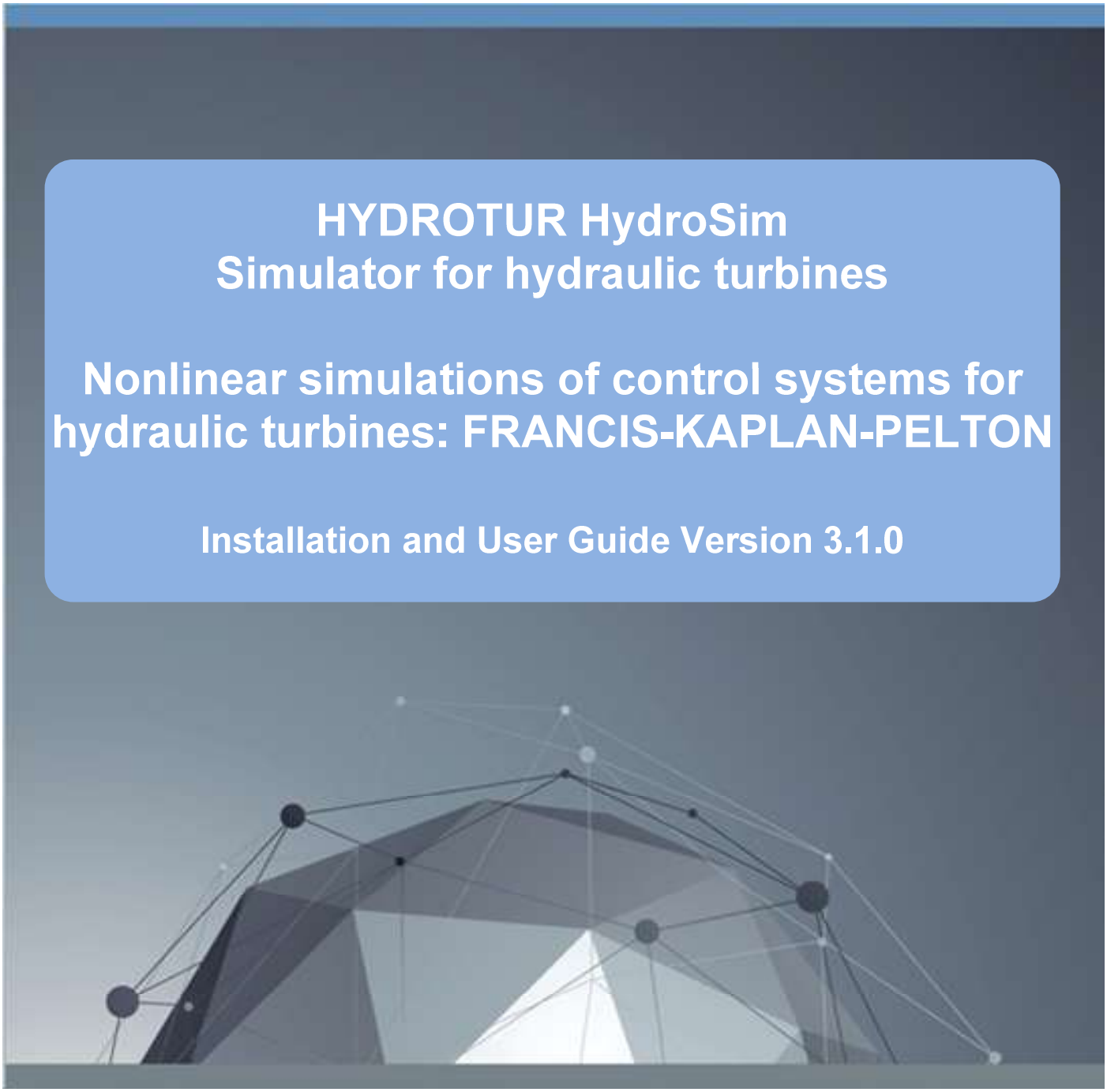


HYDROTUR

HYDROTUR HydroSim
Simulator for hydraulic turbines

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

Installation and User Guide Version 3.1.0



by Pierre Perrichon

Scilab

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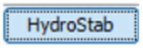
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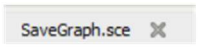
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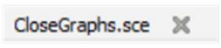
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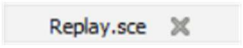
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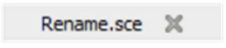
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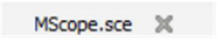
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Document type	References
Scilab Engineering	[1] [2] [3]
IEC normative references	[4] [5]
Scientific literature	[6]
University documents	[7] [8] [9]

TECHNICAL SUPPORT - CONTACT

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Automatique & Informatique industrielle

Projet HYDROTUR

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Figure 1 : Technical support for the HYDROTUR project

LIST OF HYDROTUR DOCUMENTS

Document Title
HYDROTUR – HydroSim - Installation and User Guide
HYDROTUR – HydroSim - Programming Guide
HYDROTUR – HydroSim - Schematic libraries of FRANCIS-KAPLAN-PELTON models and circuits
HYDROTUR – HydroStab Solution – Stability Studies – User Guide
HYDROTUR – HydroSim CALTUR- Calculation note CALTUR - Version 2.4 (en-fr) .xlsx
HYDROTUR – SEGPAL– Graphics components library for XCOS - Reference Guide

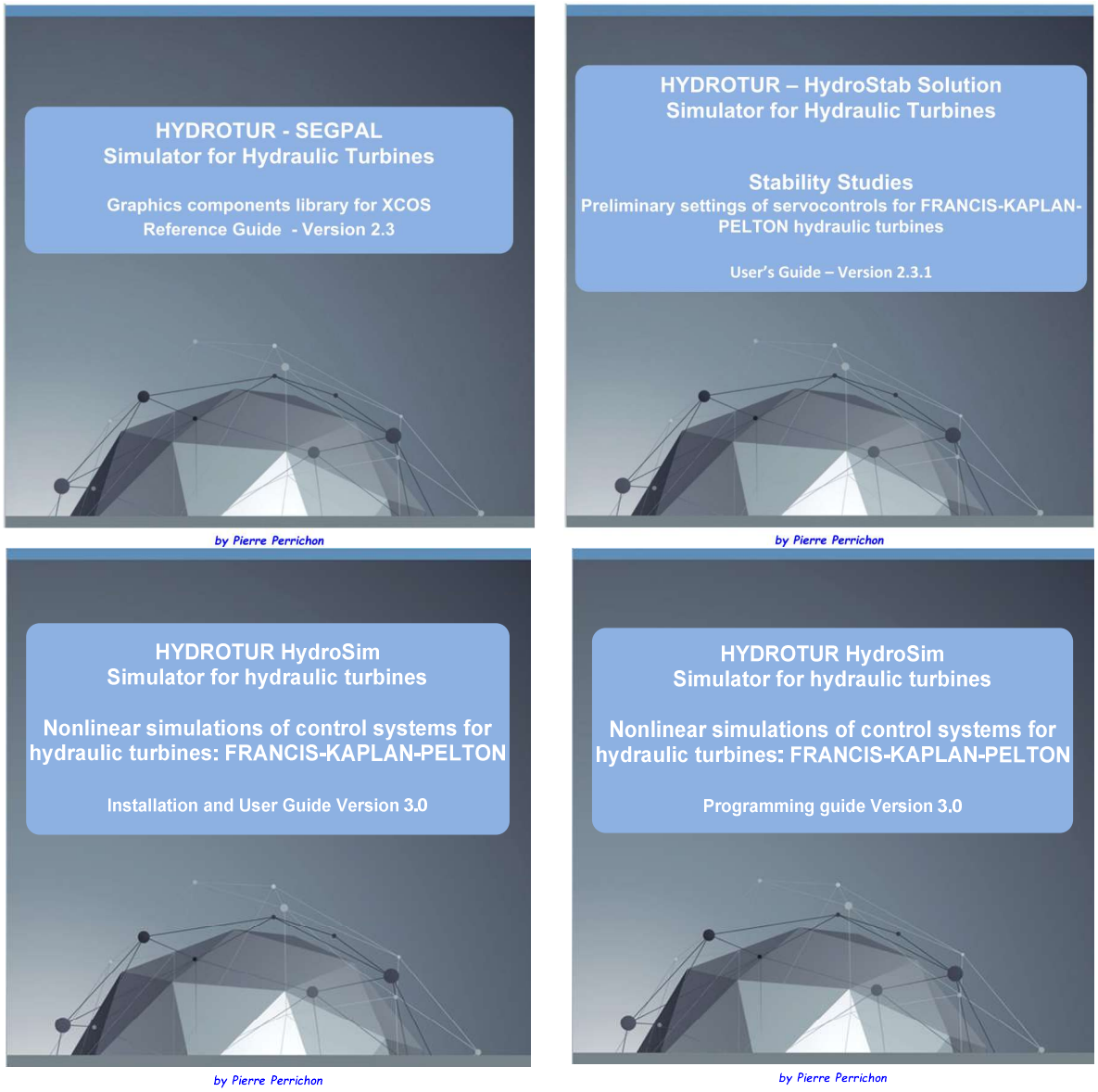


Figure 2 : List of main HYDROTUR documents

FOREWORD

The **HYDROTUR** product essentially brings together three software components created to help simulate rotating machines in the field of hydroelectricity, and is based on the study of hydraulic turbines of the FRANCIS, KAPLAN, PELTON type.

Thus, **HYDROTUR** includes the following products:

- **SEGPAL**, an extension library for the graphical components of Scilab-Xcos
- **HydroStab,** dedicated to calculating the stability of a speed regulator controlling a hydroelectric machine, and carried out with linear simulations in small motion of the processes to be analyzed.
- **HydroSim,** an extension of the **HydroStab** product, is characterized by non-linear simulations of the processes studied, in all operating modes of the turbines.

These components are written in the Scilab-Xcos environment, and are all available and downloadable as ATOMS library modules for Scilab.

1 INTRODUCTION

1.1 Presentation

The HYDROTUR-HydroSim project provides a set of new tools useful for the dynamic numerical simulation of hydraulic units driven by Francis, Kaplan, or Pelton machines. It includes detailed and robust models of speed control for rotating machines.

These programs are characterized by fully non-linear modelling across the entire operating range of the machines.

They can thus be used to simulate all start-up sequences, connection to the electrical network in an interconnected or isolated network, partial or 100% load shedding, normal shutdown of the group, on electrical or mechanical faults of the turbine.

HydroSim considers models with machine hills when available.

The project allows simulations of wave or mass rams depending on the case study and calculates the approximate pressure losses in the hydraulic conduits.

HydroSim integrates the simulation of the elements of a hydraulic turbine, in the form of XCOS diagrams:

- The turbine
- The hydraulic network supplying the turbine (water supply)
- The electrical grid
- The speed regulator and its system copying the servomotor(s)

HydroSim complies with international standards IEC 60308 and 61362 in the calculated results.

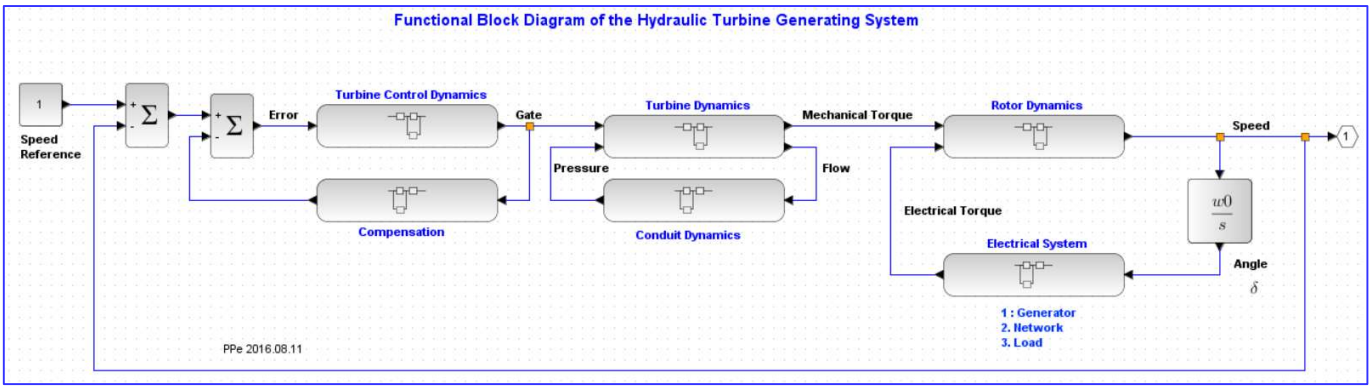


Figure 3 : General functional diagram of a hydroelectric control system

HYDROTUR is particularly well suited for technicians and engineers involved in studies, specific projects, or commissioning, in the aim to obtain secure preliminary calculations regarding the stability of control loops.

1.2 Terminology

Electro-hydraulic unit	An assembly consisting of a hydraulic turbine and an alternator coupled to the same shaft
Turbine	A device that converts hydraulic energy (kinetic energy of water under pressure) into mechanical energy (rotational torque of the shaft). It may be of the Pelton, Francis, Kaplan, or bulb type.
Alternator	A device that converts mechanical energy (rotational torque of the shaft) into electrical energy distributed on the grid.
Grid	The entire set of electrical circuits (transformers, transmission lines, etc.) and electricity consumers to which the group is connected
Hydraulic circuit	The set of components (penstocks, surge tanks, reservoir, vacuum) ensuring the circulation of water from the upper reservoir to the turbine and from the turbine to the lower reservoir.
Gross head	Difference in water level between the upper basin and the lower basin
Net head	Water pressure difference across the turbine terminals[1], i.e., between the tank outlet and the suction inlet for Francis, Kaplan, or bulb turbines, and between the injector inlet(s) and atmospheric pressure for Pelton turbines.
Adjustment device	A component used to control the flow of water sent to the turbine: a gate for a Francis turbine, an injector(s) for a Pelton turbine, or a gate-blade assembly for a Kaplan or Bulb turbine.
Copying system	An assembly whose function is to transform an electrical position command into a position of the control element. It consists of an actuator that transforms an electrical command into a pressurized oil flow, a distributor (if necessary) that amplifies the oil flow, a servomotor (controlled by the oil flow from the actuator or distributor) that drives the control element to the command position, a position measurement system that transforms the position of the servomotor or control element into an electrical signal, and an electronic control system responsible for generating the electrical command for the actuator based on the difference between the position command (from the speed controller) and the position measured by the sensor (*See Annex B*).

1.3 Limitations and restrictions of use

1.3.1 SEGPAL Additional Components Library

1.3.1.1 Principle

HydroSim's XCOS schemes include graphical components available in the **SEGPAL** graphics library.

[1] Rather than expressing this value in pascals or bars, the standard units of pressure, it is generally given in meters, which is the height of the liquid column required to create the same pressure. With water, this is measured in meters of water column (mWC), where ρ is the fluid density and ρ is the acceleration due to gravity.

For water (1000 kg·m-3 at 4 °C, and with the standard value of gravity (g = 9.80665 m·s-2), the conversion is as follows:

- 1 bar (105 pascals) corresponds to 10.1972 mCE;
- Conversely, 1 mCE corresponds to 98.0664 mbar.

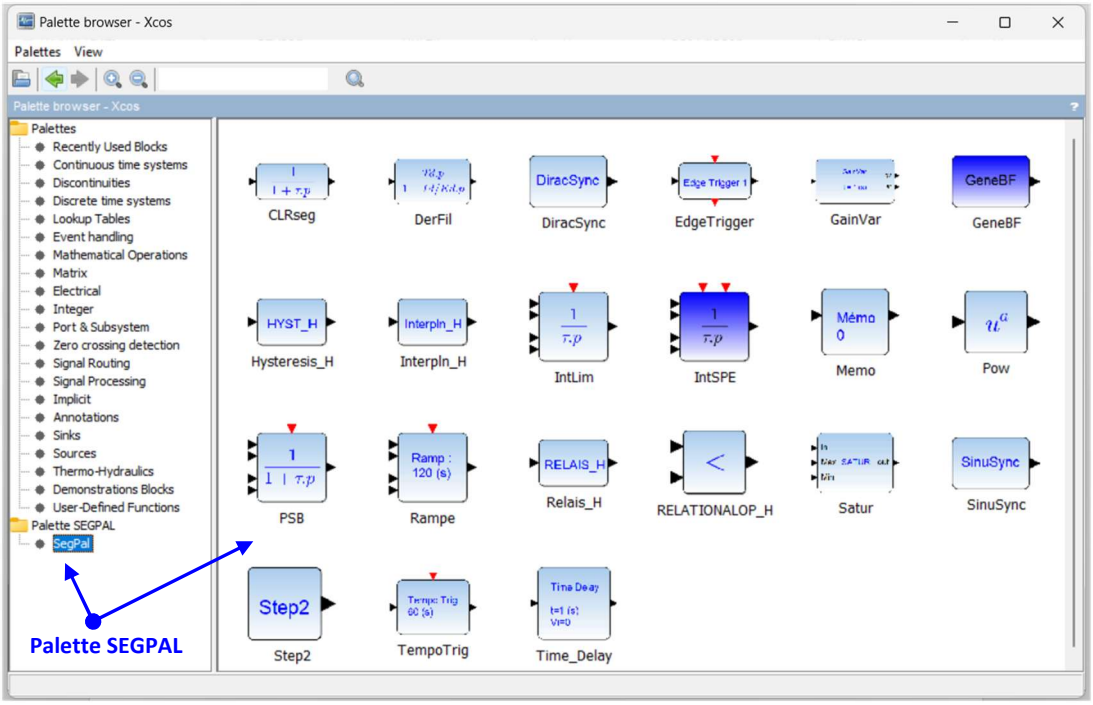


Figure 4 : Panoramic view of the additional components of the **SEGPAL** palette

1.3.1.2 Download

☞ **In this way, the installation of the ATOMS HYDROTUR-SEGPAL module is mandatory to run all simulations in HydroSim.**

To install SEGPAL, run the following command in the Scilab console:

Install command --> atomsInstall("SegPal")

The documentation "*HYDROTUR - SEGPAL - Reference Guide version 2.3.pdf",* contained in the directory "*SegPal\docs*", describes the operation of each of its components.

1.3.2 Stability studies of the HydroStab speed regulator under small movements

1.3.2.1 Presentation

HydroStab represents a functional box built in Scilab language, in the **HYDROTUR** software suite, and is dedicated to calculating the stability of a speed regulator controlling a hydroelectric machine of the FRANCIS, KAPLAN, PELTON type in small movements.

The user must provide the following input data to be entered into the HydroStab software:

- Gross or net head height of the structure (m)
- Equivalent pipe length[2] (m)
- Equivalent section of the pipe (m^2)
- Rated power of the machine (MW)
- Inertia $\mathbf{MR^2}$ of the Turboalternator group (T.m2) (Turbine + Alternator)

[2] Equivalent length and cross-section can also be obtained from the CALTUR.xlsx spreadsheet using the hydraulic diagram of the structure.

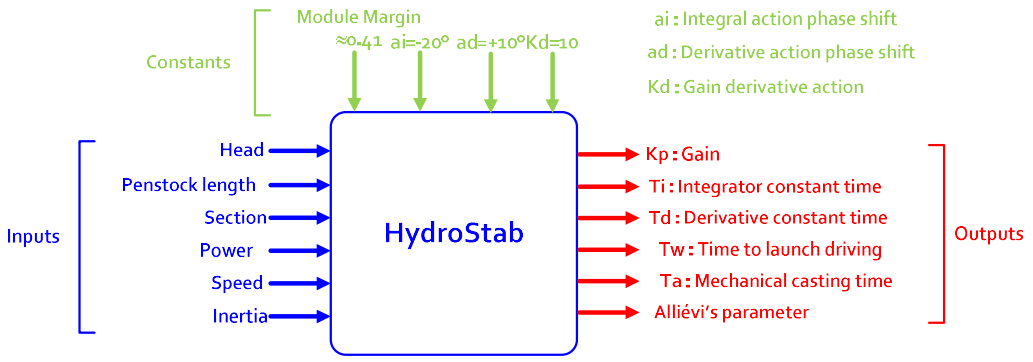


Figure 5 : Circuit for calculating the parameters of a Speed PID - Module Margin Method

HydroStab then calculates and provides the cruise control settings.

Different approaches are considered (Module Margin in the open-loop Nyquist plane, Ziegler-Nichols method, Takahashi method, etc.).

1.3.2.2 Principle – EXCEL CALTUR Spreadsheet

The **CALTUR Excel** spreadsheet, included in the **HYDROTUR** software (HydroStab or HydroSim), assists in this calculation of the equivalent length Leq and cross-section Seq of the reduced circuit of the hydraulic installation. (*see Appendix A)*

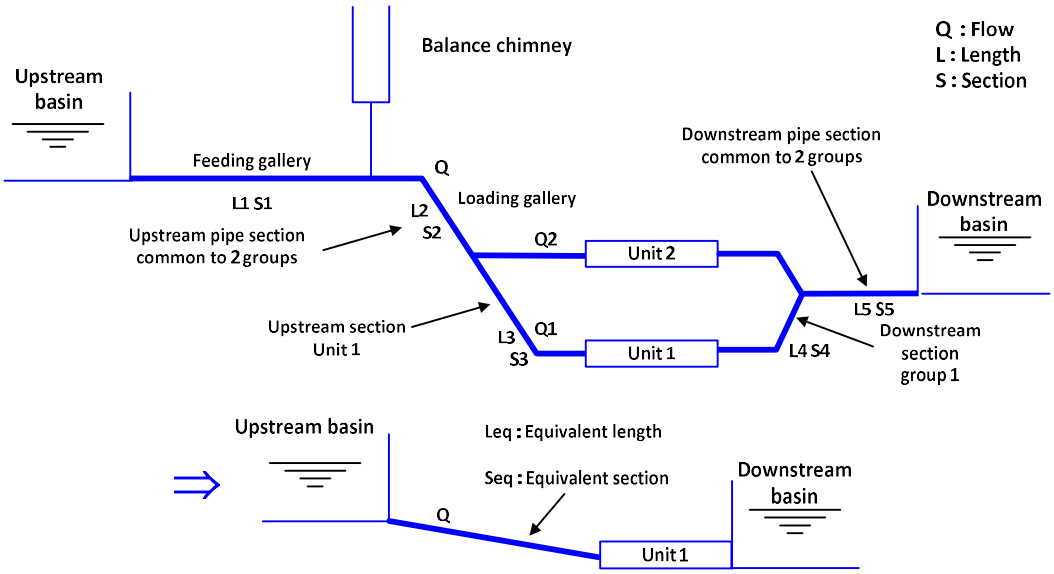


Figure 6 : Reduction of the hydraulic diagram - Preliminary calculations for the stability study of a hydraulic group

1.3.2.3 Download

HydroSim uses the text files with the suffix ".PAR" provided in the stability studies carried out with **HydroStab**.

☞ **In this way, the installation of the ATOMS HYDROTUR-HydroStab module is mandatory.**

To install HydroStab, run the following command in the Scilab console:

Install command --> atomsInstall("HydroStab")

The document "*HYDROTUR_HydroStab_Solution_User_Guide_Version_2.3.2.pdf*", located in the "*HydroStab\docs*" directory, describes the operation of this component.

1.3.2.4 Example of a stability study result in HydroStab in the Nyquist plane

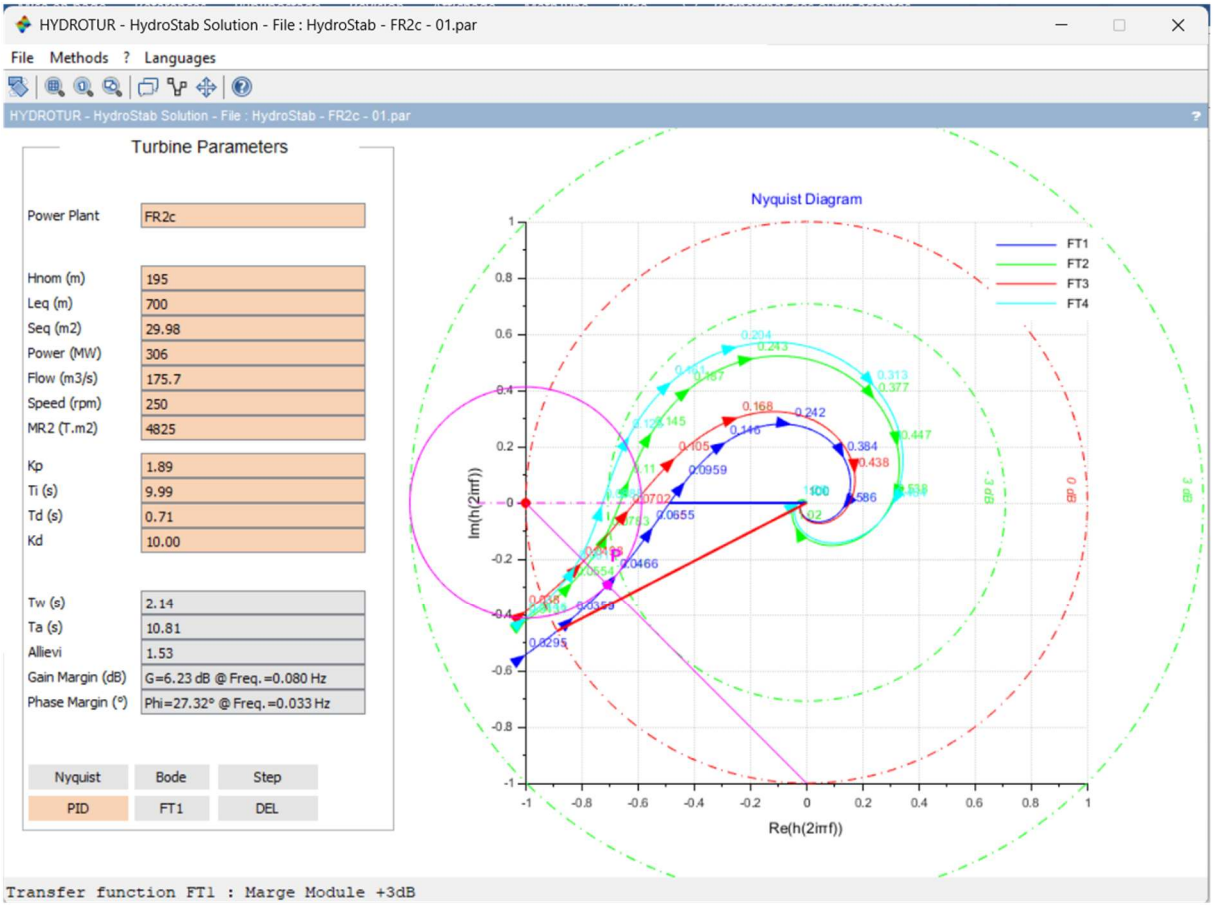


Figure 7 : Example of the result of a stability study in HydroStab in the Nyquist plane

```
TParam(1).Id="FR4 - Std";
TParam(1).Comment="Marge Module +3dB";

TParam(1).Hnom=83.400000;
TParam(1).Leq=197.370000;
TParam(1).Seq=120.760000;
TParam(1).Power=750.000000;
TParam(1).Flow=982.700000;
TParam(1).Speed=75.000000;
TParam(1).MR2=112500.000000;

Tsim(1).Kp=1.7600;
Tsim(1).Ti=9.2100;
Tsim(1).Td=0.6600;
Tsim(1).Kd=10.0000;
Tsim(1).Tw=1.9600;
Tsim(1).Ta=9.2500;
Tsim(1).rho=4.9700;
Tsim(1).k=0.020000;
Tsim(1).Ts=0.250000;
Tsim(1).aut=0.000000;
Tsim(1).Gain=1.000000;
Tsim(1).ty=0.100000;
Tsim(1).GMarge="G=6.52 dB @ Freq.=0.089 Hz";
Tsim(1).PMarge="Phi=27.20° @ Freq.=0.036 Hz";
```

Method

User data

HydroStab calculation

```
TParam(2).Id="FR4 - Std";
TParam(2).Comment="Ziegler-Nichols";

TParam(2).Hnom=83.400000;
TParam(2).Leq=197.370000;
TParam(2).Seq=120.760000;
TParam(2).Power=750.000000;
TParam(2).Flow=982.700000;
TParam(2).Speed=75.000000;
TParam(2).MR2=112500.000000;

Tsim(2).Kp=2.2600;
Tsim(2).Ti=6.2000;
Tsim(2).Td=1.2400;
Tsim(2).Kd=10.0000;
Tsim(2).Tw=1.9600;
Tsim(2).Ta=9.2500;
Tsim(2).rho=4.9700;
Tsim(2).k=0.020000;
Tsim(2).Ts=0.250000;
Tsim(2).aut=0.000000;
Tsim(2).Gain=1.000000;
Tsim(2).ty=0.100000;
Tsim(2).GMarge="G=3.72 dB @ Freq.=0.108 Hz";
Tsim(2).PMarge="Phi=20.82° @ Freq.=0.053 Hz";
```

Method

User data

HydroStab calculation

Figure 8 : Extract from a ".PAR" file generated by HydroStab

2 SUPPLY

2.1 HydroSim Installation

The **HYDROTUR-HydroSim** project is provided from a "HydroSim.zip" file, which must be unzipped. First, refresh the Atoms modules in the PC database by typing "**atomsSystemUpdate()**" in the Scilab console.

The package can be installed in different ways:

1. By entering the command **atomsInstall("HydroSim") in** the Scilab console (recommended method)
2. Using the Scilab ATOMS module installer by pointing to **HYDROTUR-HydroSim** in the "**Xcos**" module[3]
3. Manually, by placing and extracting the ZIP file into a user-defined directory, such as "HYDROTUR\HydroSim\" for example, and downloaded from the website **https://atoms.scilab.org/toolboxes/HydroSim/**

Figure 9 : Different methods of installing HydroStab

☞ **In Automatic Installation mode, the HydroSim package files are installed in the system's Roaming folder.**

The exact location can be found by typing the command SCIHOME in the Scilab console.

You can also enter the command chdir(SCIHOME) to access this directory directly.

Then access the atoms directory using the Scilab file browser by double-clicking.

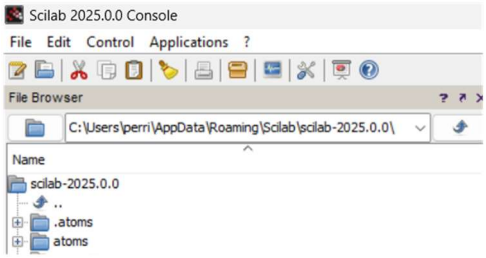


Figure 10 : HydroSim automatic installation directory

☞ More directly, launching HydroSim with the **Run_HydroSim** command creates a variable **SCI_HydroSim** allowing you to point directly to this directory, accessible with the online command **chdir(SCI_HydroSim).**

The installed package includes the following subdirectories:

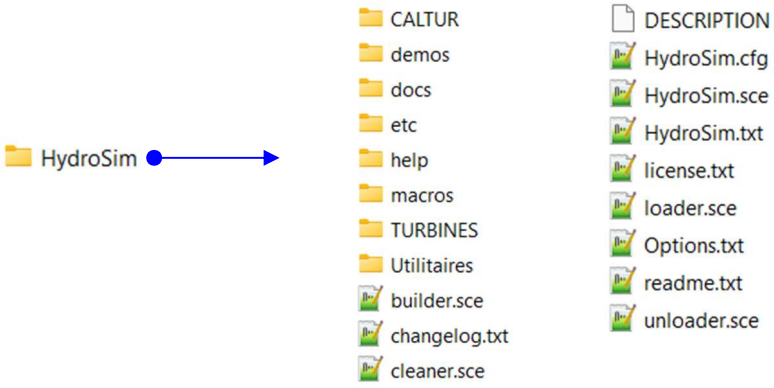


Figure 11 : Unzipping the HydroSim.zip file

The documents "*HydroSim_Installation_and_User_Guide_Version_3.0.pdf*" and "*HydroSim_Programming_Guide_Version_3.0.pdf*" located in the "*HydroSim\docs*" directory, describe the product.

HYDROTUR-HydroSim is supplied with all the source codes of the software components which constitute it, whether they be Scilab codes, XCOS regulation diagrams, machine hill traversal routines, C/C++ code, ".xls" and ".cfg" parameterization files…etc.

[3] In this case, enter "**atomsGui**" in the Scilab console and access the "**Xcos**" entity.

Only documentation files, created in WORD, are provided in ".PDF" format.

HydroSim.zip can be extracted to any directory tree or subdirectory of the user's machine.

Directory or File	Content
CALTUR	Spreadsheets (French-English) in Excel xlsx format *(see § §1.3.2, **Erreur ! Source du renvoi introuvable.**)* • Calculation of the equivalent length and section of a hydraulic circuit
demos	Examples of projects completed using HydroSim – FRANCIS-KAPLAN-PELTON turbines with 1 to 6 needles.
docs	• HydroSim documentation in French and English, in ".pdf" format
etc	Initialization (HydroSim.start file) and finalization (HydroSim.quit file). Scripts used in loading the HydroSim module (loader.sce) or unloading it (unloader.sce)
help	• Help files in XLM format divided into subdirectories in French (fr) and English (en) • Collection of images used in the online help for the components (subdirectory "gui") • ➔ **will be developed in a future version.**
macros	Macros (Files « .sci ») All source files written in Scilab language
TURBINES	The complete set of simulated XCOS models (schematic libraries) in "zcox" format, used in HydroSim, with documentation in "pdf" format. • FRANCIS Turbines Modeling • KAPLAN Turbines Modeling • PELTON Turbines Modeling
Utilitaires	The complete set of tools and commands used in manipulating HydroSim command files. These files, in ".sce" format, are automatically loaded into the "SciNotes" editor when HydroSim is launched.
builder.sce	Main builder of the HydroSim module
changelog.txt	HydroSim version change history
cleaner.sce	Deleting compiled ".bin" files in the "macros" directory. Use this with any rebuild using the "builder.sce" utility.
DESCRIPTION	Brief description of HydroSim. Used in case of local HydroSim loading.
HydroSim.cfg	HydroSim startup settings (Language, Automatic loading of ".sce" project files into Scinotes)
HydroSim.sce	HydroSim launch. HydroSim's main entry point. Do not edit this file.
HydroSim.txt	Collection of texts used in the HydroSim software. French and English languages
licence.txt	Declaration of conformity to the CeCILL license Version 2.1
loader.sce	Loading HydroSim. This file is created automatically when the HydroSim library is regenerated using the "builder.sce" constructor.
Options.txt	This file is reserved for managing the masking of digital oscilloscopes. HydroSim. Do not edit this file.
readme.txt	Recommendation for installing HydroStab on the computer
unloader.sce	Unloading HydroSim into the Scilab platform. This file is automatically created when the HydroSim library is regenerated using the "builder.sce" constructor.

Figure 12 : Contents of the HydroSim directory

2.2 HydroSim launch

HydroSim starts by launching the script "**Run_HydroSim.sce**" in the **SciNotes** window.

- In automatic mode, this file is displayed in the SciNotes window as soon as scilab starts (ATOMS module)

- If HydroSim was extracted to a user directory (manual installation), execute the following instructions in the scilab console:

No line	Scilab instructions	
1	DirectoryHydroSim="C:\HYDROTUR\HydroSim\"	// Set HydroSim directory
2	exec(DirectoryHydroSim + "loader.sce")	// Load HydroSim
3	exec(DirectoryHydroSim + "\etc\Run_HydroSim.sce")	// Run HydroSim

Figure 13 : Scilab instructions for launching **HydroSim** in manual mode

The user must modify line 1 to specify the HydroSim installation directory

☞ These three instructions can be copied or added to the Scilab startup scilab.ini file, located in the **SCIHOME** directory, for automatic launch when Scilab is opened.

```
--> exec(DirectoryHydroSim + "\etc\Run_HydroSim.sce")                    // Run HydroSim

--> // Run this script to start HydroSim

--> //-------------------------------------


--> HydroSim="C:\HYDROTUR\HydroSim\HydroSim.sce";

--> SCI_HYDROTUR_HydroSim="C:\HYDROTUR\HydroSim\";

--> VersionHydroSim="3.0.1";

--> exec(HydroSim,-1)

SCI_HydroSim = C:\HYDROTUR\HydroSim\

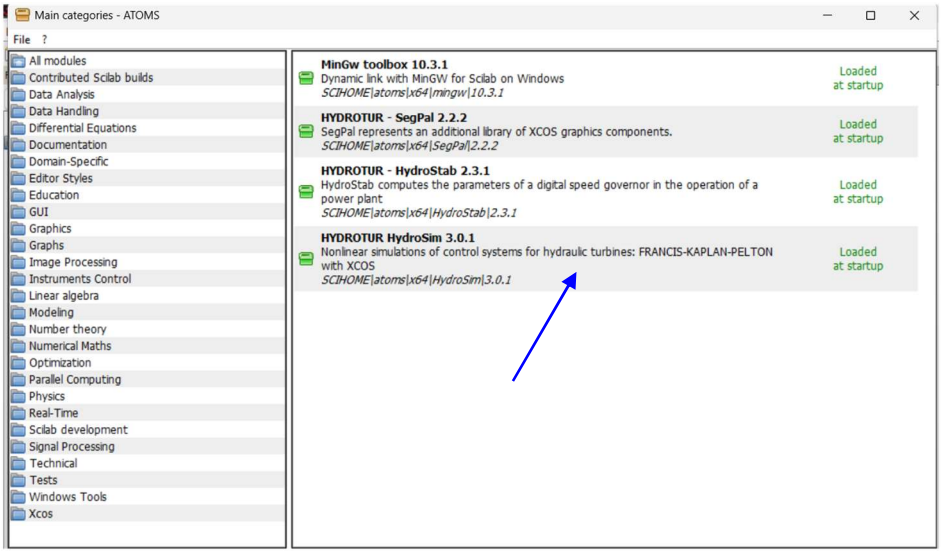
...Automatic load : FR2c.sce
...Automatic load : FR4c.sce
...Automatic load : FR5c.sce
...Automatic load : KB1c.sce
...Automatic load : Pelt4c.sce

SCI_HydroSim_TURBINES = C:\HYDROTUR\HydroSim\TURBINES\
HydroSim Version = 3.0.1
```

Figure 14 : Scilab console after starting HydroSim

2.3 Uninstalling HydroSim

- If HydroSim was installed as an ATOMS module of Scilab, uninstallation is performed by running the **atomsGui()** command in the Scilab console.



Then click on the HydroSim module and uninstall it by clicking the **Remove** button. Then restart Scilab.

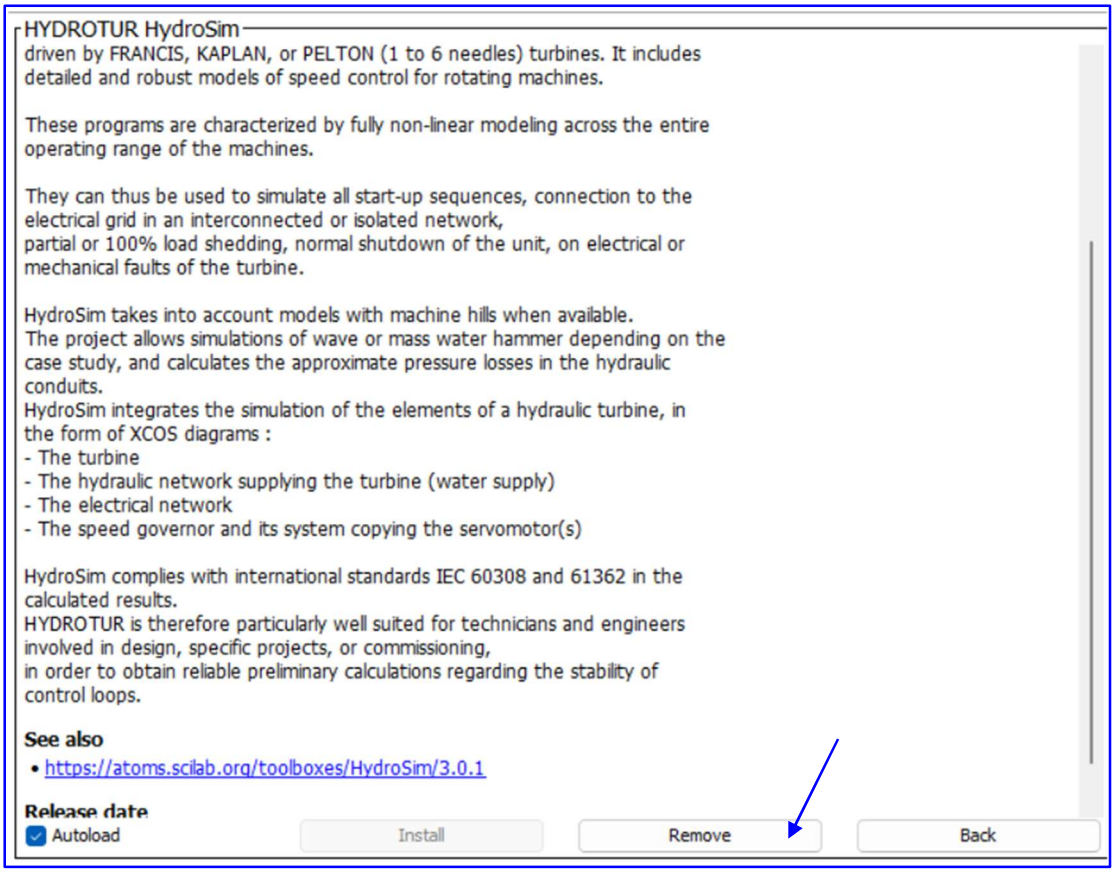


Figure 15 : Uninstalling HydroSim

- If HydroSim was loaded into a user directory, remove the module launch instructions and destroy the directory.

3 CONSTRUCTION AND LOADING OF HYDROSIM TOOLBOXES IN SCILAB

3.1 Prerequisites

The source code for the executive is entirely written in Scilab language, and is available in the **HydroSim\macros** directory.

Therefore, no prerequisites are necessary for its use.

3.2 The builder "builder.sce"

The script **builder.sce** file, located in the HydroSim directory, creates the HydroSim library and provides all the files necessary for its use:

- Compilation of all ".sci" macros associated with the macros subdirectory of HydroSim\macros

In addition, the builder.sce constructor provides and adds the following files to the HydroSim directory:

1. clearner.sce — Cancels and deletes all ".bin" object files created by the builder.sce constructor.
2. loader.sce — Loading the HydroSim library into Scilab.
3. unloader.sce — Unloading the HydroSim library into Scilab

3.3 The loader « loader.sce »

3.3.1 Loading

The loader **loader.sce** is created by the builder builder.sce, as indicated at *§3.2*

Running this script loads the **HydroSim** library into **Scilab.**

In the case of an automatic installation of HydroSim, the "loader.sce" file is launched automatically when Scibab is opened.

☞ **In the case of manual installation (case no. 3, see Figure 9), the charger must be started by the operator before using HydroSim.**

The Scilab console displays a list of operations performed:

```
--> exec('C:\PPe\0 - Scilab\0 - Xcos8\0  - Test\HydroSim\loader.sce', -1)
Start HydroSim 3.0.0 : Simulator for FRANCIS, KAPLAN, PELTON turbines
        Load macros
        Load help

...Run the "Run_HydroSim" script in the SciNotes window to start HydroSim

-->
```

Figure 16 : Example of loading the HydroSim library into Scilab – Using the loader.sce file

As shown in the figure above, the operator launches a HydroSim session by executing the "**Run_HydroSim**" script in the SciNotes part of Scilab.

3.3.2 Global variables due to the launch of HydroSim

The execution of the "**Run_HydroSim**" script loads all the compiled macros, and creates a global variable **SCI_HydroSim,** available throughout the HydroSim usage session.

```
--> SCI_HydroSim

 SCI_HydroSim =

  "C:\0 - Test\HydroSim\"

-->
```

Figure 17 : **SCI_HydroSim** environment variable

This variable points to the HydroSim installation directory.

3.3.3 Additional tooling due to the launch of HydroSim

The execution of the "**Run_HydroSim**" script also loads, in the SciNotes editor, a set of scripts allowing the execution of turbine models, and the manipulation of graphic files from the simulations.

These commands are in the directory HydroSim\Utilitaires :

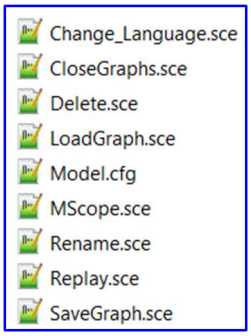


Figure 18 : HydroSim tools in the "Utilities" directory

These tools are described later in this document. (*see §4.3*)

3.4 Scilab navigation advice

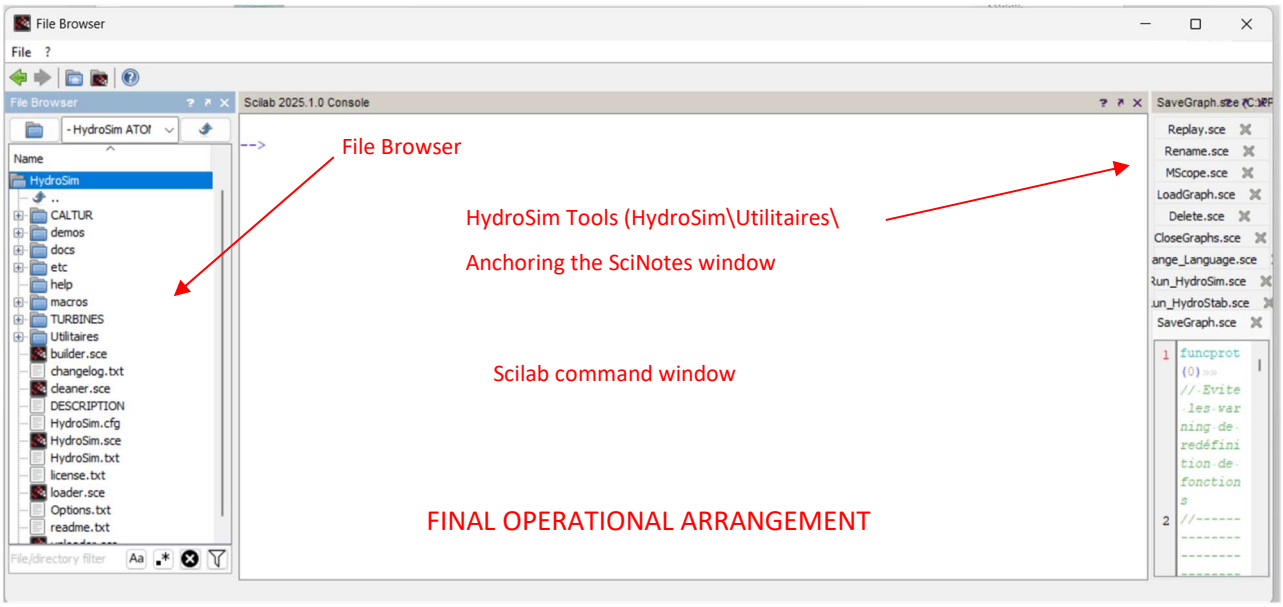


Figure 19 : Recommended navigation in Scilab for manipulating HydroSim

The user can arrange the Scilab console as described in the figure above, which is the most operational arrangement for carrying out the operations to be performed with satisfactory ergonomics.

3.5 Starting HydroSim – HydroSim.cfg file

The “HydroSim.cfg” file is executed at each HydroSim startup and defines the language used throughout the entire user session.

It can also contain operator instructions for loading project files into the Scinotes editor:

```
// Choix du langage
//-----------------
lang=2

// Chargement automatique de fichiers "sce" dans l'éditeur scinotes
//-----------------------------------------------------------------
mprintf("\n")
Load_scinotes(SCI_HydroSim + "demos\FRANCIS\FR2\Standard\FR2c.sce")
Load_scinotes(SCI_HydroSim + "demos\FRANCIS\FR4\Standard\FR4c.sce")
Load_scinotes(SCI_HydroSim + "demos\FRANCIS\FR5\Standard\FR5c.sce")


Load_scinotes(SCI_HydroSim + "demos\KAPLAN\KB1\Standard\KB1c.sce")

Load_scinotes(SCI_HydroSim + "demos\PELTON/Pelt4\Standard\Pelt4c.sce")
mprintf("\n")
```

Figure 20 : Example HydroSim.cfg startup file

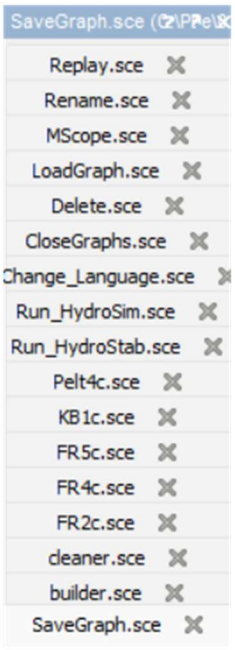
In the figure above, and using the "**Load_scinotes**" instruction of HydroSim, the FR2c, FR4c, FR5c, KB1, Pelt4c projects will be automatically loaded into the Scinotes editor.

The user can modify this file by deleting the "Load SciNotes" lines or commenting them out, and program other automatic loads by specifying the name and path of the sce files.

A report is displayed in the Scilab console when a session is launched:

```
SCI_HydroSim = C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\

...Automatic load : FR2c.sce
...Automatic load : FR4c.sce
...Automatic load : FR5c.sce
...Automatic load : KB1c.sce
...Automatic load : Pelt4c.sce
```



Files in the Scinotes editor

4 USER GUIDE

4.1 XCOS Modeling Circuits

4.1.1 Available Models

Available ☐ Forecast

Turbine type	Directory Name / zcos Template	Features
FRANCIS	FR2 **FR2.zcos**	Turbine and pipe modelled according to analytical formulas
	FR4 **FR4.zcos**	Turbine and water supply modelled using machine hills, Interpolation and extrapolation on torque and flow **(q11,c11)=F(N,O)**
	FR5 **FR5.zcos**	Turbine and water supply modelled using machine hills Interpolation and extrapolation on torque and flow **(q11,c11)=F(Arctg(φ),O)**
KAPLAN	KB1 **KB1.zcos**	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
PELTON **(HYDROTUR Scilab 6 :** **A single XCOS PELTON.zcos diagram Now covers all PELTON models.**	PELT1 **PELTON.zcos**	Horizontal-axis PELTON turbine, 1 injector and 1 deflector Deflector following the pilot injector Turbine and pipe modelled using analytical formulas
	PELT2 **PELTON.zcos**	Horizontal-axis PELTON turbine, 2 injectors and 1 deflector Deflector following the pilot injector Turbine and pipe modelled using analytical formulas
	PELT3 **PELTON.zcos**	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.zcos**	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.zcos**	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.zcos**	Pelton 6 jets, vertical axis, with or without jet dispatcher. Deflectors following the pilot injector. Turbine and pipe modelled according to analytical formulas

Figure 21 : List of available models and algorithms

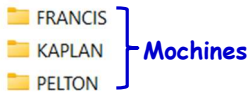
The available models are presented as a graphic file in "XCOS" format, and are available in the "HydroSim\TURBINES" directory.

A copy of each model is available in "pdf" format in the same directory.

☞ A ".zcos" file cannot be directly executed under XCOS, because each simulation requires prior loading of an execution context, defined in text files in "sce" or ".cfg", format, as described later in this document.

4.1.2 Models layout

The **HydroSim\TURBINES** directory contains all the models produced as part of the HydroSim supply.



Of course, it is possible to create new models for all types of machines, while respecting some basic construction rules and conventions.

The list of available models and algorithms has been presented in *Figure 21* of this document.



Figure 22 : Access to simulation models

This device is a generic structure common to all models.

4.1.3 Description of a turbine model using XCOS

A model consists of an XCOS file, associated with a dedicated CTX execution context, a text file written in Scilab language, and editable under a text editor (NotePAD++ for example), and an editable xxx_Loader.sce text file.

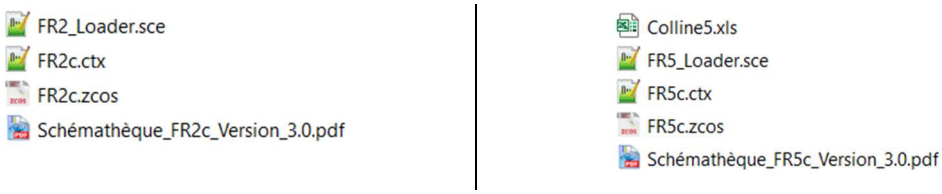


Figure 23 : Context of the XCOS FR2 and FR5 models in the HydroSim\TURBINES directory

☞ The CTX file performs the preliminary calculations for the execution of any XCOS file in the HydroSim suite (internal variables, model linearization, etc.)

☞ The xxx_Loader.sce file allows the automatic loading of files contributing to the launch of the simulation with the selected model, and launches the simulation.

☞ For the FR4 and FR5 models, a "Colline.xls" file defines the **default machine hill** used in the case of a simulation launched with these models.

4.1.4 General structure of an XCOS model

Opening an XCOS file reveals the general architecture of the simulated model, and the main generic functions developed, or sub-models, defined within that model. (*also see Appendix D*).

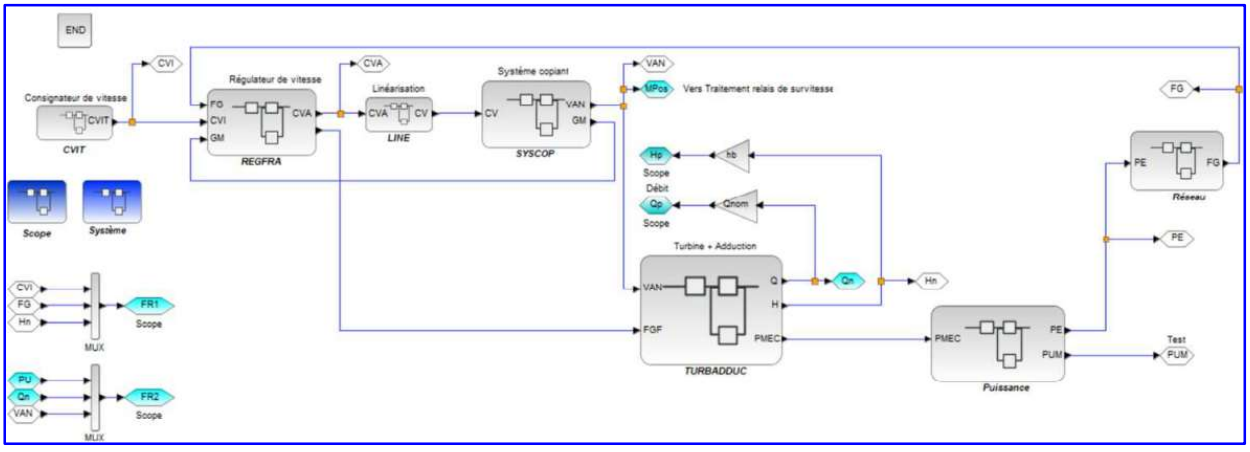


Figure 24 : Example of FR5 model architecture

A submodel is accessed by double-clicking on its functional box.

Here you will find the sub-models:

Submodel	Meaning
CVIT	Hydraulic unit speed controller
REGFRA	Speed governor
LINE	System linearization
SYSCOP	Copying system – Servomotor position controller
TURBADDUC	Water Supply Turbine – Hydraulic Circuit
Puissance	Power setpoint transformation
Reseau	Electrical network modelling
Scope	All the digital scopes associated with the model
Système	Intermediate variables in the simulation

A representation of a model can thus be summarized as a single-line diagram containing all the subsystems included in the general diagram:

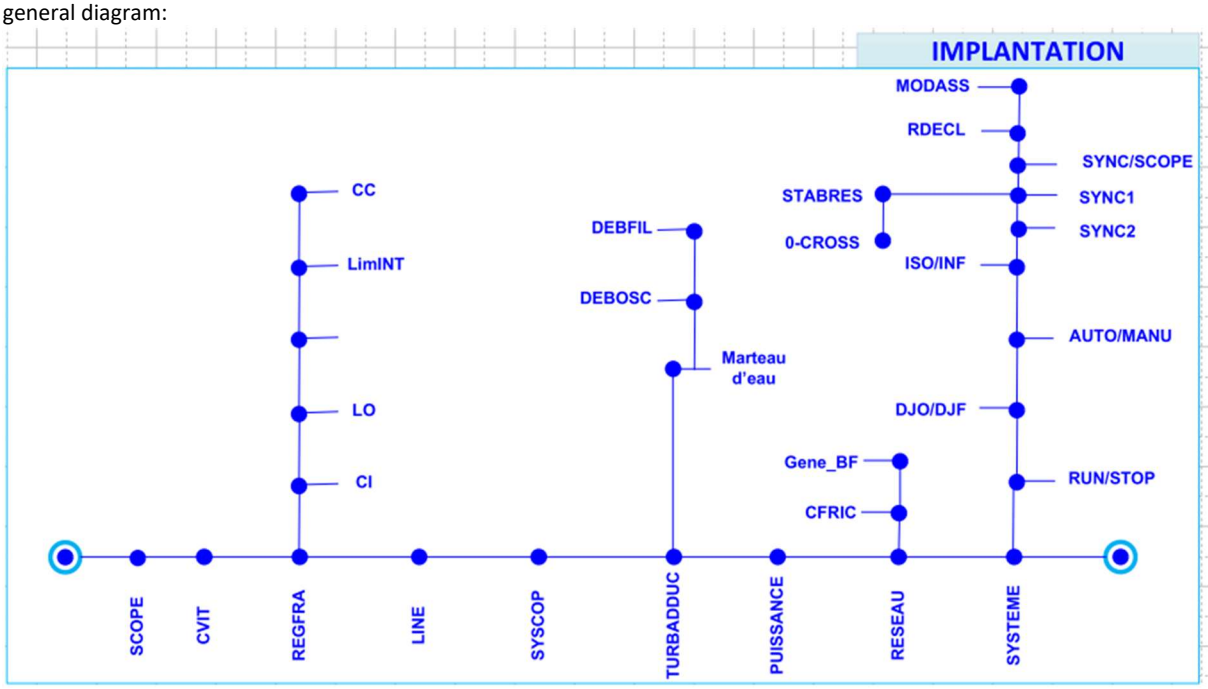


Figure 25 : Example of Functional Blocks – Single-line diagram of the FR5 circuit with machine hills

This single-line diagram is presented in all schematic libraries in "pdf" format associated with the simulated models.

4.1.5 Version of the calculation circuit ". zcos »

The version of the calculation circuit is accessible in the Xcos file:

- Open the Xcos file
- In the menu bar, click on the "**Simulation**" function, then select "**Edit Context**"

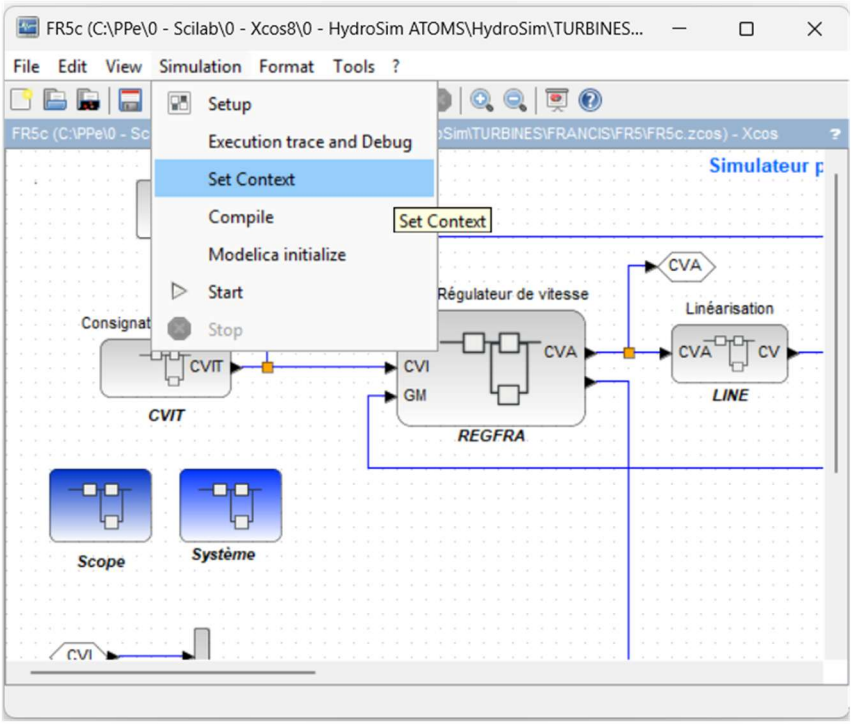


Figure 26 : Modification of the simulation context

- The circuit version can then be modified in the displayed window.

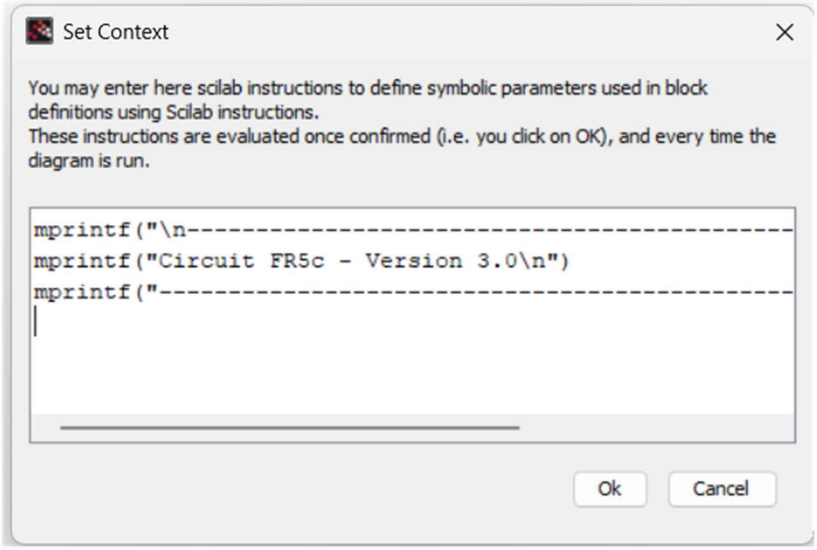


Figure 27 : XCOS file execution context – Calculation circuit version

4.2 Launching a simulation

4.2.1 Foreword - HydroSim\demos Directory

The "HydroSim\demos" directory contains simulation examples performed for all embedded models, presented in *Figure 21*.

The subdirectories that qualify a simulation are structured in a similar way:

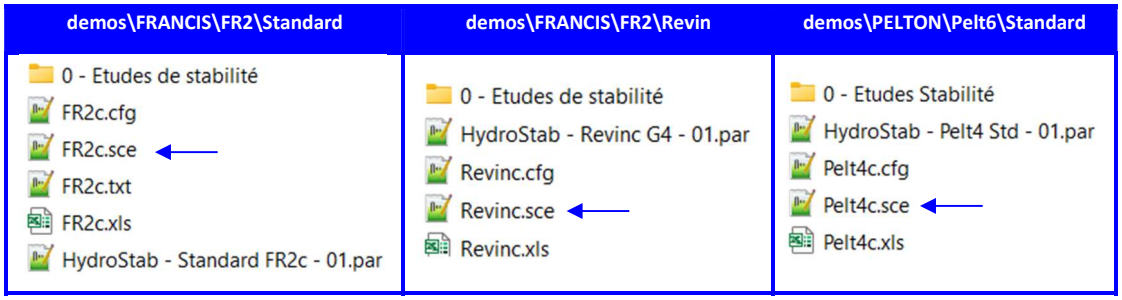


Figure 28 : General structure for configuring simulators

- The "*Stability Studies*" directory contains a set of tests carried out with the model in question, its parameterization, and the generated sequences.

  A test kit is included in the HydroSim\Utilities directory, and can be copied and/or modified by the operator:

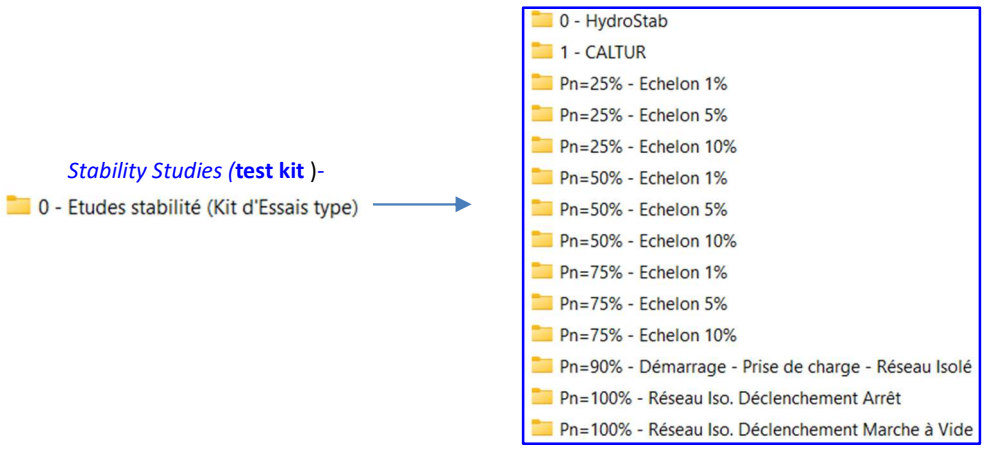


Figure 29 : Typical simulator characterization test kit

- The ".cfg" file represents the descriptor of the simulation sequence to be executed. It also contains the site's hydraulic parameters and the parameters used in the group's stability study.

  This file can be automatically modified via the "**RUNNER**" invoked each time a "sce" file is launched.

- Executing a ".sce" file launches a "RUNNER" program that allows you to modify the desired simulation sequence or the control parameters. (*see §4.2.2*)

- The ".txt" file is an optional text file containing all simulation parameters. It is generated at the start of the simulation based on the internal variable bDelTx=0 in the "**VariablesGlobales.sce**" file. (*see bDelTx in document «HydroSim_Programming_Guide_Version_3.0 »*)

- The ".xls" file contains constant parameters for a given site. Generally, this file should be defined only once and should remain unchanged in all simulations, regardless of the sequence involved (generator start-up, load steps, load shedding, etc.).

- The file "*HydroStab - xxx.par*" 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. (*See Figure 8*)

☞ Examples of files are shown in *Annex C*

4.2.2 Running a ".sce" file - Activating the "HydroSim RUNNER" driver

A simulation is launched from a "sce" file contained in the tree structure of a *HydroSim\demos* site directory.

Its execution triggers the launch of the "**HydroSim-RUNNER**" pilot.

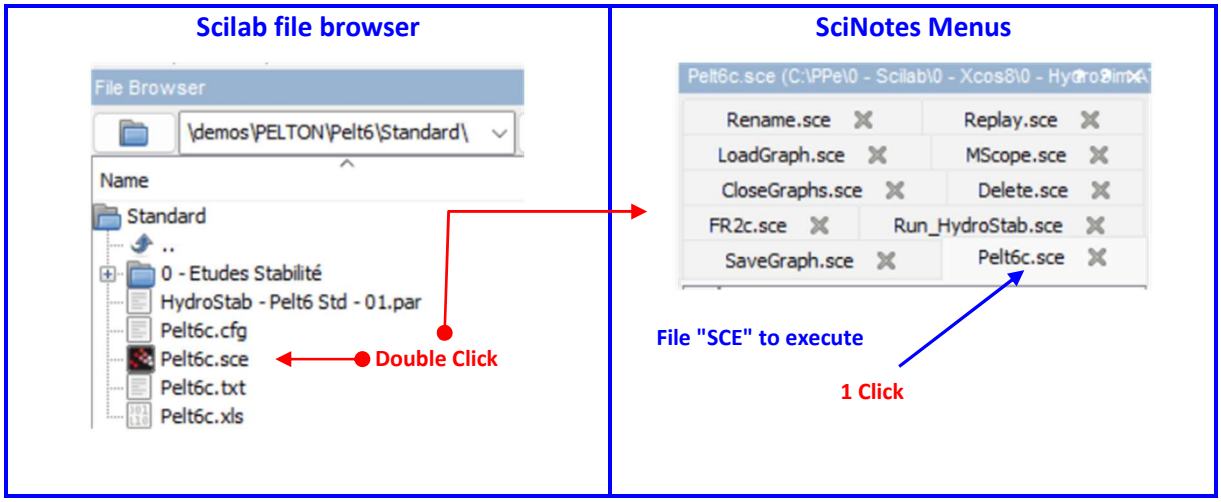
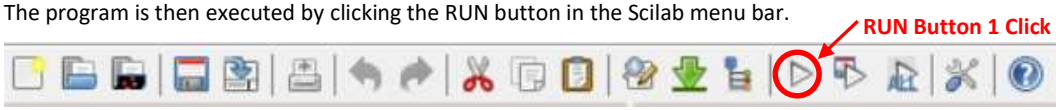


Figure 30 : Launching a simulation from a .sce file (here Pelt6c.sce)

The program is then executed by clicking the RUN button in the Scilab menu bar.



Running the "sce" file initially causes the "HydroSim RUNNER" window to appear, offering a set of menus:

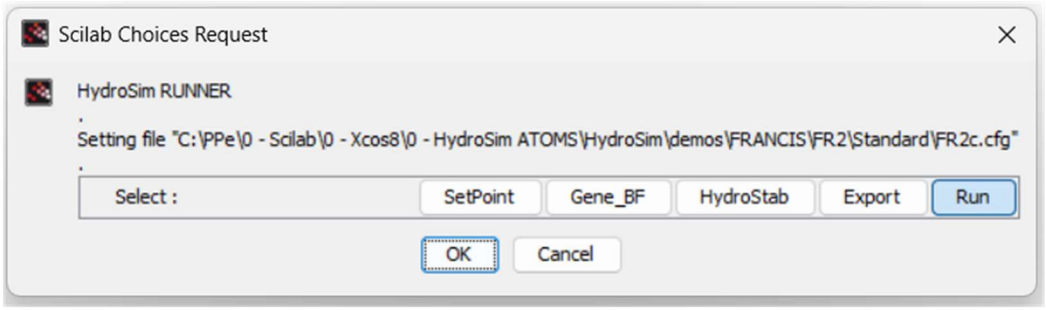


Figure 31 : "**HydroSim RUNNER**" window appears when launching a "sce" file.

Select an action from the list of choices, then confirm the selected component with the OK button.

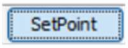
- The **SetPoint** menu sets the operating points of a simulation (Operating setpoint, isolated/separate network mode, etc.). (*See §4.2.2.1*).

- The **Gene_BF** menu initializes the disturbance recorder implemented in the "Network" folder 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 §4.2.2.2*).

- The **HydroStab** menu selects from the file "*HydroStab - xxx.par*" in the directory, a simulation method from among those experienced by use in a HydroStab session. (*See §4.2.2.3*)

- The **Export** menu exports a simulation configuration to a user-selected directory. This tool is for development use only. (*See §4.2.2.4*).

- The **Run** menu launches the simulation under XCOS with the parameters defined in the RUNNER components (*See §.4.2.2.5*).

4.2.2.1 HydroSim RUNNER – SetPoint 

The SetPoint menu sets the main parameters defining the sequence to be executed:

- Unit startup sequence or unit already connected to the network
- Unit workload to be taken into consideration
- Operation in isolated networks or interconnected units.
- Time for trip sequence of the unit with unit stop or return to idle operation
- …etc

The parameters [Tsim, ModAss, Creseau, bReseau, TDJF, Riso, TDECL] are described in the manual "HydroSim_Programming Guide" and are directly accessible using the index of this document.:

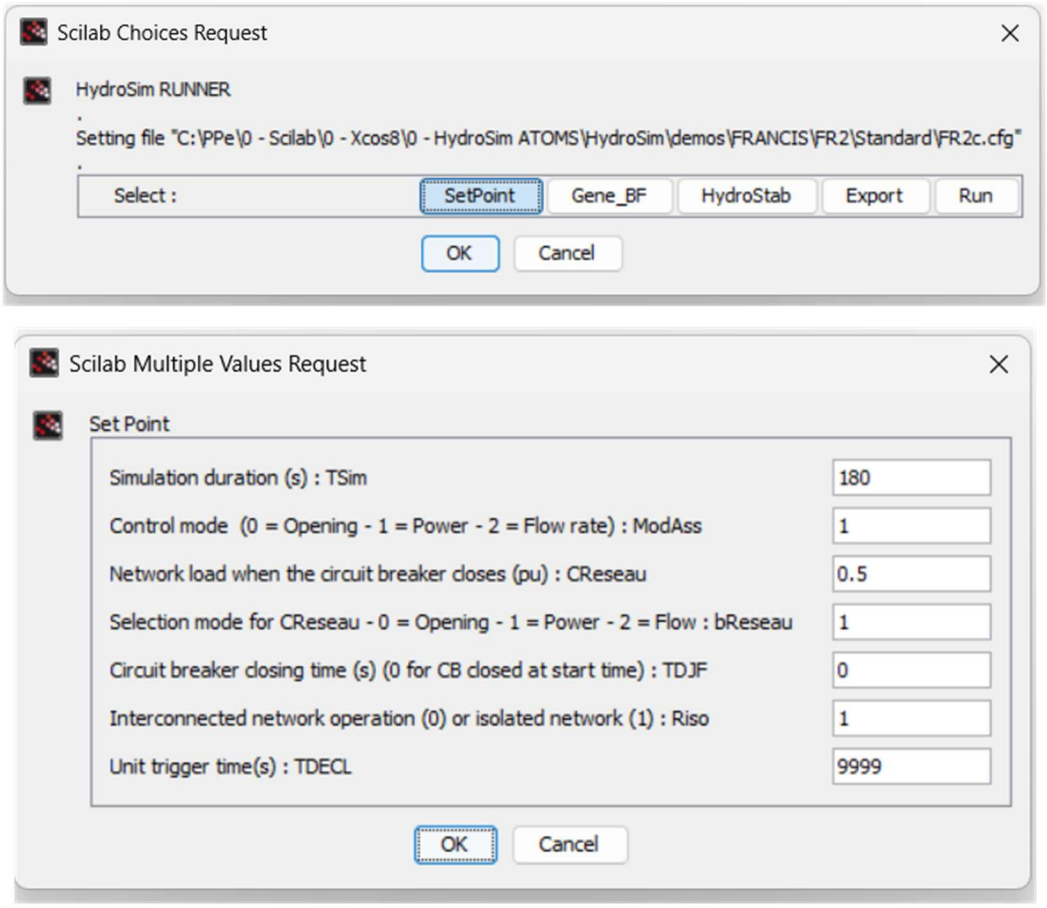


Figure 32 : SetPoint: Access to the main hydraulic unit lockout parameters

4.2.2.2 HydroSim RUNNER – Gene_BF 

The "Gene_BF" tool 

sets the parameters of the low frequency generator to disrupt the steady-state operation of the simulation.

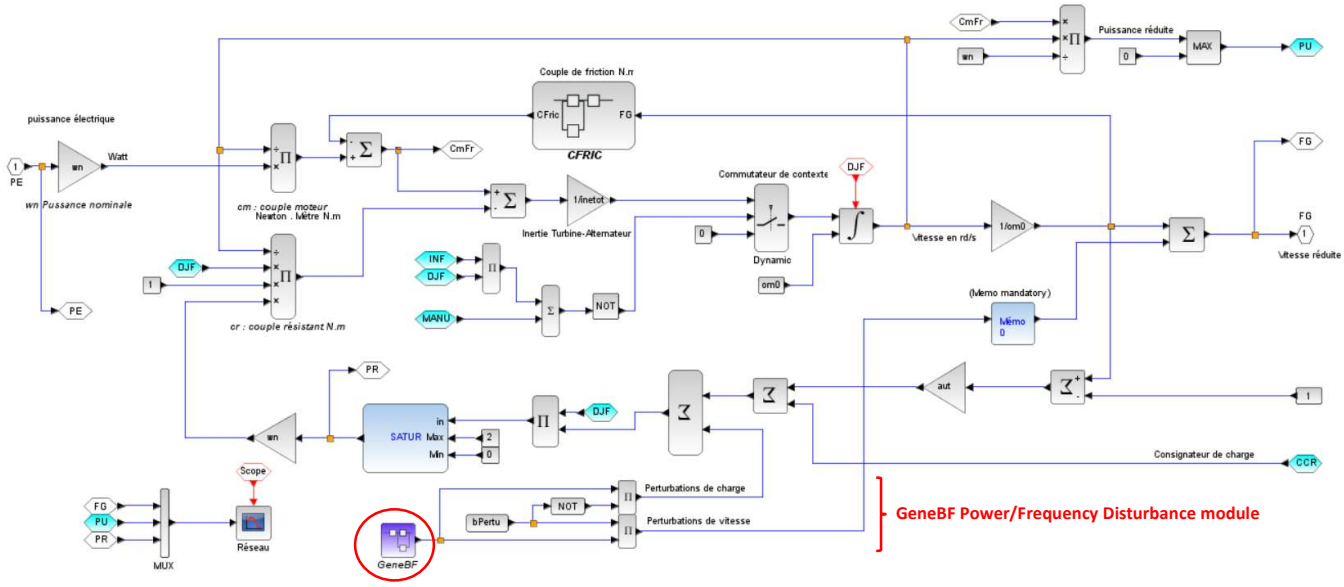
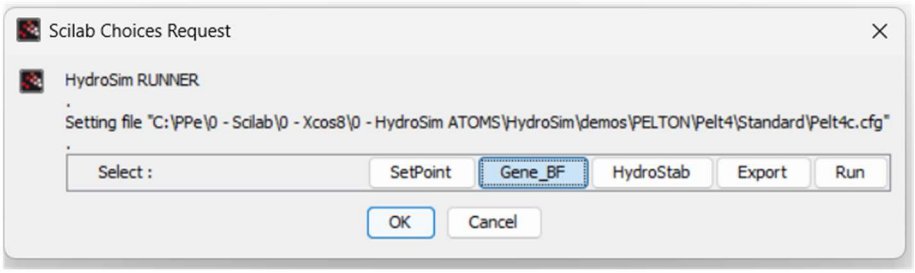


Figure 33 : "Network" folder in the HydroSim schematic libraries



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

Figure 34 : Gene_BF generator parameters

Le The "GeneBF" generator integrates seamlessly into the "Reseau" modules of the HydroSim models. (*See Figure 33*).

A selector controlled by a configurable boolean "bPertu" directs the output signal.

- Stimuli on the speed measurement of the hydraulic unit

- Stimuli on the power of the hydraulic unit

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

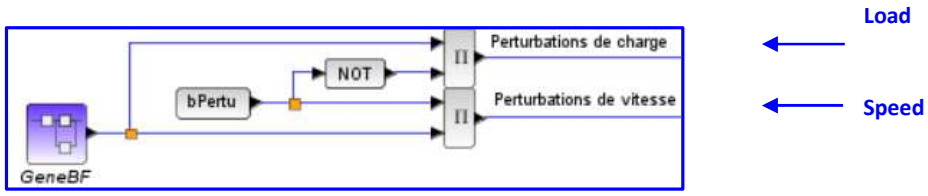


Figure 35 : General principle of the Gene_BF disturbanceograph in the "Reseau" module

The generator programming method is indicated in the HydroSim programming guide.

4.2.2.3 HydroSim RUNNER – HydroStab HydroStab

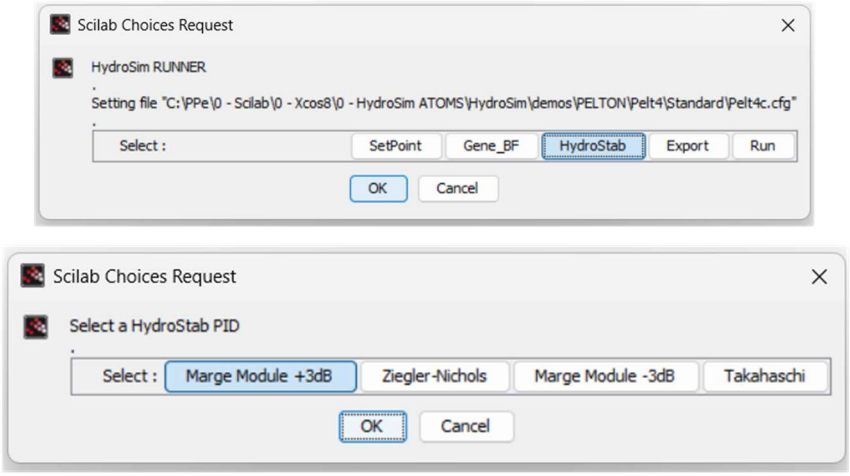


Figure 36 : HydroStab Menu - Selecting an optimization method

The file "*HydroStab - xxx.par*" 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. (*see Figure 8).*

When recording in a **HydroStab** session, it is best to perform the recording sequence in a directory shared with **HydroSim**, as shown in *Figure 28.*

The "HydroStab" tool reads the selected methods from the "*HydroStab - xxx.par*" file and presents them to the user, in the form of a list of choices, before launching the simulation.

4.2.2.4 HydroSim RUNNER – Export Export

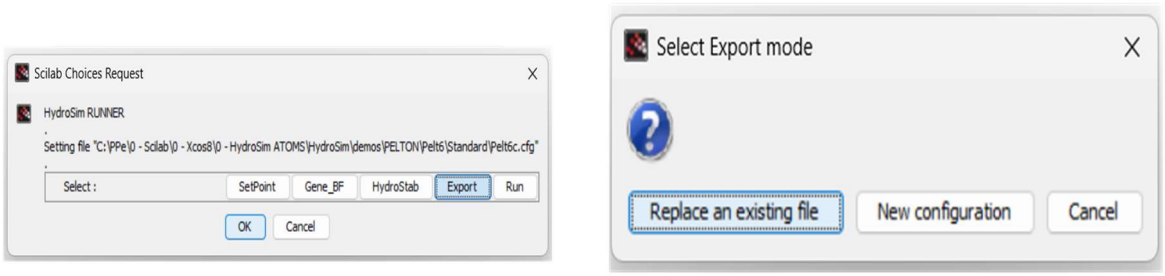
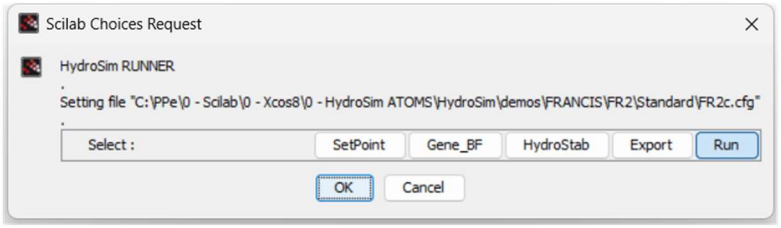


Figure 37 : Menu Export a ".cfg" file

The "Export" tool allows saving the ".cfg" file, configured by the RUNNER, either as a replacement for another "cfg" file in an existing directory, or the creation of a new "cfg" file with automatic numbering of this file in the repository directory.

4.2.2.5 *HydroSim RUNNER – Run* 



The "Run" tool terminates the execution of the "**RUNNER**", and launches the continuation of the execution of the instructions contained in the pointed-to "sce" file, after validation by the "OK" key.

The simulation thus starts with the loading of all predefined parameters, and the background execution of the model associated with the simulation, including the display of the numerical scopes programmed in the application.

This method is unique for running an XCOS file.

4.2.3 Executing a loader "xxx_Loader.sce"

4.2.3.1 *Schematic diagram*

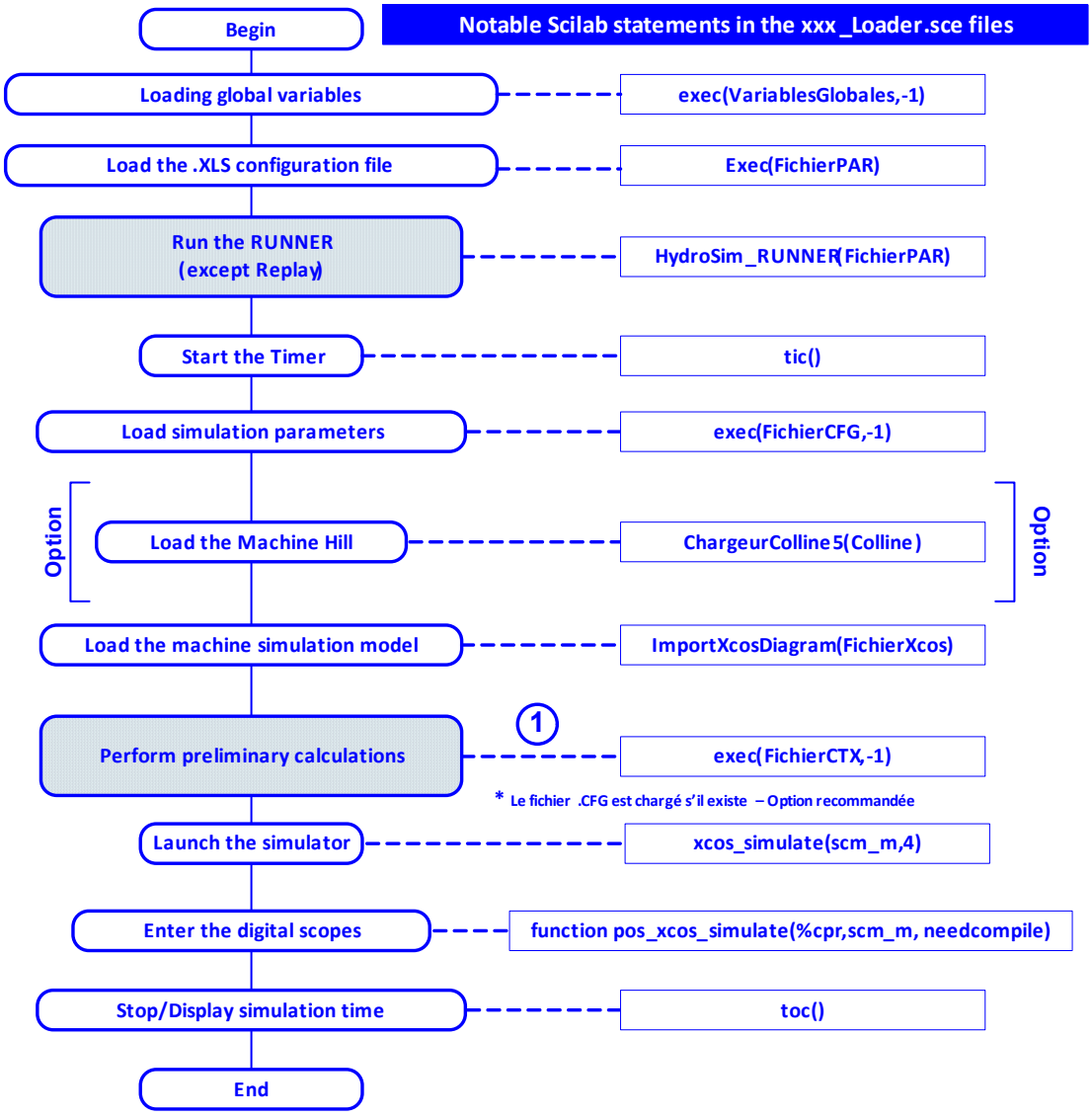


Figure 38 : General execution of a Loader script

The simulation is scheduled for the Tsim time (s) indicated in each parameter file ".cfg".

The actual duration of the calculation is displayed in the console by the **toc()** instruction, and depends on the complexity of the model, the solver used (NEWTON, RUNGE-KUTTA,…others), and the calculations to be performed.

4.2.3.2 Preliminary calculations in the simulated model

The preliminary calculations associated with the main program in the XCOS file are activated as soon as the simulation is launched. (Point ① in *Figure 38*), during the execution of the "sce" file.

These calculations are included in an editable text file "ctx", which must have the same name as the Xcos execution file:

Example : FR2c.zcos and FR2c.ctx

These two files must be in the same directory.

They are developed by the model designer, to provide all the data for all calculations useful for the execution and stability of the model, according to the sequencing conditions defined in the parameterization "xls" or "cfg" files.

These calculations guarantee a smooth, bumpless start to the simulation.

```
// Importation du diagramme fonctionnel
//-------------------------------------
FichierXcos=Root2 + ModeleXcos + ".zcos";
FichierCTX=Root2 + ModeleXcos + ".CTX"   <-- Define the CTX file

printf("Modèle : %s\n",FichierXcos)
importXcosDiagram(FichierXcos);

printf("\n")

// Clear any pre_xcos_simulation
//------------------------------

function continueSimulation=pre_xcos_simulate(%cpr, scs_m, needcompile)
   continueSimulation=%t;
endfunction

// Clear any post_xcos_simulation
//-------------------------------

function post_xcos_simulate(%cpr, scs_m, needcompile)
   Legendes_FRANCIS();  // Rajoute Légendes et Titres des graphiques
                chdir(SaveRoot)
endfunction


// Load the blocks library and the simulation engine
//--------------------------------------------------
loadXcosLibs(); loadScicos();


//First batch simulation with the parameters embedded in the diagram
//------------------------------------------------------------------
mprintf("Chargement du contexte d''exécution %s\n\n",FichierCTX)
exec(FichierCTX,-1)   <-- Run the CTX file

xcos_simulate(scs_m, 4);
```

Figure 39 : Executing a "ctx" file in the simulator's "FR2_Loader.sce" launch script

Examples:

- If the simulation starts with the circuit breaker closed (TDJF=0), the group speed is at nominal.
- If the load setpoint is non-zero for a simulation starting with the circuit breaker closed, the initial flow rate, valve or injector, and blade values are then calculated to start the simulation smoothly.
- Programming of the disturbance steps df1 and df2 at times tdf1 and tdf2
- …etc

The figure below shows an example of calculating the hydraulic resistance of the circuit, performed in a "ctx" file:

```
// Calcul du diamètre hydraulique
//-------------------------------
Dh=sqrt(Seq*4/%pi);

// 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);

// 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 40 : Example of hydraulic resistance calculation - Extract from file FR2c.ctx

4.3 HydroSim Tools

4.3.1 List of HydroSim tools for manipulating simulation data

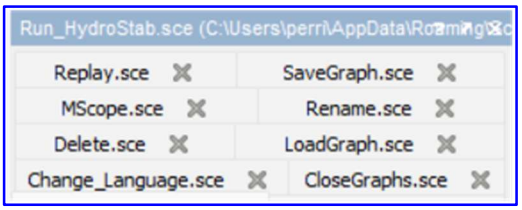


Figure 41 : List of HydroSim tools

4.3.2 SaveGraph : Saving simulation data



4.3.2.1 Selecting a recording directory

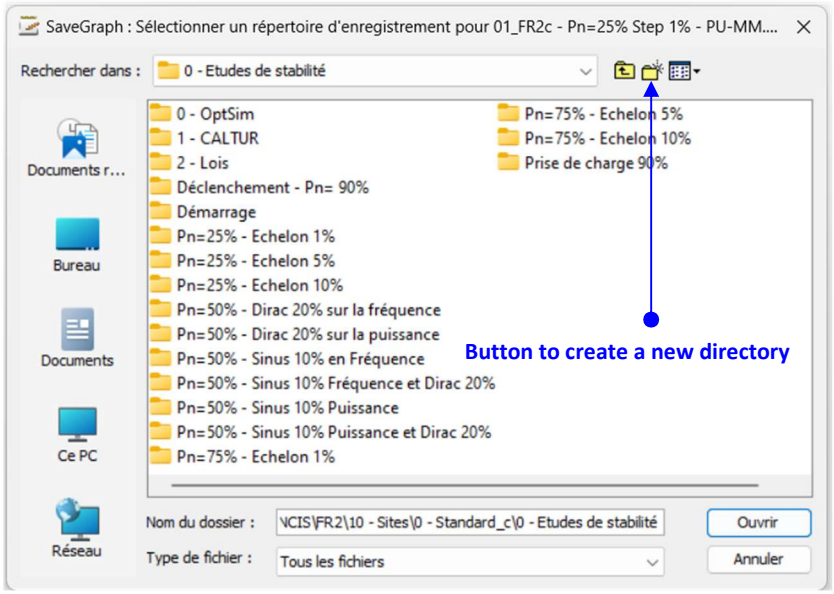


Figure 42 : SaveGraph File Browser

Saving figures and settings in a simulation session is done from the current directory by running the script "SaveGraph.sce.".

☞ Note: the button  allows you to create a directory in the current tree structure.

4.3.2.2 *Structure and numbering of backup files*

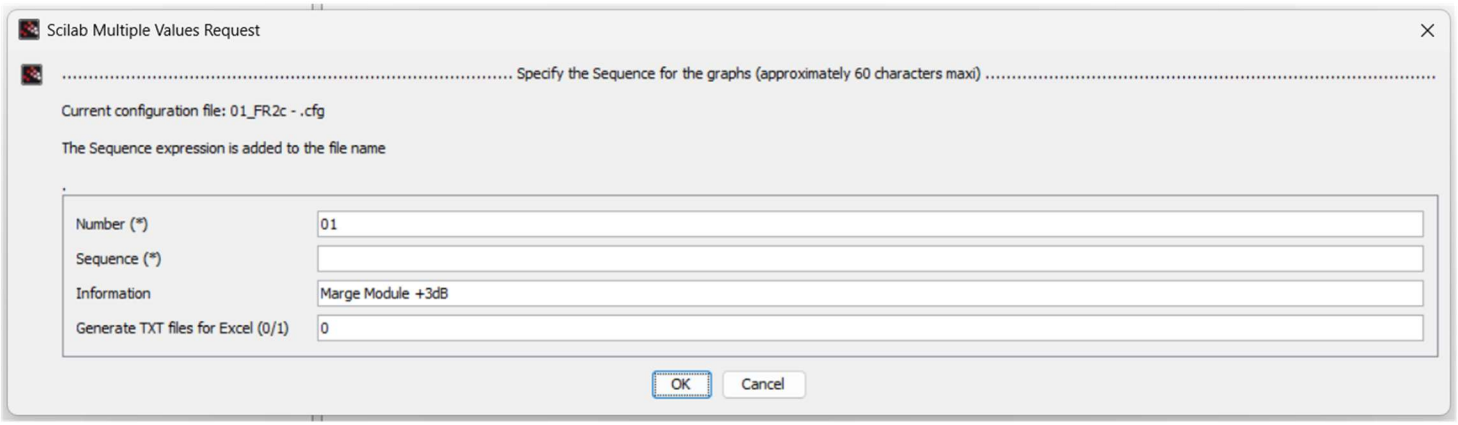


Figure 43 : File structuring interface for records

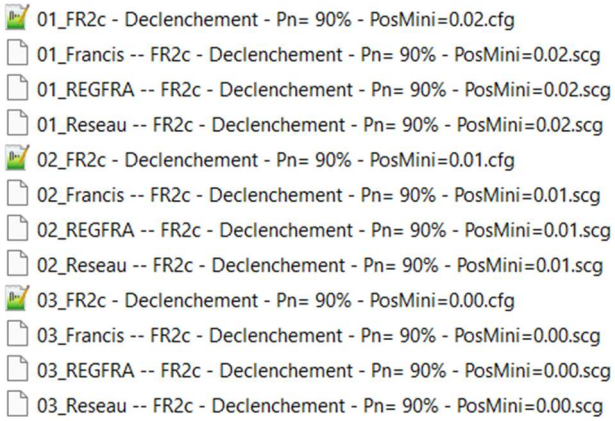
The dialog box shown in ***Figure 43*** defines the parameters considered in the naming of the saved files.

The "**Information**" field is a comment added to all the numeric scopes in the "**info_message**" area, located at the bottom of each of the graphs.

If it is a new directory, the numbering of the saved files starts at index 01; otherwise, the record index is that of the highest one, incremented by one.

There is no limit to the value of the record index (1000, 9999, 100000…etc). In this sense, within the same directory, and therefore corresponding to identical sequencing, the index number can identify and separate distinct attempts (*modification of Kp, for example, or of an option parameter, or of the value of any other parameter*).

4.3.2.3 *File Types*



HydroSim\demos\FRANCIS\FR2\Standard\0 - Etudes de stabilité\Déclenchement -

Figure 44 : Example of file saving after simulation

The files saved with the SaveGraph utility are of three types.

4.3.2.3.1 *The « .cfg » files*

The "cfg" files are text files representing a copy of the generic "cfg" file executed when a ".sce" file is launched. They therefore contain a copy of the parameters from the RUNNER, plus parameters setting specific configurations (PosMini, etc.), located at the end of this file.

Configuration files of type .cfg can be directly used by HydroSim, with the **Replay**, **Rename**, **Delete** utilities.

The file names are structured as follows:

Number_FileNameSCE - Title.cfg

Example:

01_FR2c - Pn=25% Step 1% - PU-MM.cfg

```
//-------------------------------------------------------------------------------------------
// Paramétrisation complémentaire
//-------------------------------------
//
//
// Les paramètres introduits ci-dessous sont en surcharge de ceux déjà présents dans le fichier
// de paramétrage Excel .XLS
//
//-------------------------------------------------------------------------------------------

//-------------------------------------------------------------------------------------------------------
// Paramétrage HydroSim RUNNER ----------------------------------------------------------------------
//-------------------------------------------------------------------------------------------------------

TSim=180.000;                          // Durée de la simulation (s)

//-------------------------------------------------------------------------------------------------------
// Réglage de la consigne de charge -----------------------------------------------------------------
//-------------------------------------------------------------------------------------------------------
ModAss=1.000;                          // Mode d'asservissement : 0 = Ouverture - 1=Puissance - 2=Débit
CReseau=0.250;                         // Charge réseau à la fermeture du disjoncteur (pu)
bReseau=1.000;                         //Mode de sélection pour CReseau -  0 = Ouverture - 1=Puissance - 2=Débit : bReseau

TDJF=0.000;                            // Instant de fermeture du disjoncteur (s) (0 pour démarrage DJF)
TDECL=9999.000;                            // Instant de déclenchement du groupe (s)

Riso=1.000;                            // Fonctionnement réseau interconnecté (0) ou réseau isolé (1)

//-----------------------------------------------------
// Perturbations sur le réseau ---------------------
//-----------------------------------------------------

    //-------------------------
    // Génétateur BF par défaut
    //-------------------------

bPertu=0;                              // Type de perturbation (0=Charge - 1=Vitesse) bloc Reseau
modPer=0.000;                          // Mode de perturbation (0=Echelons 1=SinuSync)
```

Figure 45 : Extract from a cfg backup file

Also see 01_FR2c - Declenchement - Pn= 90% - PosMini=0.02.cfg for the introduction of a special sequence with the PosMini parameter.

4.3.2.3.2 The «.scg » files

Graphic files of type .SCG can be used directly by Scilab, or can be rendered with the **LoadGraph** utility.

The file names are structured as follows:

Number_ScopeName -- FileNameSCE - Title.scg

Examples:

01_Francis -- FR2c - Pn=25% Step 1% - PU-MM.scg

01_Reseau -- FR2c - Pn=25% Step 1% - PU-MM.scg

The registration number is identical to that of the .CFG generator file.

ScopeName is the name of a numeric scope utility in the XCOS simulation file.

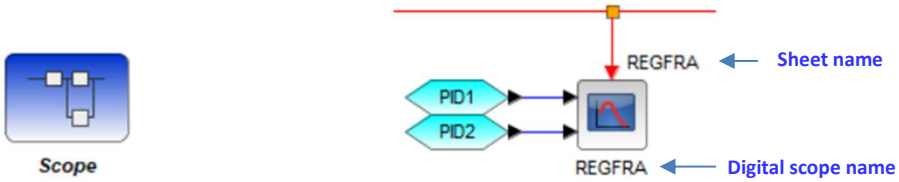


Figure 46 : "REGFRA" scope in the FR2 simulator – "Scope" component – "REGFRA" sheet

4.3.2.3.3 The «.txt » files (Gateway to Excel)

ASCII files in txt format offer a parallel format, intended for data reuse on related software, such as Excel, FlexPro,…others.

These files are only produced if the "Generate txt files for Excel" option in the dialog box in ***Figure 43*** is set to 1.

	A	B	C	D
1	Time	Vitesse réduite	Puissance Groupe	Puissance Réseau
2	0	1	0.5000052	0.5
3	0.1	1.0006831	0.4996777	0.5
4	0.2	1.0013743	0.4988098	0.5
5	0.3	1.002073	0.4984943	0.5
6	0.4	1.0027451	0.4990545	0.5
7	0.5	1.0034381	0.4999015	0.5
8	0.6	1.0041522	0.5005985	0.5
9	0.7	1.0048435	0.5010782	0.5
10	0.8	1.0055524	0.5014238	0.5
11	0.9	1.0062638	0.5017097	0.5
12	1	1.0069914	0.5019704	0.5
13	1.1	1.0076931	0.5022177	0.5
14	1.2	1.0084245	0.5024562	0.5
15	1.3	1.0091299	0.5026902	0.5
16	1.4	1.0098509	0.5030417	0.5
17	1.5	1.010575	0.5031636	0.5
18	1.6	1.0112915	0.5012573	0.5
19	1.7	1.0119936	0.497423	0.5

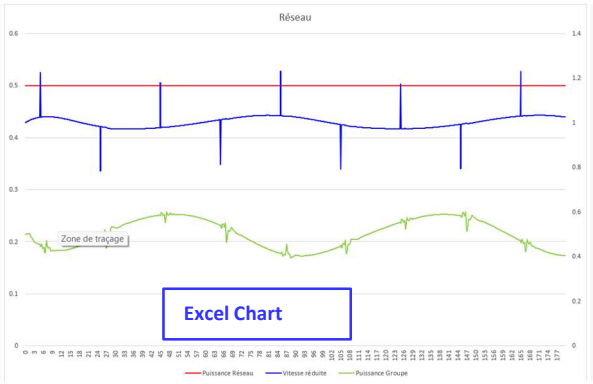
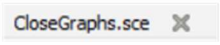


Figure 47 : Excel Gateway - File 01_Network -- FR2c - Pn=50% - Sine 10% Dirac Frequency 20%.txt and .xlsx

A graphical example is shown in *Annex G*

4.3.3 CloseGraph: Close all graphics windows



The CloseGraphs utility closes all graphical windows viewed in a Scilab session, and has no influence or impact on the different simulation directories.

4.3.4 LoadGraph: Restoration of previously saved graphs



The rendering of figures previously saved with the "SaveGraph" utility is done from the current directory, by executing the "LoadGraph.sce." script.

This device allows viewing identical sequences in which the user has modified parameters.

4.3.4.1 Example 1 : Influence of the speed integrator conditioning in the simulation of a Kaplan turbine

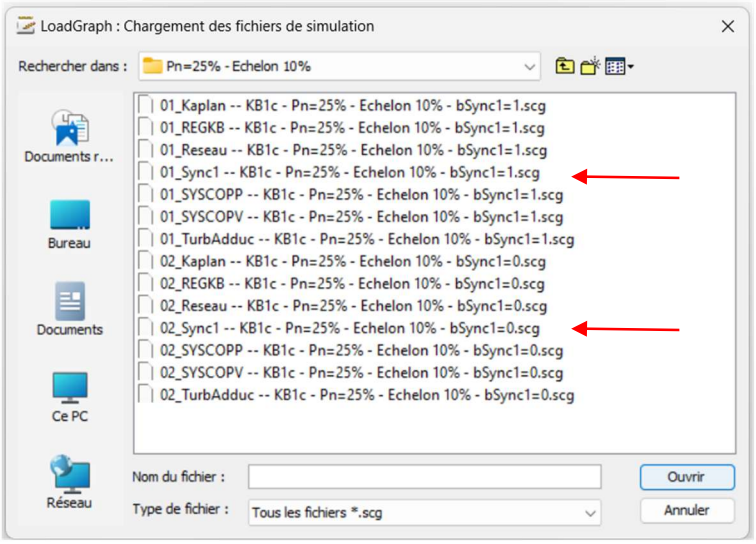
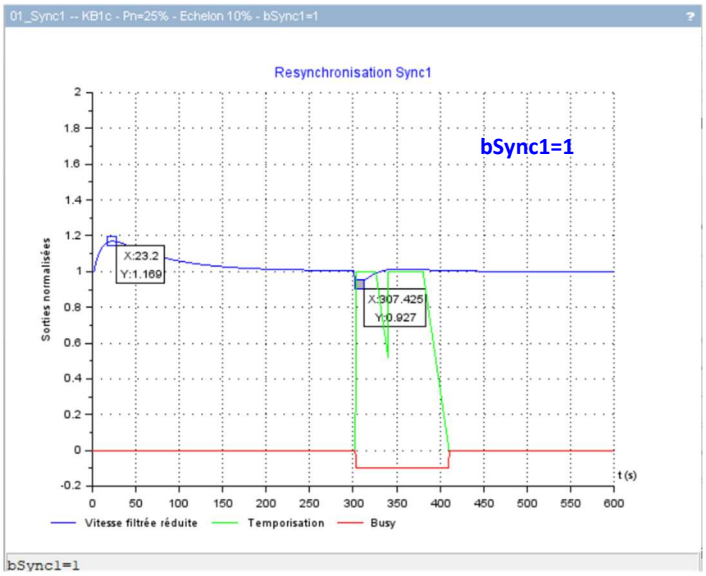


Figure 48 : LoadGraph File Browser



HydroSim\demos\KAPLAN\KB1\Standard\0 - Etudes stabilité\Pn=25% - Echelon 10%

Figure 49 : 01_Sync1 -- KB1c - Pn=25% - Echelon 10% - bSync1=1.scg

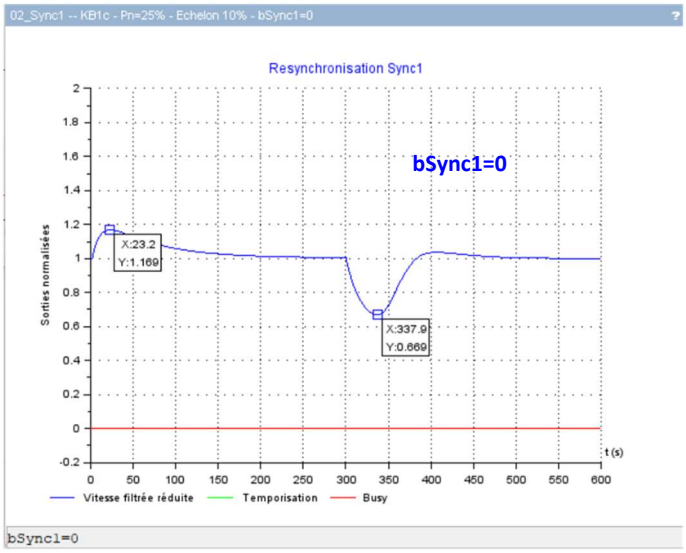


Figure 50 : 02_Sync1 -- KB1c - Pn=25% - Echelon 10% - bSync1=0.scg

In the 2 figures presented above, we can appreciate the improvement of the hydraulic transients, by effect of the resynchronization parameter of the speed integrator bSync1, in the context of a KAPLAN machine.

We also obtain a gain of more than 20% on the machine's underspeed.

4.3.4.2 *Example 2 : Influence of the pre-positioning of the valve in a FRANCIS unloading sequence*

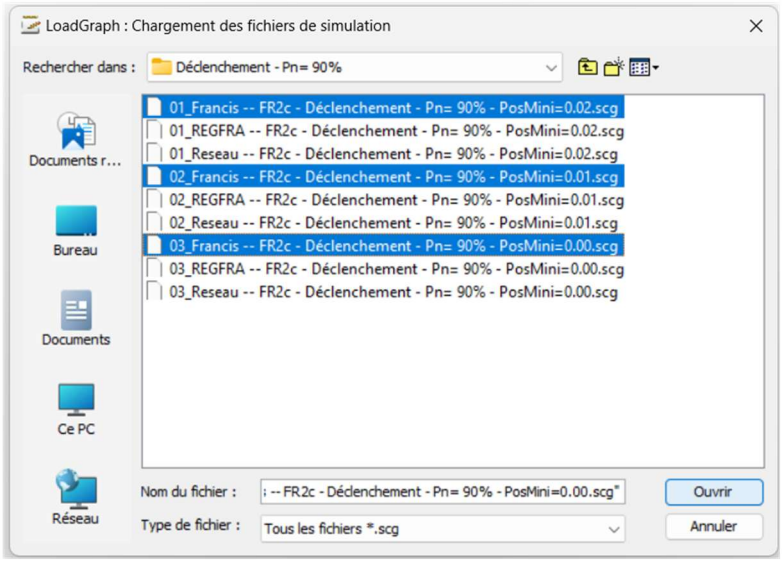


Figure 51 : Selecting FRANCIS offloading files with LoadGraph

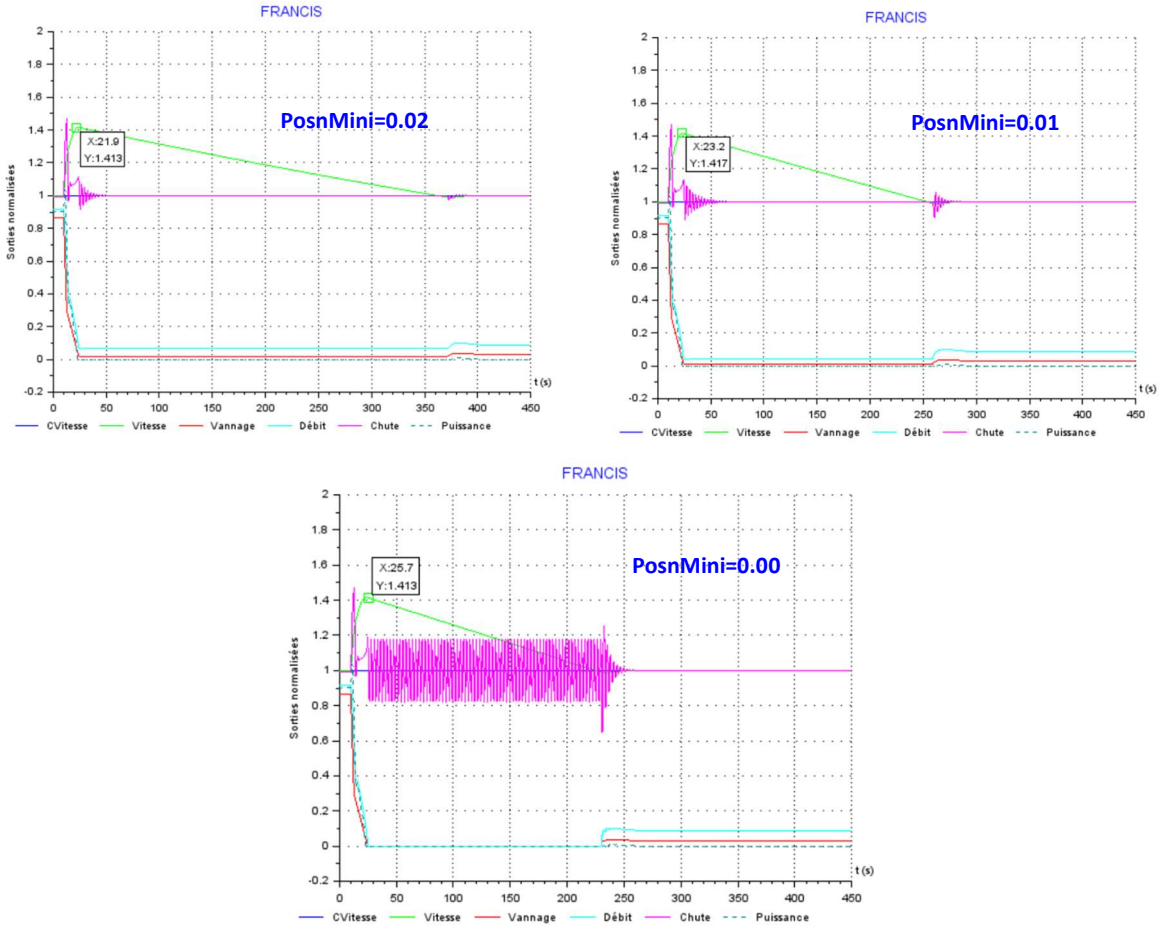


Figure 52 : Influence of the pre-positioning of the valve in a FRANCIS load shedding sequence

PosMini parameter

4.3.5 Replay: Restarting a simulation sequence

Replay.sce

4.3.5.1 Presentation

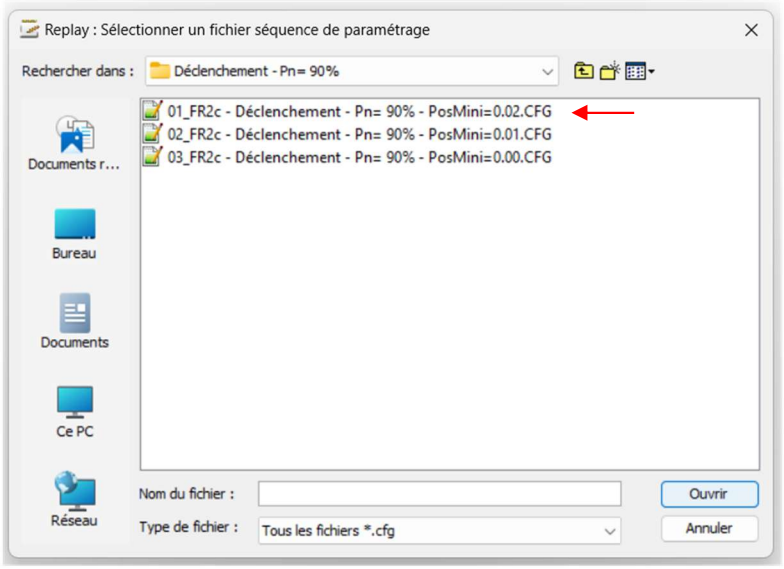


Figure 53 : File browser for restarting a saved simulation

Running the "Replay.sce" utility restarts a previously recorded simulation.

The file browser lists all the ".cfg" files already saved in a selected directory.

Double-clicking on a "cfg" file automatically replays the associated simulation sequence.

4.3.5.2 Searching for the executable file ".sce"

The utility first extracts the name of the "sce" file associated with the "cfg" file, according to the rule for constructing a "cfg" file.

Number_FileNameSCE - Title.cfg

This search is performed in the directories upstream of the "cfg" file.

For example, the file « *01_FR2c - Déclenchement - Pn= 90% - PosMini=0.02.CFG* » indicated contains the following information:

FRANCIS\FR2\10 - Sites\0 - Standard\FR2c.SCE

Figure 54 : Header line of a "cfg" file

HydroSim displays an error message if the "sce" file cannot be located:

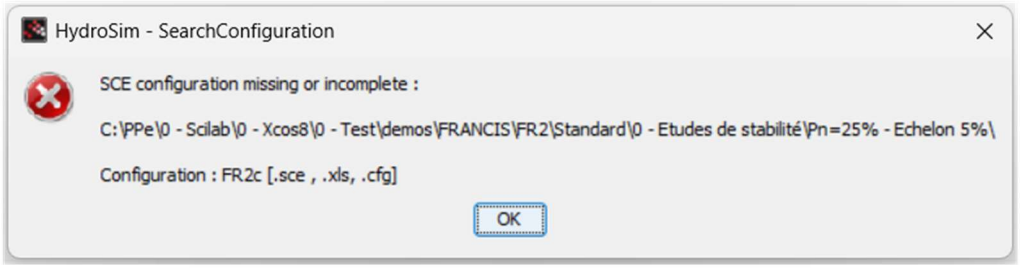


Figure 55 : Error message when a "sce" file cannot be located

☞ **This mechanism allows the user to implement HydroSim anywhere on their PC, guaranteeing the re-execution of tests saved in all directories.**

4.3.6 Rename: Renaming records

Rename.sce

The **Rename** script offers the option to select a "cfg" sequence from a specified directory:

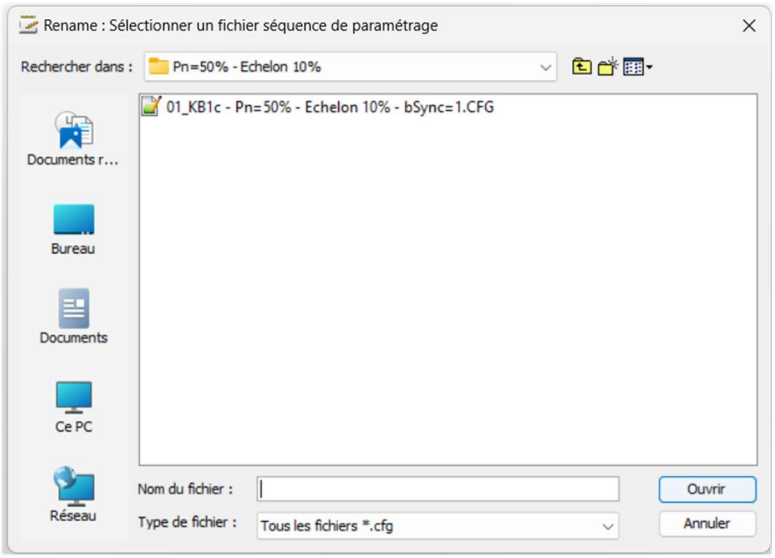


Figure 56 : Selecting a sequence to rename

Upon operator approval, a new menu allows the recording to be renamed:

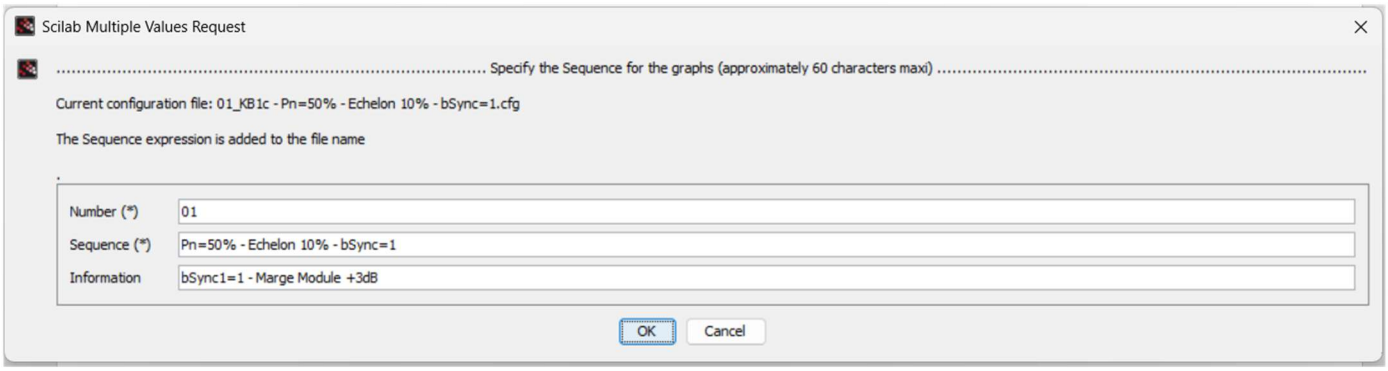


Figure 57 : Renaming parameters for a sequence

A report of the operations is then displayed in the Scilab window:

```
Rename
-------------
01_KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.cfg

01_Kaplan -- KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.scg
01_REGKB -- KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.scg
01_Reseau -- KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.scg
01_Sync1 -- KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.scg
01_TurbAdduc -- KB1c - Pn=50% - Echelon 10% - bSync=1 - Marge Module 3dB.scg

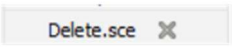

...Rename : 6 fichiers renommés
```

Figure 58 : Example of a report in the Scilab window after renaming

The script renames the "cfg", "scg", and "txt" files if they are present.

The new graphical windows are redisplayed with their modified characteristics.

4.3.7 Delete: Deletion of a simulation sequence and related files



The **Delete** script offers the option to select a "cfg" sequence from a specified directory:

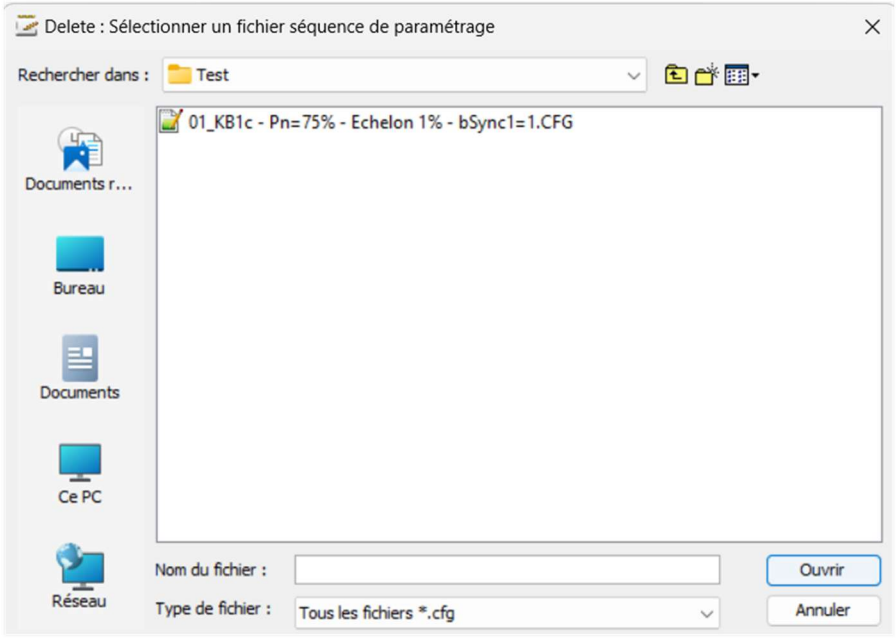


Figure 59 : Selecting a sequence to delete

Upon operator confirmation, the Delete script removes:

- The .cfg configuration file
- All linked .scg and .txt files if they are present in the directory
- Clears any graphical figures if they are present in the Scilab window.

A report of the operation is then displayed in the Scilab window:

```
Delete
-------
...01_KB1c - Pn=75% - Echelon 1% - bSync1=1.CFG

...01_TurbAdduc -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_SYSCOPV -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_SYSCOPP -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_Sync1 -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_Reseau -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_REGKB -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg
...01_Kaplan -- KB1c - Pn=75% - Echelon 1% - bSync1=1.scg

Suppression de 8 fichier(s) HYDROTUR
```

Figure 60 : Example of a report in the Scilab window after deleting a sequence

4.3.8 MScope: Masking of digital scopes present in simulations



4.3.8.1 Access to digital scopes in HydroSim schematic libraries

HydroSim simulation files in Xcos format incorporate series of digital oscilloscopes, useful for monitoring the states of simulated processes (example: FR2c.zcos, KB1.zcos, PELTON.zcos…etc)).

All digital scopes are accessible from the "Scope" component available on the main folio of Xcos models:



Figure 61 : Access to the digital scopes of HydroSim's Xcos models

Double-clicking on this component displays all the scopes included in the displayed model:

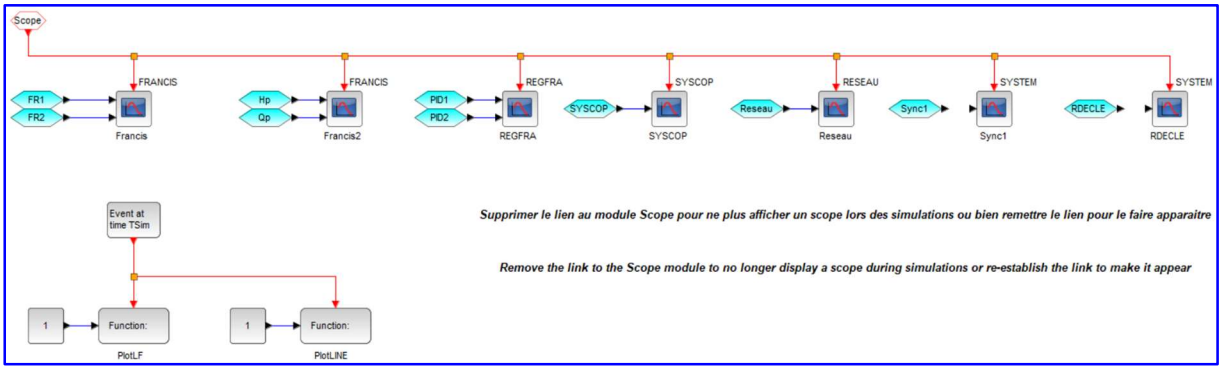


Figure 62 : Digital scopes in the FR2 model

Each scope is represented in red by its time base, labels and connections generated in the schema library folios, the name of the folio in which the scope is created, and the name of the scope appearing in the graphical screen.

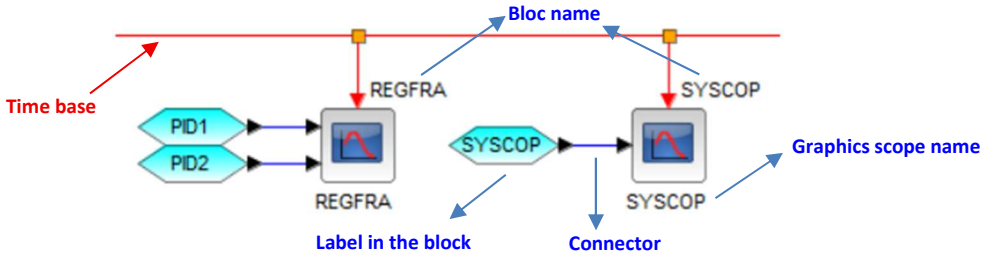


Figure 63 : Description of a digital scope

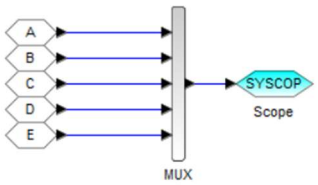


Figure 64 : Scope "SYSCOP" within the "SYSCOP" block

Some of these scopes are partially used for developing the embedded algorithm and can be hidden afterward. This feature is provided by the **MScope.sce** utility.

The reasons for this utility are justified:

- During the model development phase, it may be necessary to introduce additional scopes for algorithm validation.
- It is easy to remove a scope from a model, but more complicated to reintroduce it with relevant links.
- Currently, Scilab does not allow hiding scopes during the simulation phase.
- Not all scopes are necessarily useful in the exploitation phase of a model for a simulated site with its input data.

- …etc.

Machine	FRANCIS	KAPLAN	PELTON
Maximum number of scopes	11	12	16
Maximum number of scopes that can be masked by MScope	8	9	12

Figure 65 : Maximum number of scopes per machine type

4.3.8.2 Scope Removal – Level 0 Masking

It is possible to delete a scope directly in the "Scope" folio of the models.

This solution is the least elegant, as it requires editing the template file, and reintroducing the destroyed scope can prove risky.

4.3.8.3 Scope Disconnections - Level 1 Masking

Level 1 masking involves removing the link to a scope in the "Scope" folio.

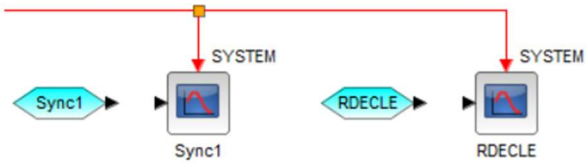


Figure 66 : Example of a level 1 scope mask

The figure above shows the disconnections of the "Sync1" scopes and the "RDECL" relay.

This solution is preferable to the previous one. However, it also has the disadvantage of requiring editing of the template file.

4.3.8.4 MScope - Level 2 Masking

4.3.8.4.1 Presentation

Running the MScope utility displays the control screen for digital oscilloscopes:

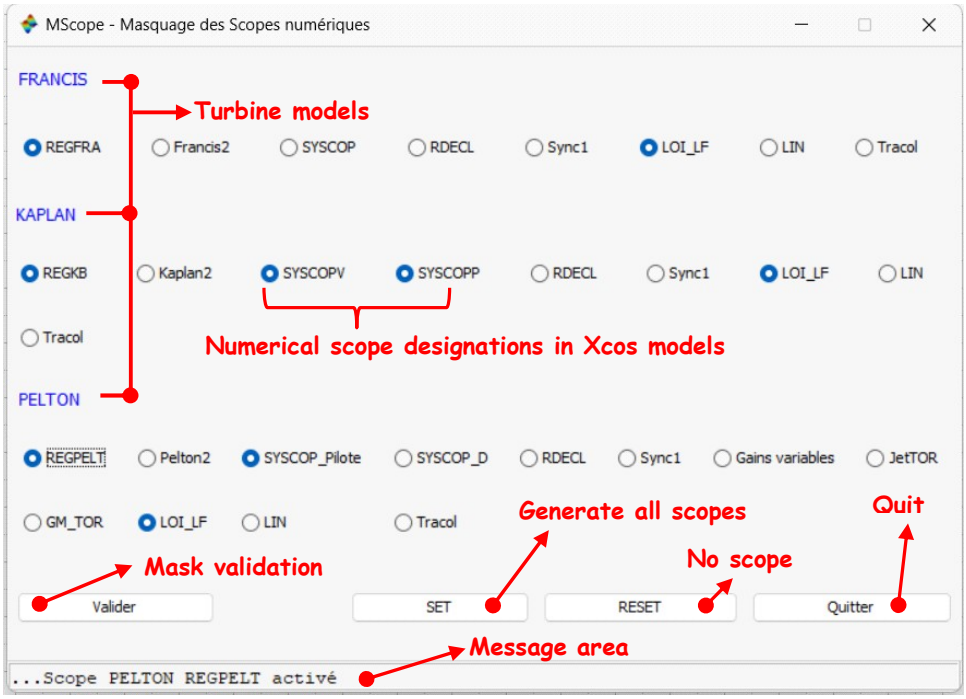


Figure 67 : MScope function home screen - Principle

4.3.8.4.2 General principle

Each of the figures to be masked, present in the Xcos files, is represented by "radio buttons", specifying the scope names indicated in the Xcos files.

Clicking on a "radiobutton" either activates the associated scope if the "radiobutton" is on, or deletes the scope at the end of the simulation if it is off.

This method has the advantage of not editing the template file.

4.3.8.4.3 Validate button



Pressing the "**Validate**" button saves the masks to the HydroSim system file named **Options.txt**, located in the *SCI_HydroSim* directory.

This file contains all the scopes that should be hidden, that is, all the oscilloscopes whose "radiobuttons" are turned off in the MScope menu.

➔ The corresponding graphical windows disappear at the end of the simulation.

```
//-----------------------------------------------------------------------------------------------------------------
// Fichier système HYDROTUR : Options.txt
// Ce fichier est réservé à l gestion de masquages des scopes HYDROTUR. Ne pas éditer ce fichier
// This file is reserved for managing masking of HYDROTUR scopes. Do not edit this file
//-----------------------------------------------------------------------------------------------------------------

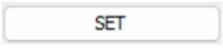
Mask_Francis=[ "Francis2"  "SYSCOP"  "RDECL"  "Sync1"  "LIN"  "Tracol" ]

Mask_Kaplan=[ "Kaplan2"  "RDECL"  "Sync1"  "LIN"  "Tracol" ]

Mask Pelton=[ "Pelton2"  "SYSCOP D"  "RDECL"  "Sync1"  "Gains variables"  "JetTOR"  "GM TOR"  "LIN"  "Tracol" ]
```

Figure 68 : Oscilloscope masking file "Option.txt" in the ***SCI_HydroSim*** directory

4.3.8.4.4 SET Button



The "SET" button illuminates all radio buttons selected in the preliminary selection menu:

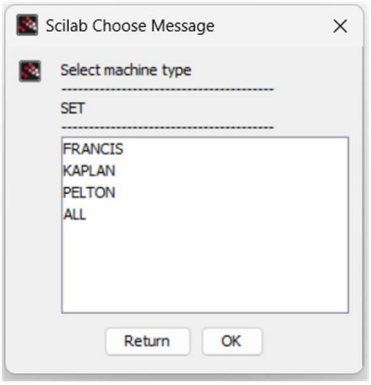


Figure 69 : Selecting masks for the SET function

Consequently, the ***Options.txt*** file will contain empty masks when selecting the "ALL" item:

```
1  //-----------------------------------------------------------------------------------------------------------------
2  // Fichier système HYDROTUR : Options.txt
3  // Ce fichier est réservé à l gestion de masquages des scopes HYDROTUR. Ne pas éditer ce fichier
4  // This file is reserved for managing masking of HYDROTUR scopes. Do not edit this file
5  //-----------------------------------------------------------------------------------------------------------------
6
7  Mask_Francis=[]
8
9  Mask_Kaplan=[]
0
1  Mask_Pelton=[]
```

Figure 70 : MScope.txt masking file following a "SET" action on all machines

4.3.8.4.5 *RESET Button* RESET

The "RESET" button turns off all radio buttons selected in the preliminary selection menu:

It follows that the ***Options.txt*** file will contain all the masks from the MScope menu.

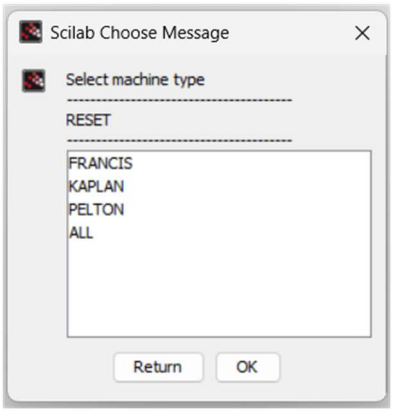


Figure 71 : Selecting masks for the RESET function

4.3.8.4.6 *Quit Button* Quit *or MScope window closing cross* ×

The Quit button or the Close button ends the MScope session.

If the configuration has not changed, the MScope window closes immediately.

Otherwise, a fleeting message will offer to save the configuration before closing the program.

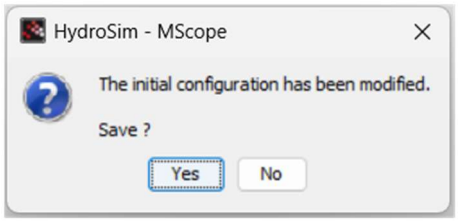


Figure 72 : Registration offer message before "Quit"

4.3.8.4.1 *Machine Hill Layout Addition of Additional Scopes: Linearization – Multi-slope Law for Servomotor Closure*

In addition to the scopes contained in the simulation files, it is possible to obtain at the end of the simulation the plot of the linearization laws of the models, the plot of the multi-slope closure law of the servomotor, or the plot of the machine hills if the model is defined with hills (examples in the FR4, FR5, KB1 models)

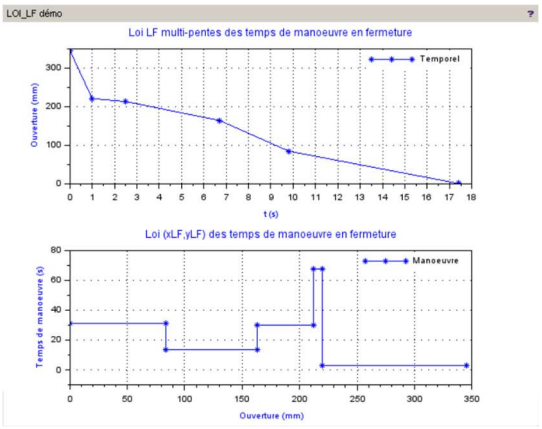


Figure 73 : Multi-slope closure law **LOI_LF**

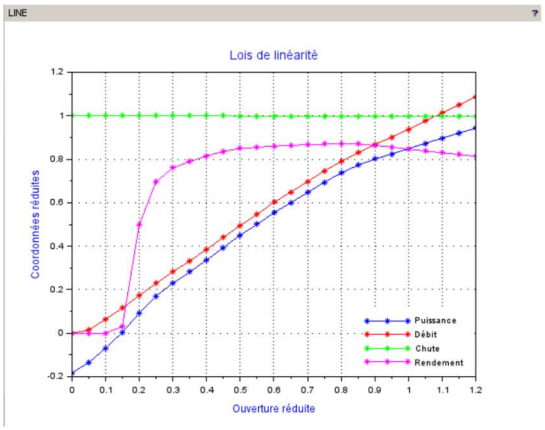


Figure 74 : Linearization laws **LINE**

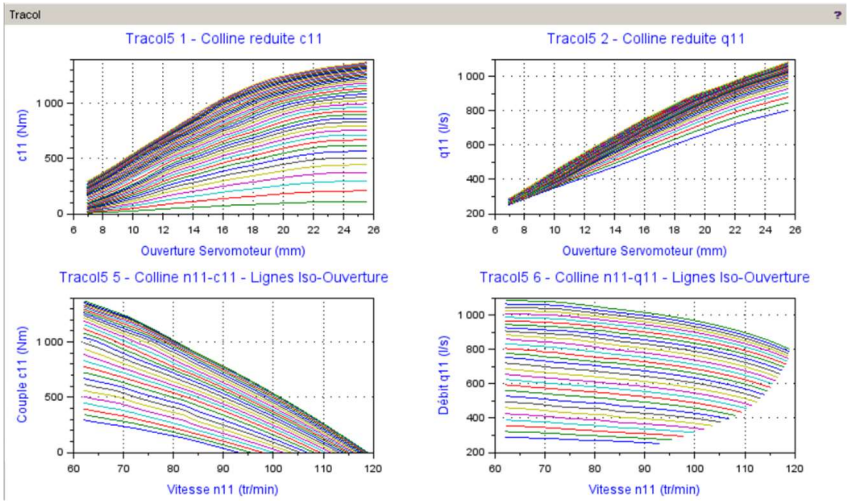


Figure 75 : Tracing of the **Tracol** Machine Hills using Scilab-HydroSim

This device is obtained by turning on the radio buttons **LOI_LF, LIN, Tracol** in the MScope menu.

4.3.9 Change_Language: Change language English/Français

Change_Language.sce

This script allows switching between Français (fr) and English (en) languages.

Only messages produced by HydroSim in the Scilab console are affected.

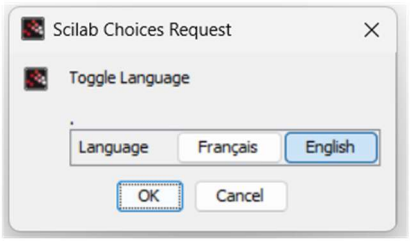


Figure 76 : Changing the language under HydroSim

To change the global language level in Scilab, see the instruction *setdefaultlanguage.*

The recommendations can be followed by entering the Scilab console: --> doc setdefaultlanguage

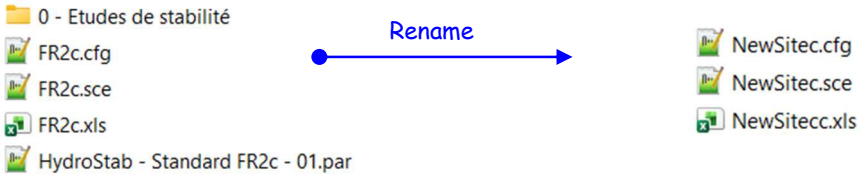
4.4 Creation of a new study project

The easiest way to create a new study project is to copy and paste the entire directory of an existing study, respecting the folder structures shown in *Figure 22*.

1. For example, to carry out a study like the *Standard* study, located in the FR2 directory, Copy/Paste the *Standard* directory, and rename it *NewSite*, if *NewSite* is the name of the new study.



2. In the new *NewSite* directory, rename the execution and parameter files, and delete the *0-Stability Study* directory and the HydroStab *HydroStab Standard FR2c – 01.par* file



- Perform a stability study with the hydraulic parameters of the *NewSite* site, using the **HydroStab tool (Run_HydroStab.sce)** provided for this purpose, and save the study file "**.par**" in the NewSite directory.
- Copy the test type directory *0 - Etudes stabilité (Kit d'Essais type)*) located in the HydroSim\Utilities directory, into the *HydroSim\Utilitaires* directory of *NewSite.*

  Reorganize this directory according to the tests you wish to run.



3. Only the project root is accepted. Otherwise, HydroSim will display filenames that do not conform to the root defined in the "sce" file:

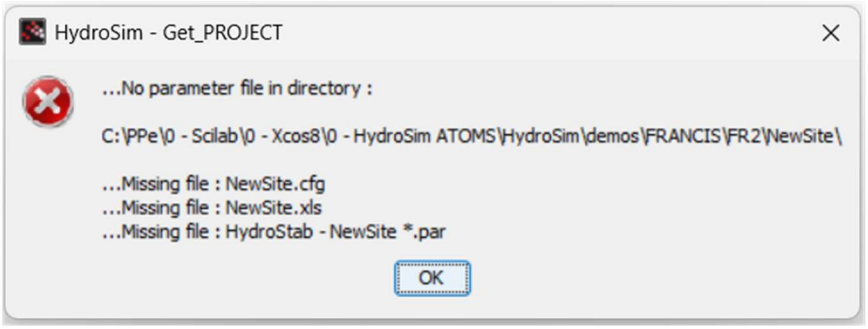


Figure 77 : Example of file conformity detection for a project

4. ☞ At this stage, the *NewSite* project is executable and ready to use.

In Scilab, navigate to the *NewSite* directory, and double-click on the "*NewSite.sce*" file to place this file in the SciNotes section of the navigation screen.

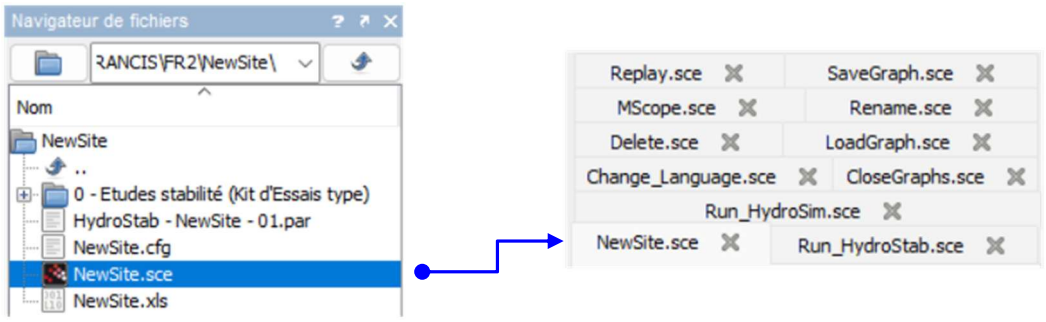


Figure 78 : Installing the new project in the Scilab working environment in the Scinotes window of Scilab

… Of course, the next step is to configure the new project with the new site features:

5. Perform a study and reduction of the hydraulic circuit using **CALCUR**

6. Conduct a site stability study using **HydroStab** provided in the **HYDROTUR** package, and create the file "*HydroStab - NewSite - 01.par"* containing several methods if needed.

7. Redefine the site parameters in the "xls" file

8. Enter the simulation parameters when launching the "sce" file using the **RUNNER HydroSim**

4.5 Interrupting a simulation

A running simulation can be interrupted at any time by entering the sequence "CTRL+C" in the Scilab console[4].

In this case, Scilab stops the calculations in progress, and displays the indicator " **-1->** " at the command prompt.

Then enter the "**abort**" instruction to restore normal operation in the Scilab console.

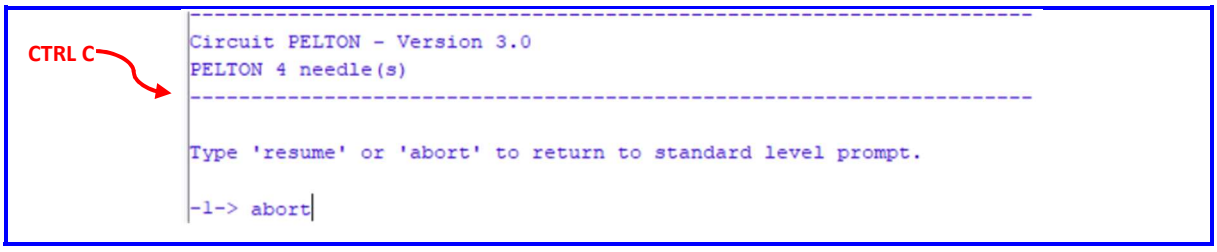


Figure 79 : Interrupting a simulation

☞ **If pressing "CTRL+C" does not work, try "CTRL+Q" followed by "CTRL+C".**

[4] For an unknown reason, program interruption is not possible in the FFR2.zcos model.

5 PARAMETERIZATION OF MODELS

5.1 HydroSim Programming Guide - Parameterization Files

5.1.1 Presentation

The parameters used in all "XCOS" models are described in the "Programming Guide" of the HydroSim package:

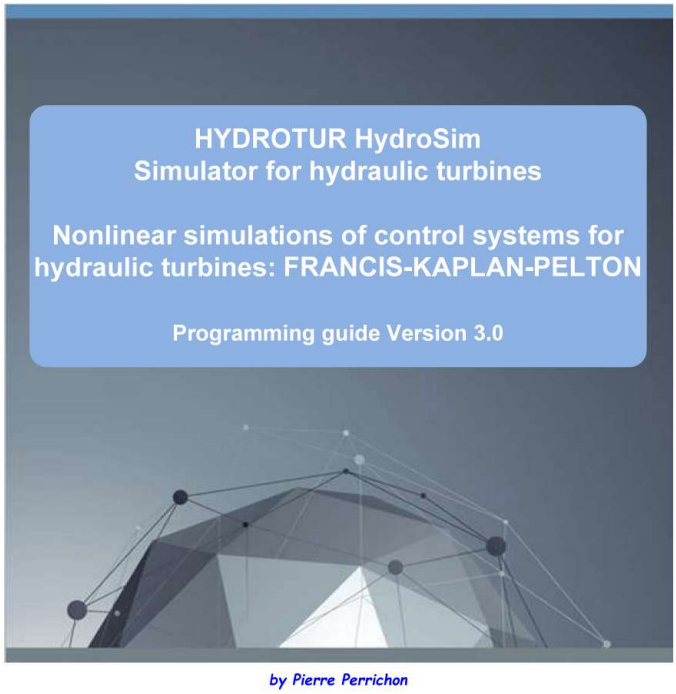


Figure 80 : HydroSim Programming Guide

5.1.2 About the Index Table

An index table provides quick access to the description of each of the parameters used:

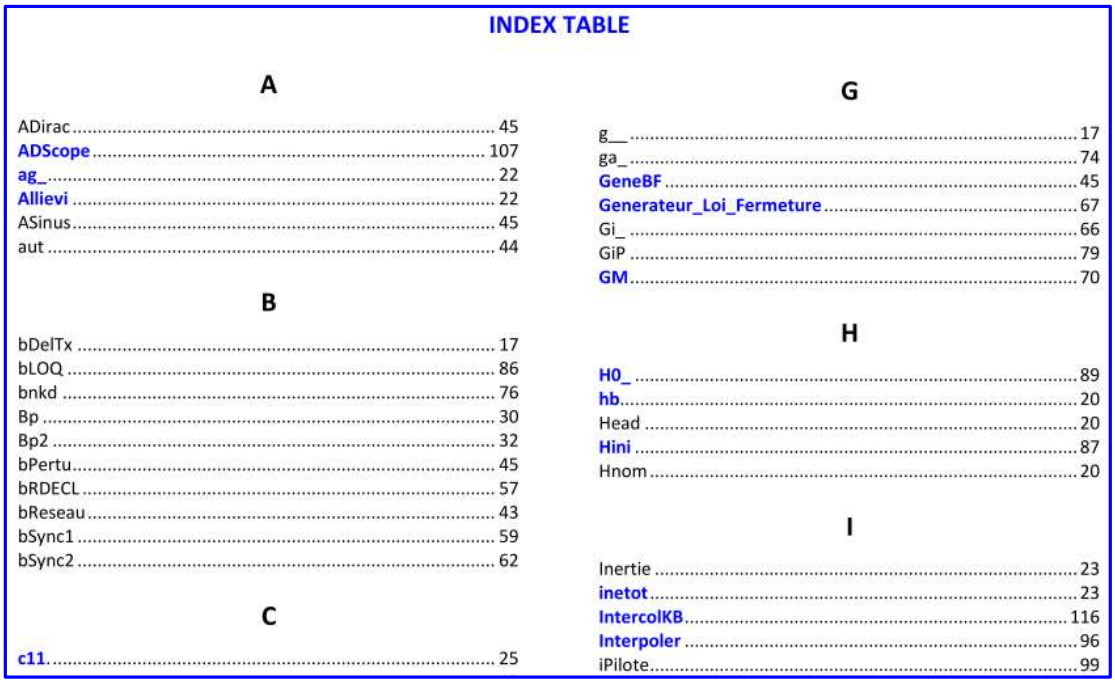


Figure 81 : Overview of the index table in the "Programming Guide" document

In this table, the parameters indicated in blue, bold type, are not parameters present in the parameterization files, but parameters calculated, in general, in the preliminary calculations (file ".ctx") for each simulation circuit.

5.2 Excel parameterization files “XLS”

These files are normally common to all simulations performed for a model. The goal is to maintain consistency across all tests.

An XLS file can contain multiple sheets depending on the templates:

Excel Sheet	Meaning	Feature
PAR	General settings	Mandatory
TM	Operating time for opening/closing the servomotors	Mandatory
REND	Turbine efficiency law	Depending on the model
LINE	Linearization Law Power/Aperture according to site data	Based on site data (K2 FRANCIS)
HILL	Machine Hills	Based on site data (FR4, FR5)

Figure 82 : Sheet names in Excel "xls" files

☞ **Excel spreadsheets must not contain any graphical plotting, otherwise HydoSim may malfunction.**

6 LAWS AND CONJUGATION SURFACE

6.1 Adjustment of the operating times of the control elements – LF multi-slope law

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

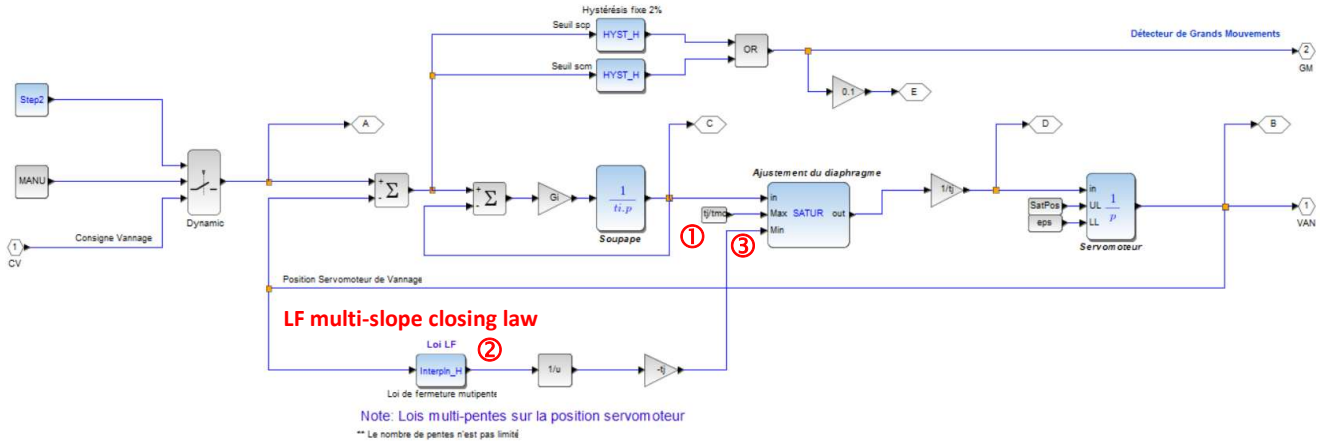


Figure 83 : SYSCOP module for controlling the copying system of wicket gates in HydroSim

The LF closing law to be programmed is a two-dimensional law where the x-axis represents the closing time (s), from the fully opened servomotor at time t=0 until the servomotor is completely closed. The x-axis values are expressed in seconds.

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

From the programmed **LF** law, the remarkable instruction " **Generateur_Loi_fermeture** ", automatically called in .CTX files, automatically generates the two vectors **xLF** and **yLF** used in the **SYSCOP** modules, as indicated in □ in the *Figure 83*.

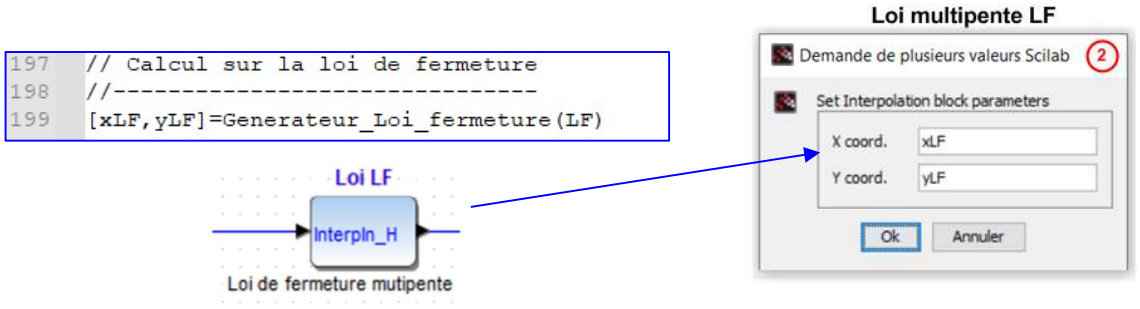


Figure 84 : Calculation of closing manoeuvring times based on the LF law in CTX files

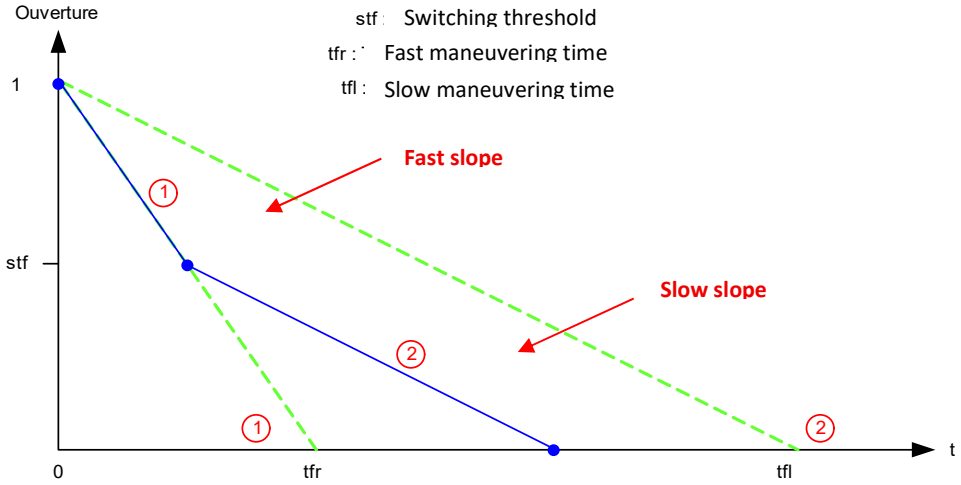


Figure 85 : Principle of parameterizing multi-slope closure laws

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

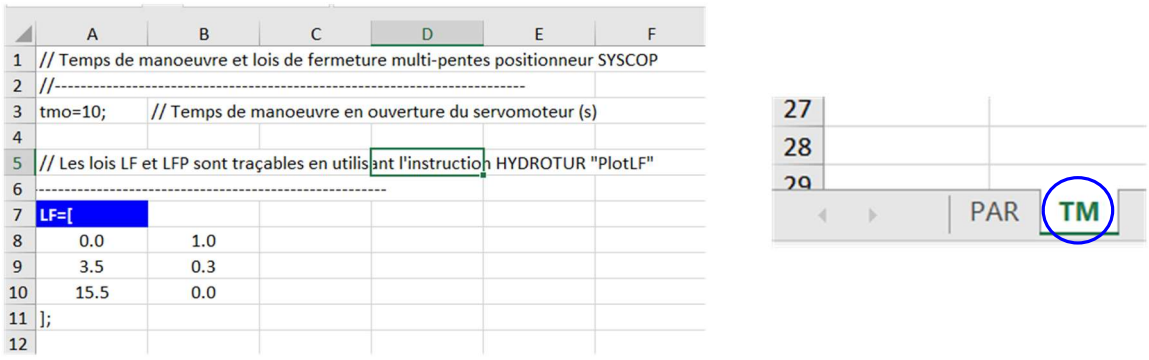


Figure 86 : Multi-slope law in the TM sheet of the HydroSim\FRANCIS\FR2\Standard\FR2c.xls project file

On the other hand, the "**PlotLF**" instruction allows visualization of the programmed **LF** manoeuvre law, as well as the automatically calculated manoeuvre time law [xLF ; yLF] by HydroSim.

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

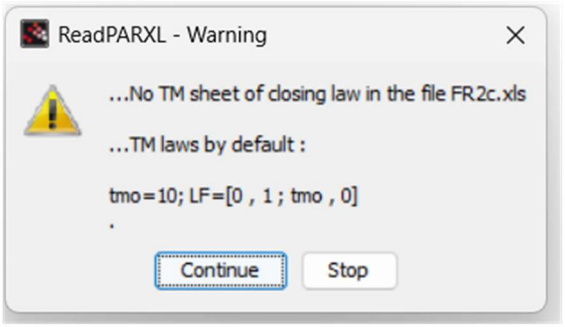


Figure 87 : Default manoeuvring law if the TM sheet is absent

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

A demonstration of the closure law is performed by entering the command "**PlotLF demo**" or "**PlotLF demo**" in the Scilab console. (*See Figure 100*).

```
"LF"

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

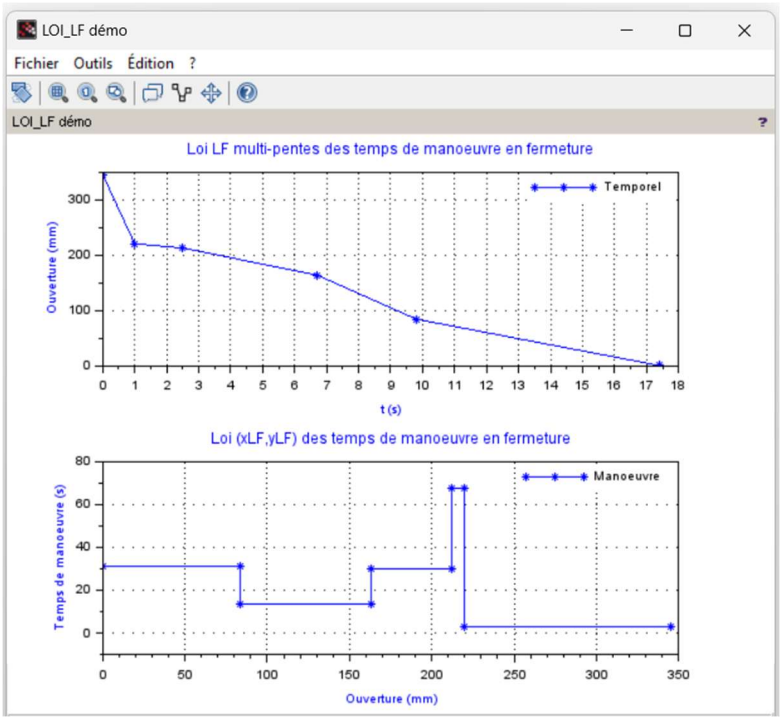


Figure 88 : Example of a multi-slope closure law - Plotting instruction "**Plot LF demo**"

6.2 Efficiency Law

From a 2-tuple table (xTend, tRend), this law considers the efficiency of the machine in the calculation of the mechanical power supplied by the hydraulic unit, according to the law:

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

where η is the efficiency law *Rend*.

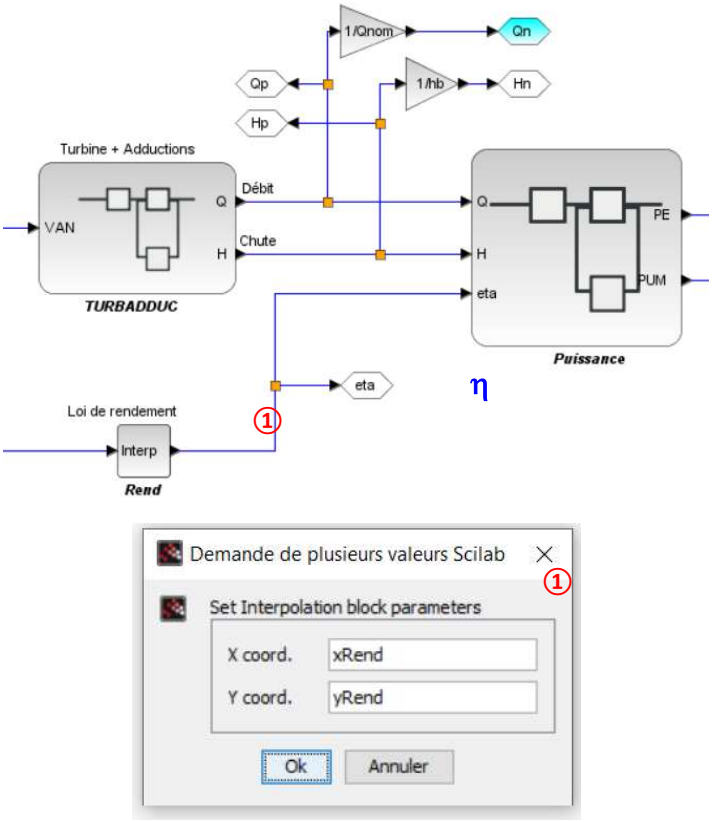


Figure 89 : Consideration of the efficiency law Rend in the main FR2 module

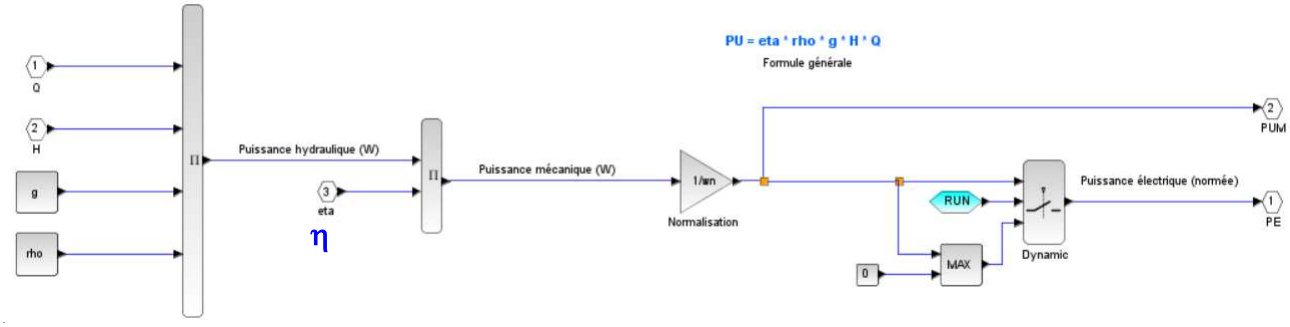


Figure 90 : Consideration of efficiency in the FR2 circuit power module

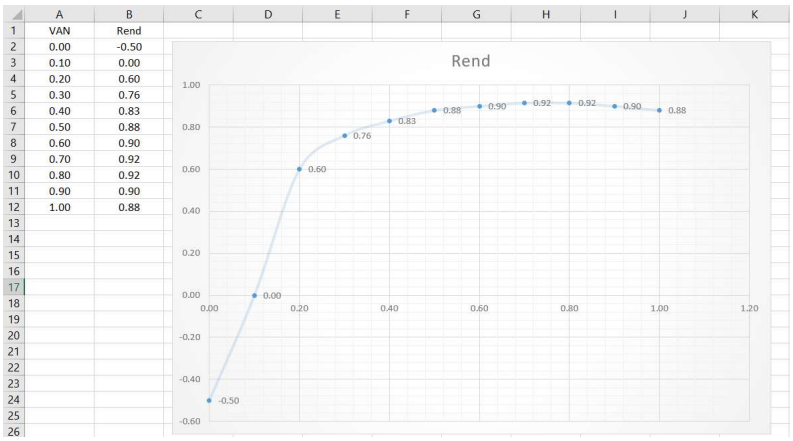


Figure 91 : Example of an efficiency law in the FR2 circuit (File FR2 - Lois.xlsx)

☞ An efficiency law is defined by default in the file "**GlobalVariables.sce**". This file is loaded when every simulation is launched and is in the directory "**HydroSim\macros\":**

```
//-----------------------------------------------------------------------------------------------------------
// 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 92 : The efficiency distribution is defined by default in the file "**GlobalVariables.sce**"

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

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

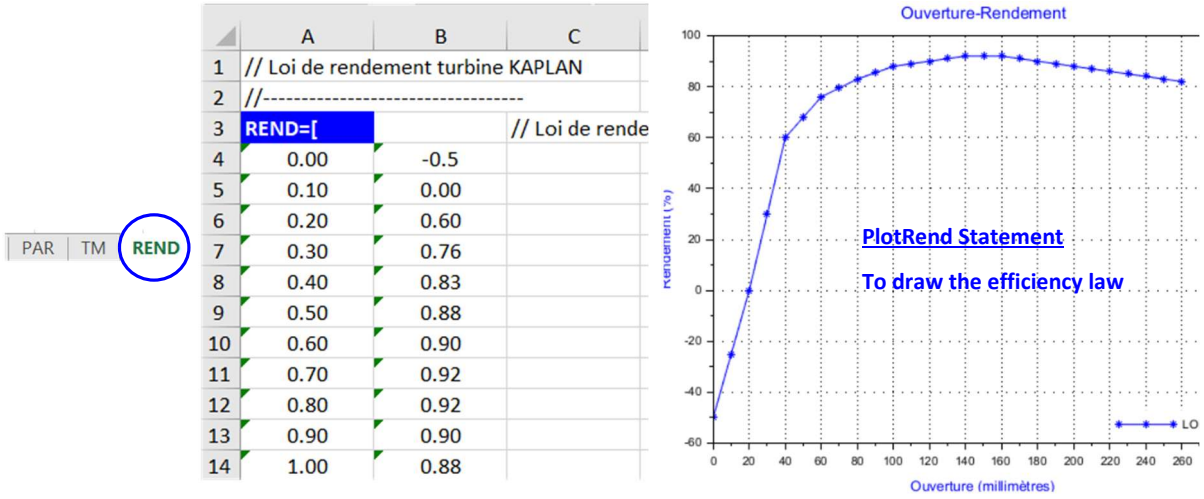


Figure 93 : Efficiency law defined in the file HydroSim\demos\KAPLAN\KB1\Standard\KB1.xls

The efficiency law can be plotted by entering PlotRend in the Scilab console. (*See* Figure 100).

6.3 Hydraulic or electric braking of the hydraulic machine

HydroSim incorporates a turbine braking device.

This principle is implemented in the "CFRIC" sub-module within the "Reseau" module of the schematic libraries.

The reader should consult the CFRIC parameter in the programming guide.

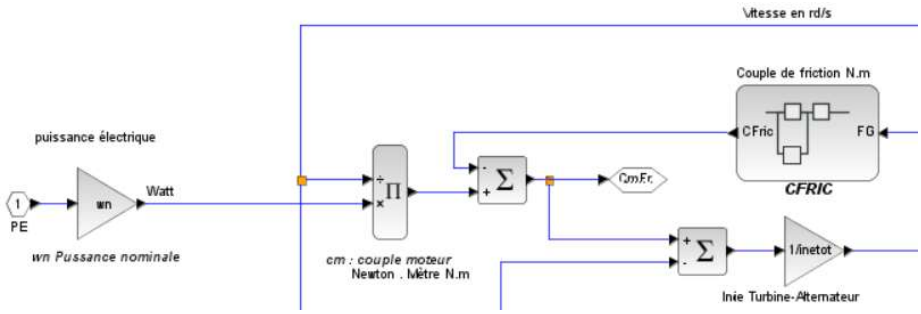


Figure 94 : Application of friction torque in the "Reseau" module

6.4 Linearities and linearization laws

6.4.1 Introduction

Linearization laws establish a linear relationship between the different quantities in the calculation circuit (opening, flow rate, head drop, power, pressure loss, etc.). HydroSim integrates several methods for processing these laws in the simulated systems.

The general principle of implementation consists of rewriting the **TURBADDUC** circuit in literal form (Turbine+Adduction), and iterating this routine until a convergence point deemed satisfactory is reached.

These routines are available in the HydroSim\macros[5] directory and executed in the "ctx" files of the HydroSim\TURBINES directories. (*seer §**Erreur ! Source du renvoi introuvable.***).

These calculations also guarantee a smooth start for the simulations (bumpless start)

The algorithm put in place offers a choice between two possible behaviours, programmable by a **bLOQ** parameter.

The linearization laws can therefore be:

- defined by the user **following site testing** (see below parameter **bLOQ=1**)
- computed by the simulator from an analytical approximation of the Flow/Opening law, and calculations of pressure losses using the Colebrook-White and Darcy-Schwartz laws (**bLOQ=0**)

➢ Also see ***F Plotting linearity curves – FR2 circuit – File FR2_LOIS.XLSX***

6.4.2 Program bLOQ=0 if the linearization laws are not known – LINE Law

- If **bLOQ=0** :

The flow rate Q is simulated by an analytical and hypothetical law $Q = O^{nq}$, where $nq = 0.7$ and O the opening of the wicket gates

The differential offset compensations *yDifQ* and *yDifH* at the output of the circuit are then zero.

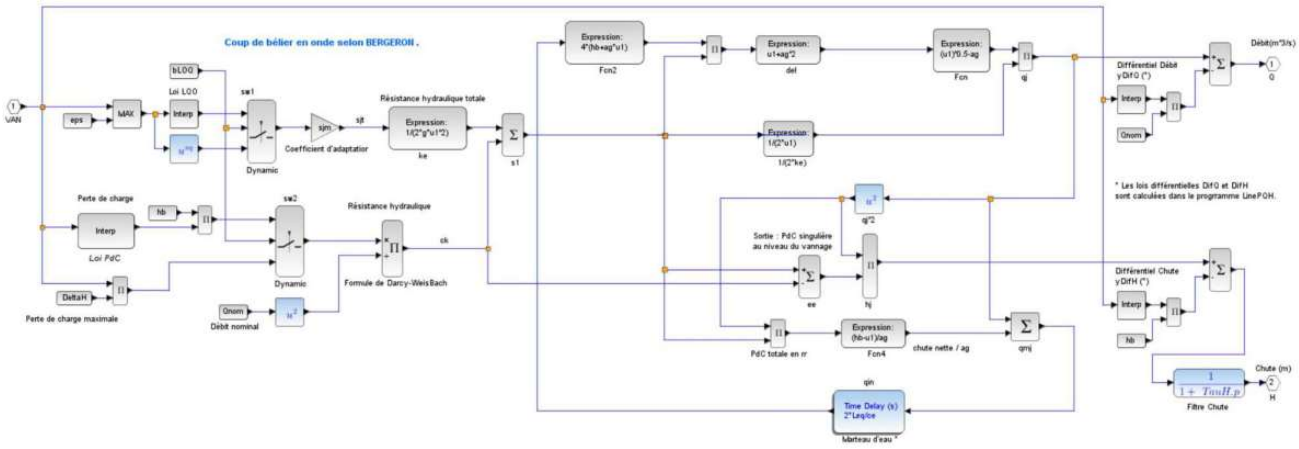


Figure 95 : TURBADDUC circuit (without machine hill)

☞ **The linearization laws and dependencies P, Q, H, PDC are calculated automatically when the simulation is launched (file .sce). Therefore, it is not necessary to enter them.**

In this case, a default yield law [xTend,tRend] is mandatory and defined in the GlobalVariables.sce file, located in the HydroSim\macros directory.

[5] Routines LINE_TURBADDUC.sci, LINE_TURBADDUC_FR4FR5.sci, LINE_TURBADDUC_KB.sci

```
//Opening
//---------------
xRend=[0:00 0.10 0.20 0.30 0.40 0.50
0.60 0.70 0.80  0.90 1.00];

//Efficiency
//---------------
yRend=[0.00 0.75 0.85 0.88 0.9 0.905
0.91 0.91 0.905 0.90 0.89];
```

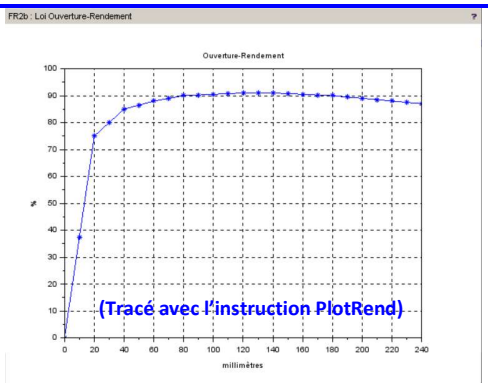


Figure 96 : Default yield law in the **GlobalVariables.sce** file

☞ **If this rule is not suitable, it should be revised by programming a Rend rule in the "XLS" file in the site directory, with a new relationship (xRend, yRend), in an "REND" sheet of Excel.** *(See §6.2).*

6.4.3 Program bLOQ=1 if the linearization laws are known

6.4.3.1 Principe

- If **bLOQ=1** :

  The flow rate is calculated using an experimental linearization law Q=f(O), obtained from linearity readings measured directly at the production site and provided in an Excel file on the **LINE** sheet. (*see§6.4.3.2, file **K2c.xls**, directory **HydroSim\demos\FRANCIS\FR2\K2_c**)*

  In this case, the TURBADDUC calculation circuit produces, by construction, a shift relative to the measured site values.

  For this reason, differential components, gap compensators *yDifQ* and *yDifH,* are added at the output of the circuit to guarantee the static values of flow and drop, while retaining the dynamic aspect of the simulation, for the simulation of water hammer and pure delays in pipes.

  ☞ *The **yDifQ** and **yDifH** laws are automatically calculated in the preliminary phase of launching the simulation.*

  It is then necessary to specify the linearization laws, as indicated in the following chapter.

6.4.3.2 Entering the linearization laws - LINE Law

The linearization laws of the study must be introduced into the .XLS files, in a sheet named "LINE", by copying and pasting the columns from the Excel tables specifying them in user coordinates, into the line-oriented vectors (in the Scilab sense):

- Vectors O[] (opening), Q[] (flow rate), P[] (power) Rend[] (efficiency), H[] (head), PDC[] (head loss) ()



	// 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	]	]	]	]	]	]

Figure 97 : Inserting linearization laws into an XLS file - **LINE** sheet - *HydroSim\demos\FRANCIS\FR2\K2_c* directory)

Definition points can be added to define the zero-opening operating points.

HydroSim primarily uses the Scilab instruction "**interpln**"[6] to manage interpolations across the entire operating domain.

This instruction assumes monotonic distributions sorted in ascending order. It is not necessary to reverse the Excel tables if they are in a different order, as HydroSim performs an automatic rearrangement of the distributions when the simulation is launched.

Therefore, Scilab's **interpln** function can be applied to all the following internal and global variables:

HydroSim variable	Meaning	Unit
xLPO / yLPO	Abscissa / Ordinate of law Opening / Power	Reduced
xLQO / yLQO	Abscissa / Ordinate of law Opening / Flow rate	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 / Head loss	Reduced
yDifQ	Column vector - Difference between model flow rate and experimental flow rate	Reduced
yDifH	Column vector - Differential between model Head and experimental Head	Reduced
O	Vector column Opening	mm
Q	Vector column Flow rate	m^3/s
P	Vector column Power	MW
H	Vector column Head	m
Rend	Vector column Efficiency	Reduced
PDC	Vector column Head loss	m

Figure 98 : Global variables used in linearization laws

[6] Enter « help interpln » in the Scilab console to get help on this function, or "interpln Scilab" on the NET (Firefox, google...etc)

It is more readable to display a vector in its transposed form (vector nx1). Thus, in the Scilab console, type "O'" instead of "O".

However, in the **interpln** instructions, it is mandatory to enter line vectors (1xn) "O"

Opening :	**Opening :**	**Flow rate :**	**Flow rate :**
-->interpln([P;O],210) ans = 186.88185	-->interpln([yLPO;O],210/Pnom) ans = 186.88185	-->interpln([P;Q] ans = 52.71551	-->interpln([yLPO;Q],210/Pnom ans = 52.71551

Figure 99 : Scilab **interpln** function syntax

All combinations are possible with the variables indicated in *Figure 98*

6.4.4 Plotting and verifying linearization laws

Special instructions have been developed to visualize linearization curves.

The plotting functions are available from the Scilab console, after an initial loading of the laws (or the initial launch of a simulation with a ".sce" file)

. ☞ En By entering the "**Plot**" command in the Scilab console, you obtain online help summarizing all the plotting functions:

```
--> Plot <-------- Instructions to be entered in the Scilab console
-------------------------------------------------------------------------------
Online Help :

        HYDROTUR linearization law tracing functions

        A configuration file must be previously loaded before use

        Enter a comand in the Scilab Console:
        -----------------------------------------------------------------------
         PlotP            : Power/Opening Curve
         PlotQ            : Flow/Opening Curve
         PlotPQ           : Flow/Power Curve
         PlotQP           : Power/Flow Curve
         PlotH            : Head/Opening Curve
         PlotRend         : Efficiency Law
         PlotPDC          : Pressure Loss Law
         PlotDifH         : Head differential
         PlotDifQ         : Flow differential
         PlotLINE         : Set of linearization laws
         PlotLF           : Multi-slope law of closing maneuver times
         PlotLF demo      : Multi-slope law of closing maneuver times
         PlotHill         : Hill machine
         PlotHill demo    : Hill machine
         PlotAll          : All Relationships
-------------------------------------------------------------------------------
```

Figure 100 : Online help on plotting linearization laws in the Scilab console

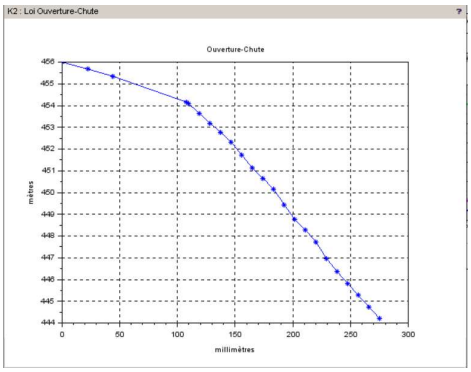


Figure 101 : **PlotH** Instruction

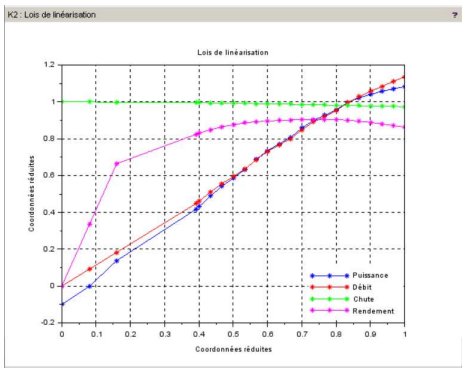


Figure 102 : **PlotLINE** Instruction

6.4.5 Adding interpolation points to linearization laws

It is possible to add interpolation points to linearization laws using the "**Interpoler**" instruction, which is present in the new version of HydroSim. (*Figure 103*)

This device allows the laws to be completed when the domain indicated in the Excel file remains partial, or to ensure that the operating point defined in a sequence needs to be re-specified.

If this is not the case, the operating point will be calculated by linear interpolation in the linearization laws, which may potentially cause a transient regime to appear when the simulation is launched. (*non bumpless*)

The aim is therefore to refine the laws.

For example, in study K2, you will find the LINE sheet in the file K2c.xls.:

```
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 103 : Using the HydroSim '**Interpoler**' function

The syntax is as follows: **Interpoler**("o=xxx, p=yyy") to interpolate the point at the aperture xxx millimeters at the power yyy in MW. It is also possible to interpolate in flow rate, by replacing "p" with "q" in m³/s

In this case, the power is evaluated from the efficiency law of the unit, the only law required in the simulations.

The points to be interpolated are generally deduced from the recordings, when they are not present in the linearization laws provided (example: the idle run in a trip sequence)

If adding an interpolated point breaks the monotony of the law, an error is reported and the simulation is not started.

This is the case if we try to interpolate the point here: **Interpoler("**o=183.3, p=210") (the instruction is commented out //)

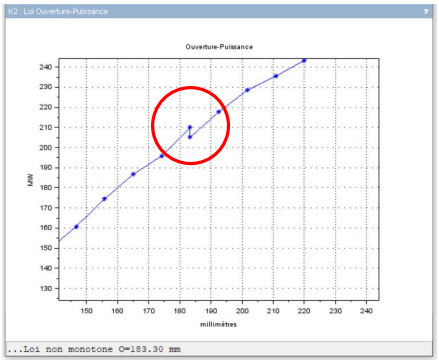


Figure 104 : Detection of a break in monotonicity in linearization laws

7 MACHINE HILLS

7.1 General Information - Variable Speed Characteristic Curves

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

To do this, turbine manufacturers establish, using tests on reduced models, nomograms, valid for a specially machined turbine, designed to obtain the best efficiencies of the wheels.

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

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

The parameters obtained are as follows, depending on the rotational 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 unit and sizing the flywheel).

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

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

- Flow rate Q becomes unit debit Q11 (or q11)
- Speed n becomes unit rotation speed n11
- Torque C becomes unit torque C11 (or c11)

Indeed, rules of homothety then allow us to go from the characteristics of the reduced models to the characteristics of the real machine.

The standardized quantities used in the modelling are:

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

$$n_{11} = \frac{n.D}{\sqrt{H}}$$ 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 a 1 m head ($m^{1/2}/s$)

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

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

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

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

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

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

Machine hills allow the simulation of group behaviour, considering the basic diagram shown below:

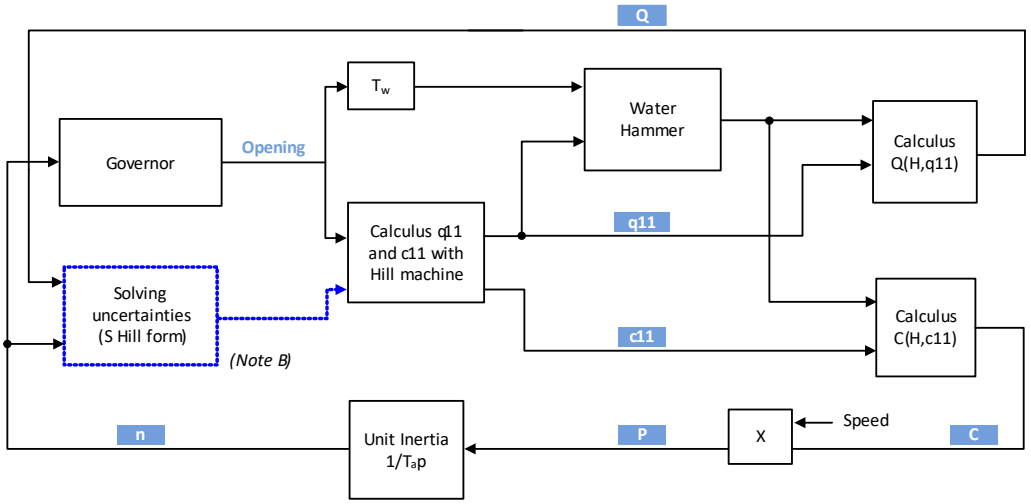


Figure 105 : Modeling principle using characteristic hills

7.2 Organization

The machine hills are loaded when the "**SCE**" file of the model taking this data in is launched, or in a "**Replay**" sequence of a recording in the corresponding directory.

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

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

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

In these modules, the hill interpolators have the following common features in their solutions within the SCILAB SOLVERS; the outputs of these modules depend on the embedded algorithm:

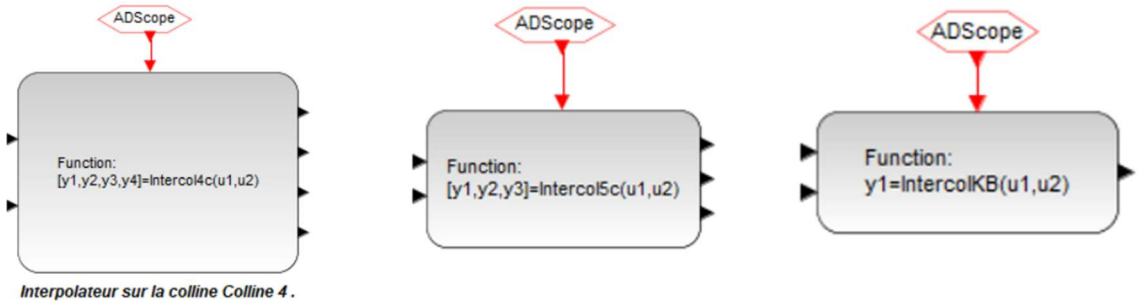


Figure 106 : Hill Functions in Xcos TurbAdduc Modules FR4-FR5-KB1

- The 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 way.
- The ADSCope period can be modified in the "System" component, common to all circuits, and is currently set to 2 ms..

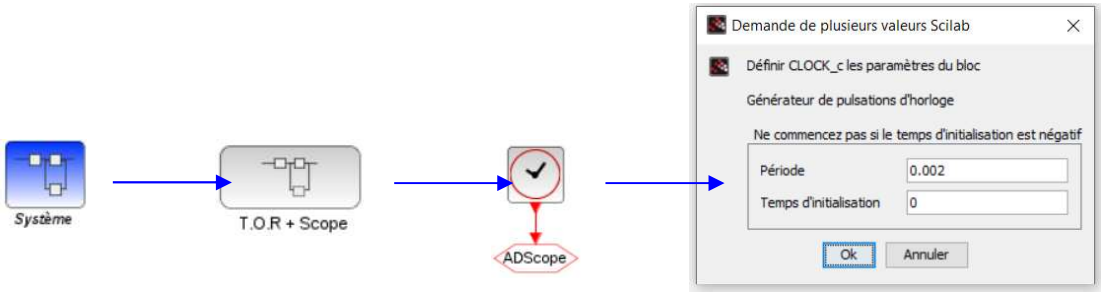


Figure 107 : Interpolator Sampling - Machine Hill

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

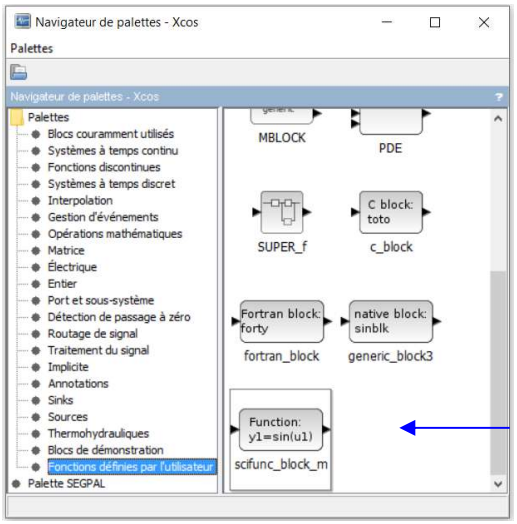


Figure 108 : The "**scifunc_block_m**" function in the Xcos standard palette

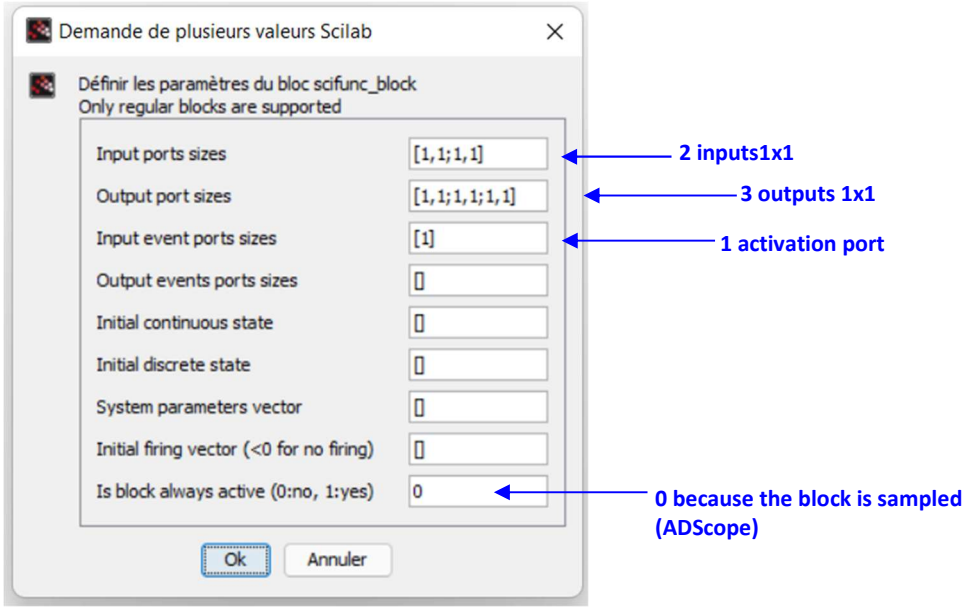


Figure 109 : Functional box of the **Intercol5c** interpolator – FR5 circuit (Box 1/2)

7.3 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:

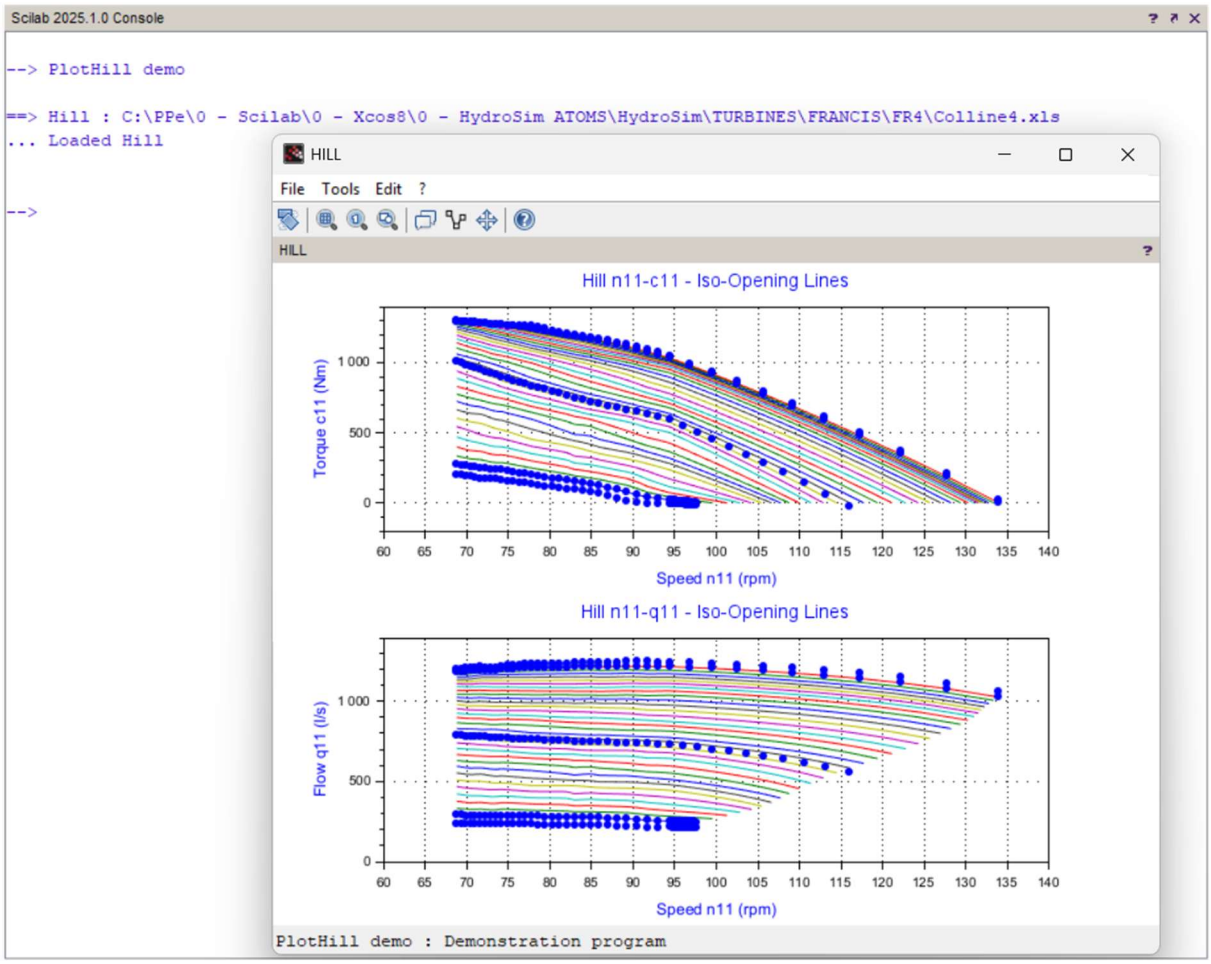


Figure 110 : **PlotHill demo** - Demonstration of a hill machine interpolator

7.4 Hills for Francis Machine type FR4

7.4.1 Representation in the TurbAdduc circuit

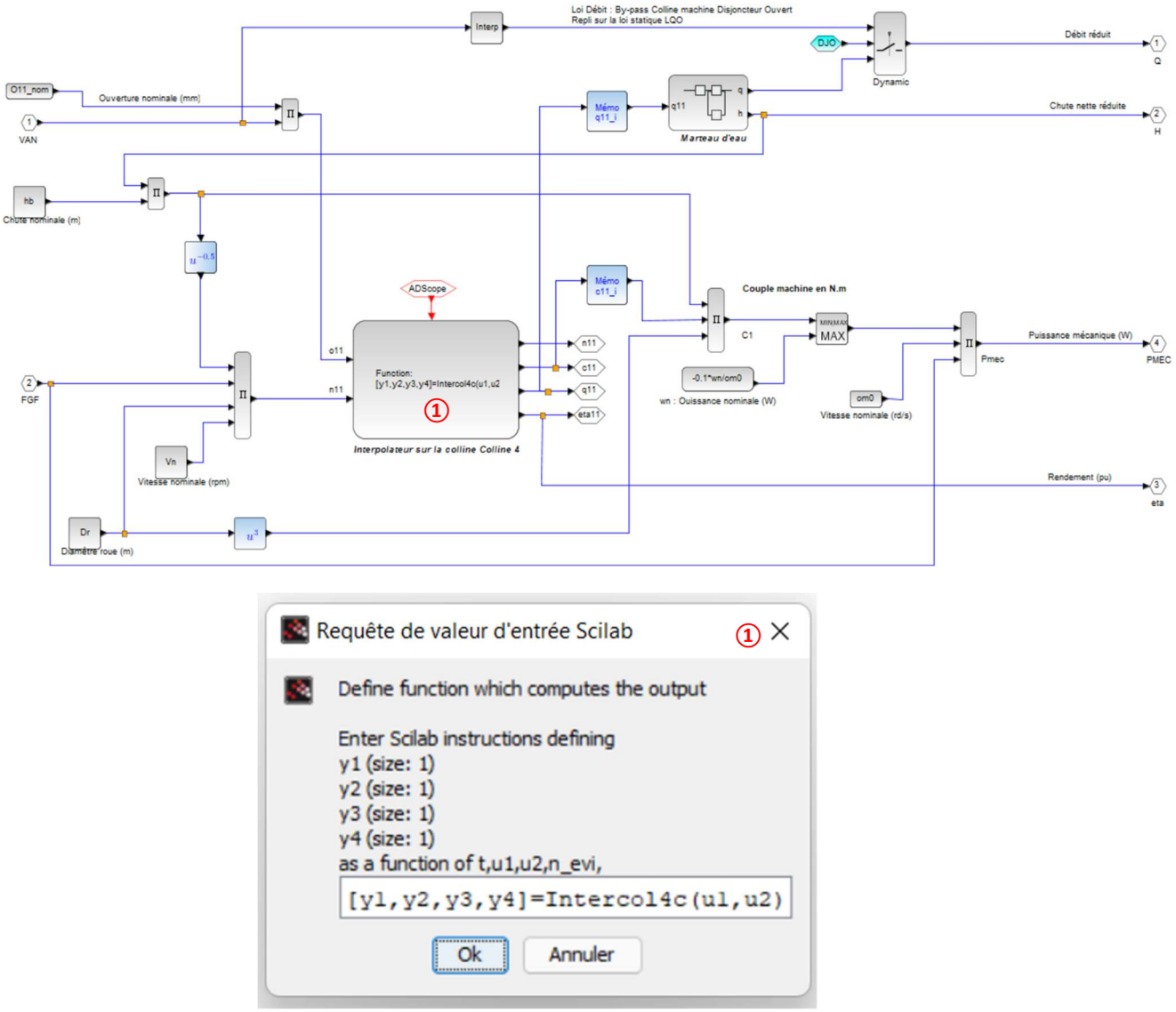


Figure 111 : Hills for FRANCIS Machine Type FR4 – Interpolator **Intercol4.sci** (Box 2/2)

7.4.2 Loading FR4 Hills

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 112 : Declaration and insertion of the FR4 machine hill into the XLS parameterization file

It is then loaded by the "FR4_Loader" loader:

At the end of the script execution, if all formats have been respected, a message will appear in the Scilab console indicating that the operation was successful:

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

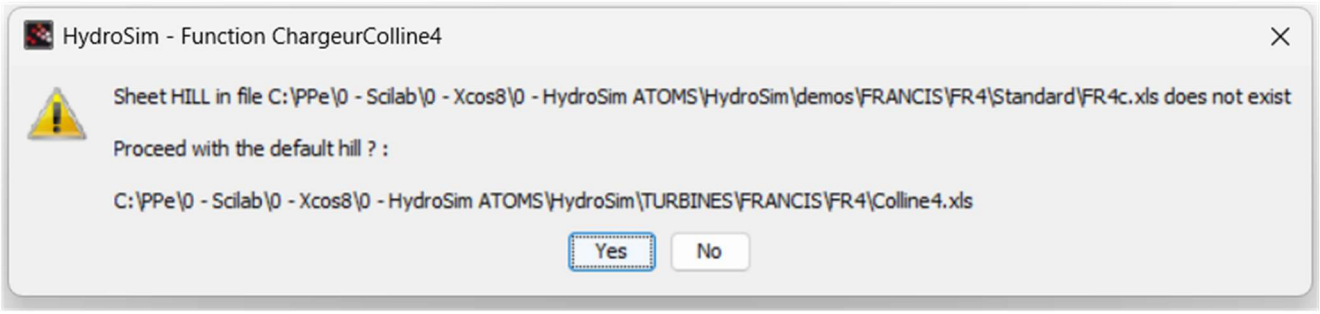
==> Hill : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR4\Standard\FR4c.xls
... Loaded Hill

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 113 : Loading diagnostics for an FR4 hill in the Scilab console

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



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

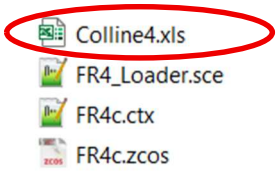


Figure 114 : Default Hill Colline4.xls

7.4.3 FR4 Hill Format

The FR4 Hill file (for example 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:

	A	B	C	D	E	F
1	Index	Opening (mm)	N (rpm)	Q (l/s)	ETA (%)	C (N.m)

Figure 115 : FR4 Hills Format

The fields are separated by a tab character ("\t" in C language or ASCII code 09h)

The table must be sorted:

- **First, through increasing 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 116 : Sort extracted from the file Colline4.txt

7.4.4 Plotting the FR4 hills

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

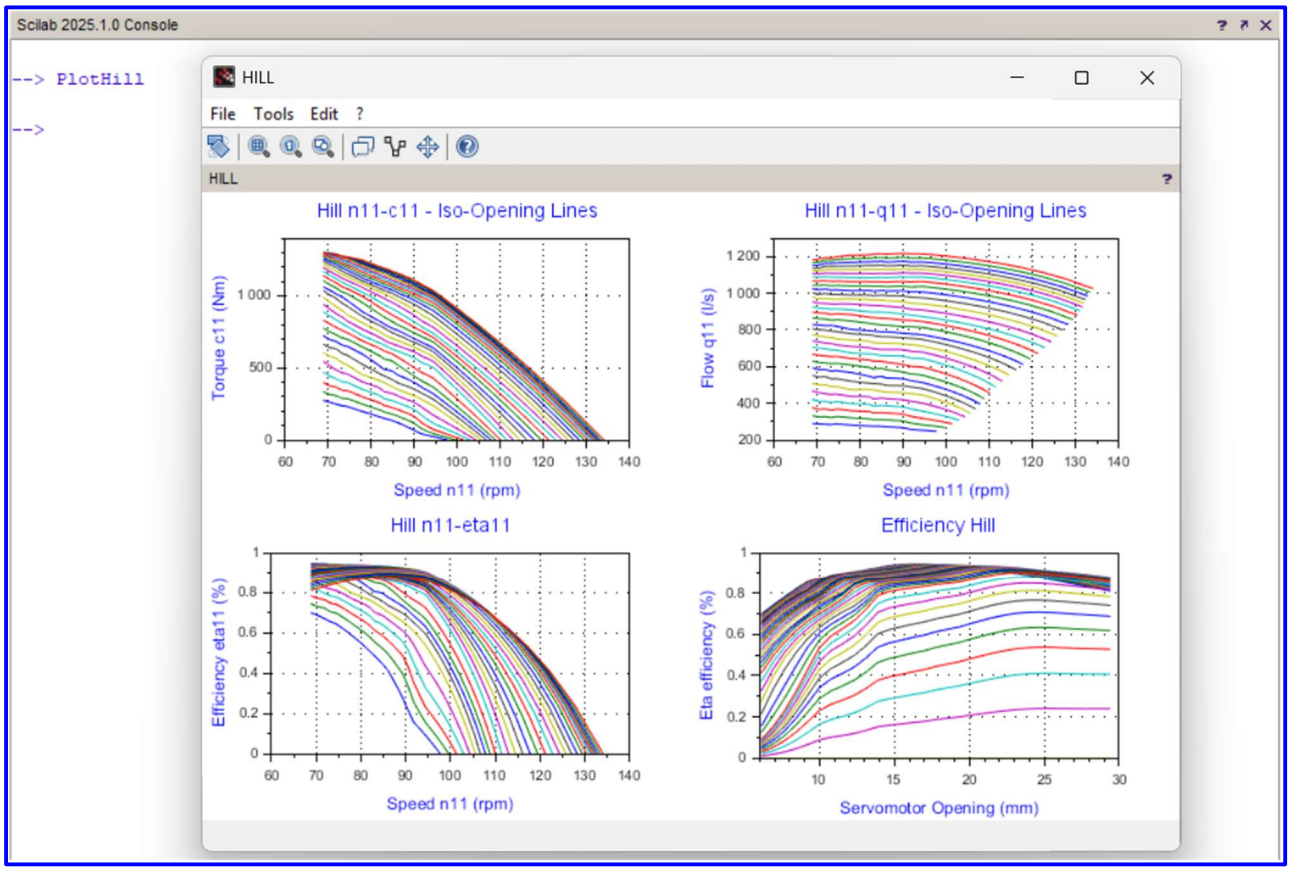


Figure 117 : Plotting of the FR4 hill in the Scilab console

7.5 Hills for Francis FR5 type machine

7.5.1 Representation in the TurbAdduc circuit

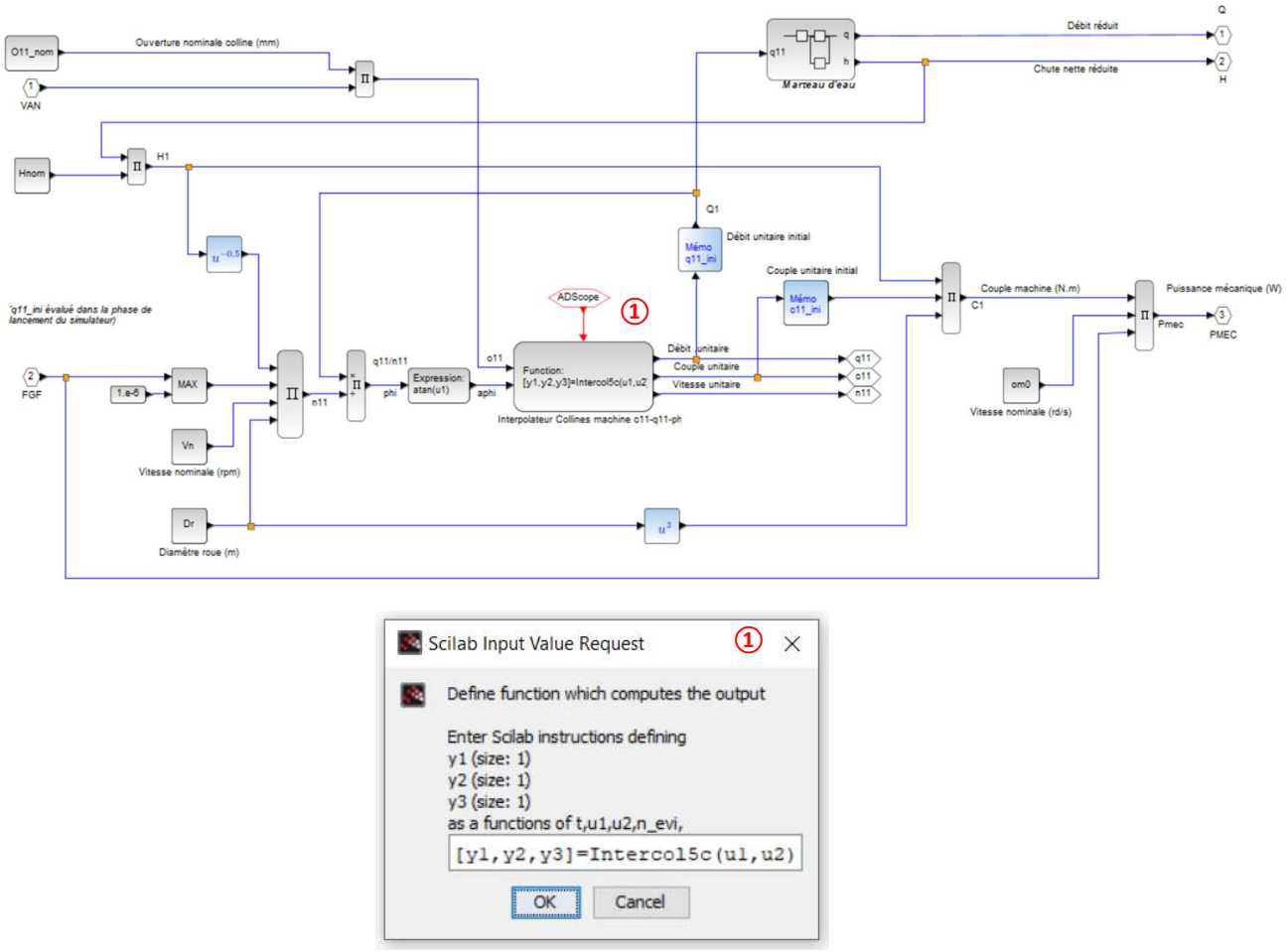


Figure 118 : Hill for FRANCIS Machine Type FR5 – Interpolator Intercol5c.sci (Box 2/2)

7.5.2 Loading FR5 Hills

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 119 : Declaration and insertion of the FR5 machine hill into the XLS parameterization file

It is then loaded by the "FR5_Loader" loader:

At the end of the script execution, if all formats have been respected, a message will appear in the Scilab console indicating that the operation was successful:

```
-------------------------------------------------------------------
Machine :         FRANCIS
Xcos Model :      FR5c.zcos
Project :         FR5c
-------------------------------------------------------------------

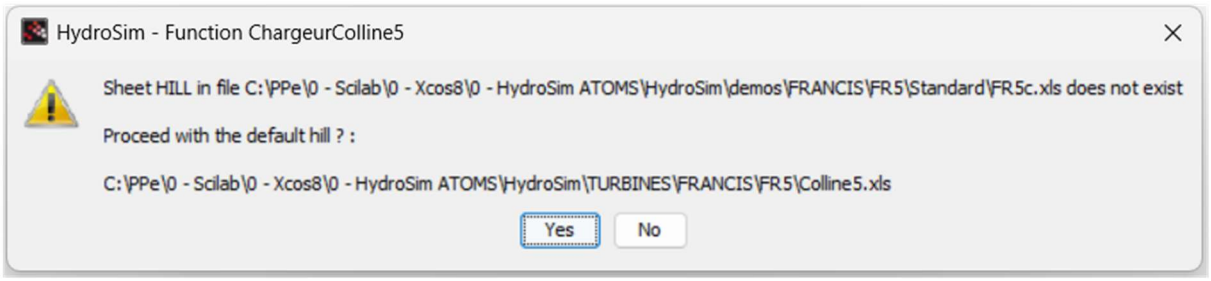
==> Hill : C:\PPe\0 - Scilab\0 - Xcos8\0 - HydroSim ATOMS\HydroSim\demos\FRANCIS\FR5\Standard\FR5c.xls
... Loaded Hill

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

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

Figure 120 : Loading diagnostics for an FR5 hill in the Scilab console

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



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

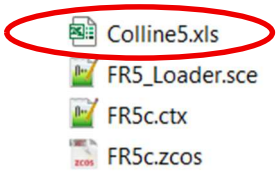


Figure 121 : Default Hill Hill5.xls

7.5.3 FR5 Hills Format

The Hill FR5 file (for example 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:

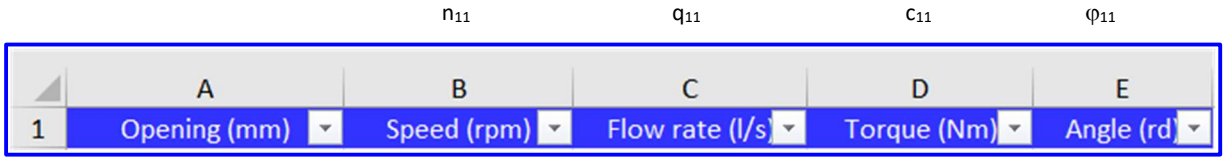


Figure 122 : FR5 Hills Format

The fields are separated by a tab character ("\t" in C language or ASCII code 09h)

On each line, we can verify 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 "Arc Tangent".

The table must be sorted:

- **First, through opening increasing**
- **Then, for each opening, by increasing angle φ11**

	A	B	C	D	E
1	Opening (mm)	Speed (rpm)	Flow rate (l/s)	Torque (Nm)	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 123 : Sort extracted from the file Colline5.txt

7.5.4 Plotting the FR5 hills

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

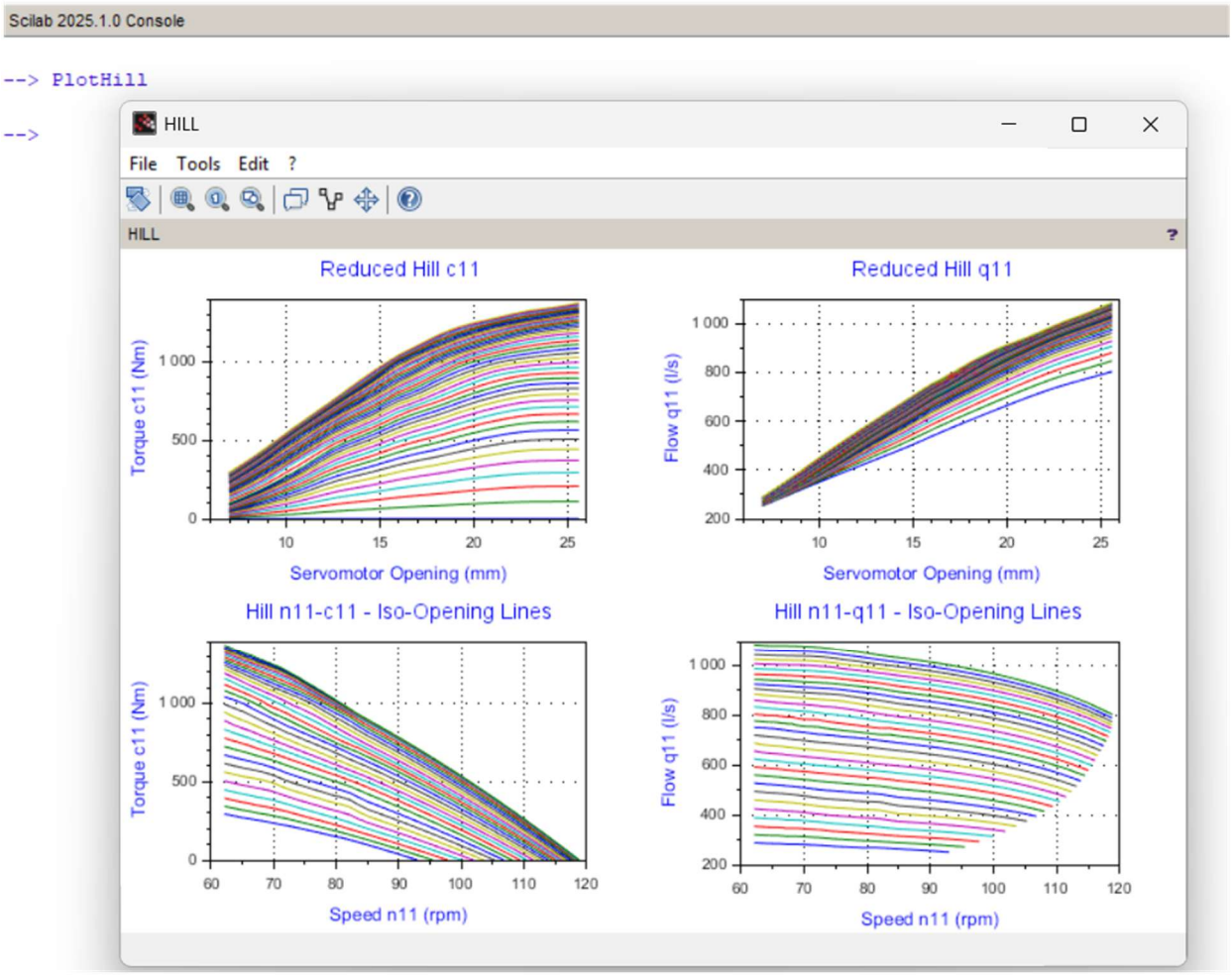
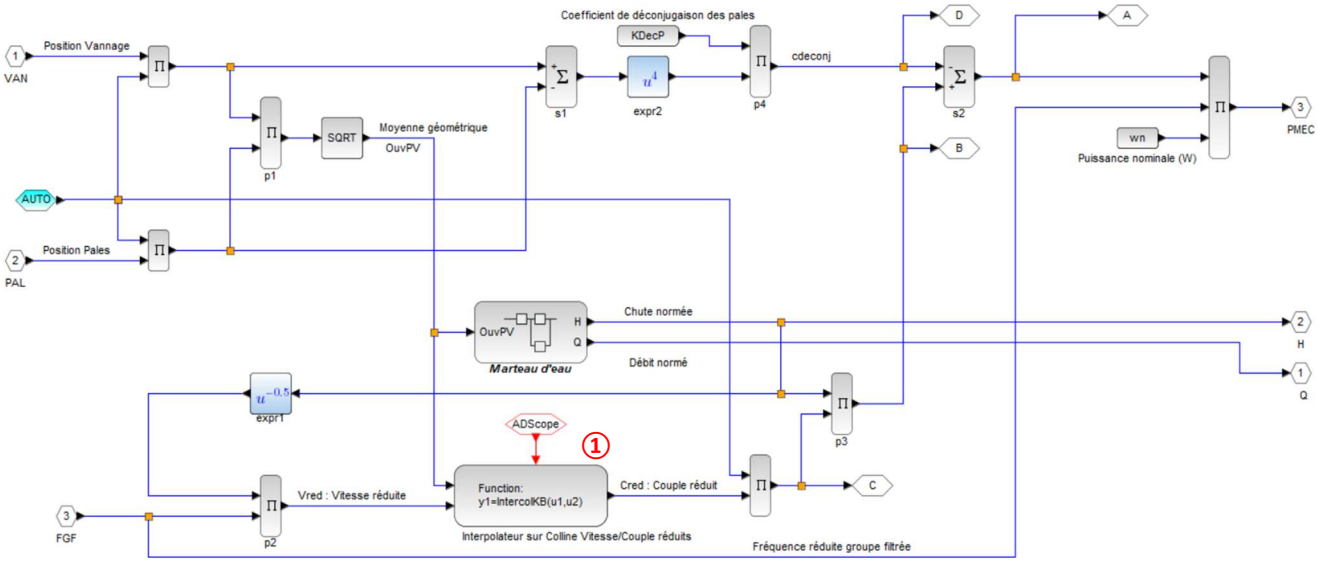


Figure 124 : Plotting of FR5 hill in the Scilab console

7.6 Analytical Hill for KB1 Kaplan Machine

7.6.1 Representation in the TurbAdduc circuit



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

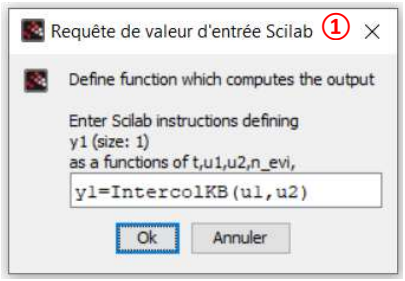


Figure 125 : Hill for Kaplan Machine KB1 – **IntercolKB** Interpolator (Box 2/2)

7.6.2 Plotting the KAPLAN hill

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

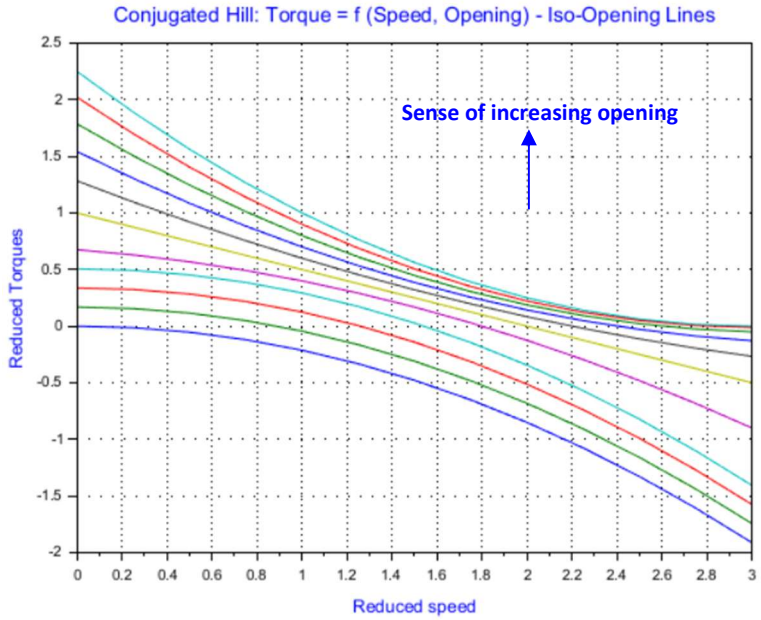
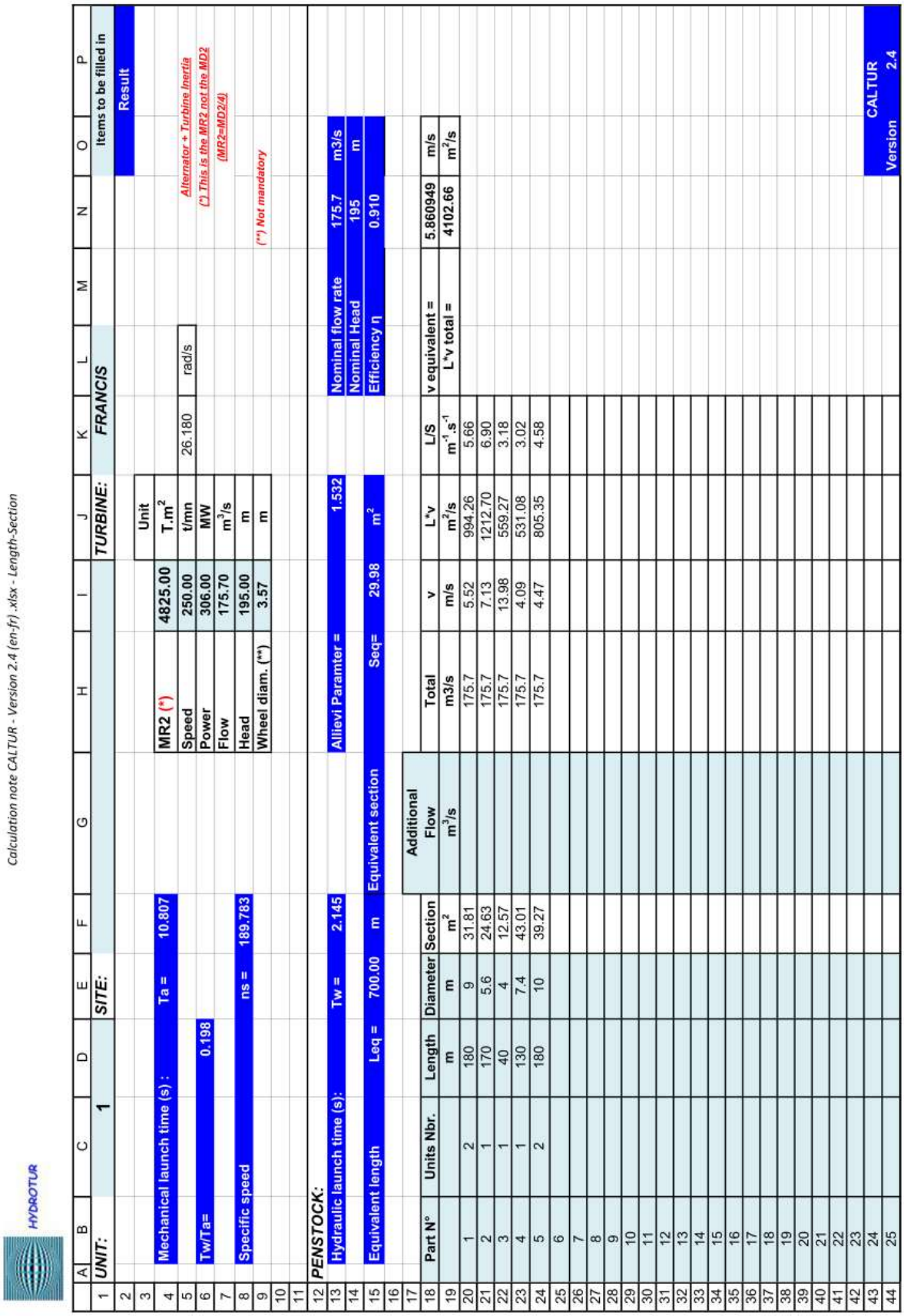


Figure 126 : KB1 Analytical Hill Iso-Opening Lines

APPENDICES

A. ELEMENTS OF CALCULATION IN THE HYDRAULIC CIRCUIT CALTUR EXCEL



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		UNIT:	1		SITE:					TURBINE:	FRANCIS				Items to be filled in	
2																Result
3										Unit						
4		Mechanical launch time (s) :	Ta =	10.807				MR2 (*)	4825.00	T.m^2						
5								Speed	250.00	t/mn	26.180	rad/s			Alternator + Turbine Inertia	
6		Tw/Ta=		0.198				Power	306.00	MW					(*) This is the MR2 not the MD2	
7								Flow	175.70	m^3/s					(MR2=MD2/4)	
8		Specific speed	ns =	189.783				Head	195.00	m						
9								Wheel diam. (**)	3.57	m					(**) Not mandatory	
10																
11																
12		PENSTOCK:														
13		Hydraulic launch time (s):	Tw =	2.145				Allievi Paramter =		1.532		Nominal flow rate	175.7	m3/s		
14												Nominal Head	195	m		
15		Equivalent length	Leq =	700.00	m	Equivalent section		Seq=	29.98	m^2		Efficiency η	0.910			
16																
17							Additional									
18		Part N°	Units Nbr.	Length	Diameter	Section	Flow	Total	v	L*v	L/S	v equivalent =	5.860949	m/s		
19				m	m	m^2	m^3/s	m3/s	m/s	m^2/s	m^{-1}.s^{-1}	L*v total =	4102.66	m^2/s		
20		1	2	180	9	31.81		175.7	5.52	994.26	5.66					
21		2	1	170	5.6	24.63		175.7	7.13	1212.70	6.90					
22		3	1	40	4	12.57		175.7	13.98	559.27	3.18					
23		4	1	130	7.4	43.01		175.7	4.09	531.08	3.02					
24		5	2	180	10	39.27		175.7	4.47	805.35	4.58					
25		6														
26		7														
27		8														
28		9														
29		10														
30		11														
31		12														
32		13														
33		14														
34		15														
35		16														
36		17														
37		18														
38		19														
39		20														
40		21														
41		22														
42		23														
43		24													CALTUR	
44		25													Version 2.4	

Calculation note CALTUR - Version 2.4 (en-fr) .xlsx - Length-Section

09/09/2025

1/1

Figure 127 : Calculation note en/fr CALTUR.xlsx

B. OLEOHYDRAULIC STRUCTURE OF THE SYSCOP A 2-STAGE COPYING SYSTEM

B.1 Operating principle of the double-stage copying system

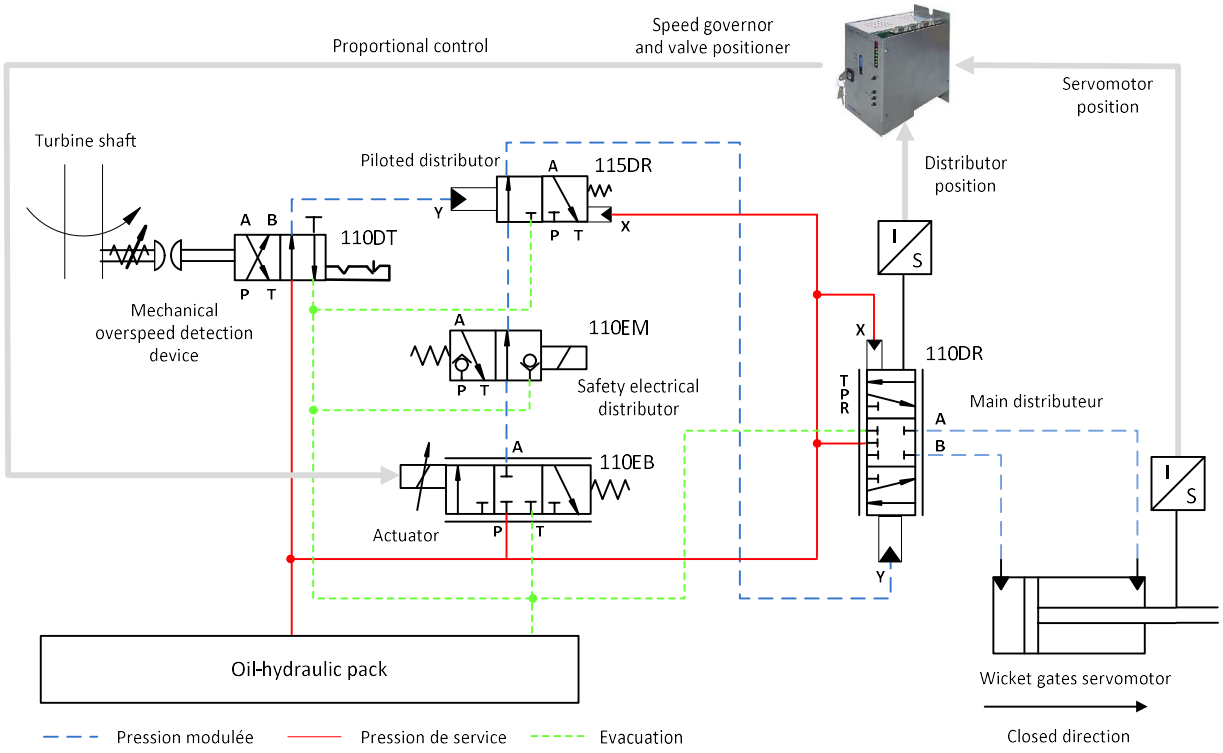


Figure 128 : Simplified diagram of the control unit for the adjustment mechanism – SYSCOP copying system with 2 components

C. EXAMPLE OF A SETTINGS FILE

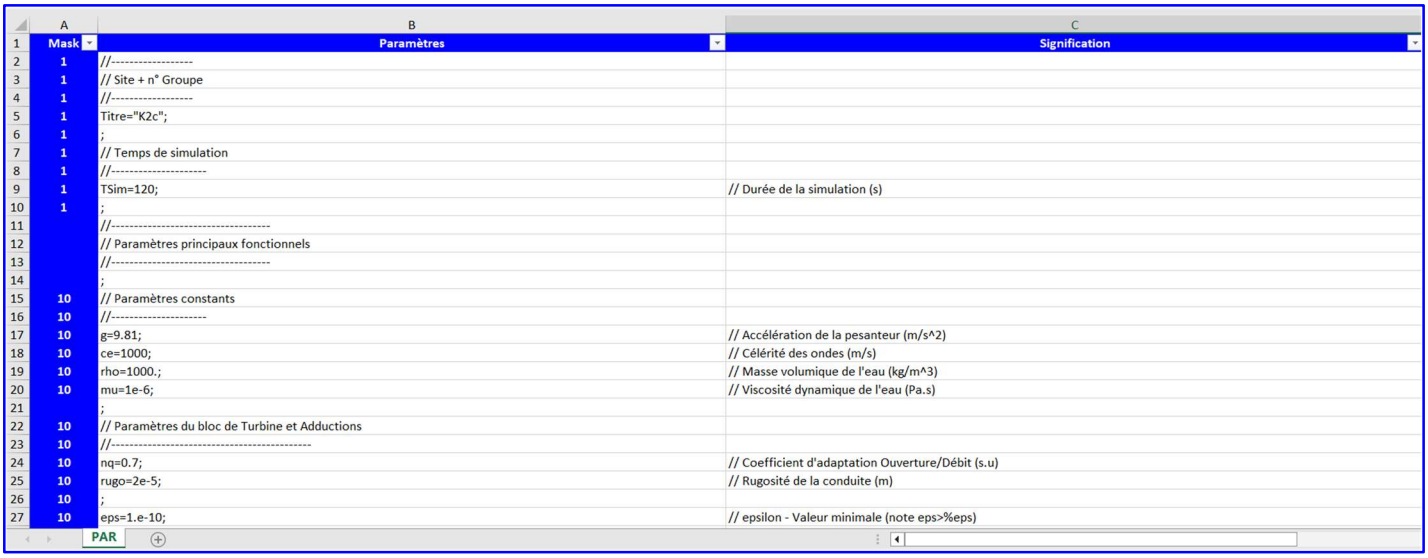
C.1 «FR2c .xls » File

"xls" files, in EXCEL 97 2003 format, are becoming the new form of model parameterization.

As a reminder, the ".txt" file is always obtained by programming "bDelTxt=1" in the file "HydroSim\macros\GlobalVariables.sce"

Each line of an "xls" file is structured in 3 columns

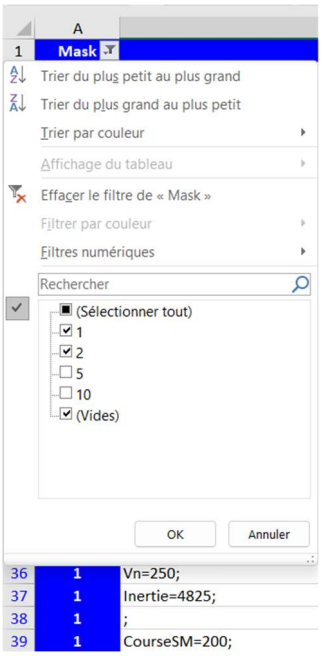
Column A	Column B	Column C
Multi-level display mask (Integer 1, 2 ,…etc)	Setting (ex : Tsim=120)	Optional comment on a parameter (ex : // Simulation duration (s))



	A	B	C
1	Mask	Paramètres	Signification
2	1	//----------	
3	1	// Site + n° Groupe	
4	1	//----------	
5	1	Titre="K2c";	
6	1	;	
7	1	// Temps de simulation	
8	1	//----------	
9	1	TSim=120;	// Durée de la simulation (s)
10	1	;	
11		//----------	
12		// Paramètres principaux fonctionnels	
13		//----------	
14		;	
15	10	// Paramètres constants	
16	10	//----------	
17	10	g=9.81;	// Accélération de la pesanteur (m/s^2)
18	10	ce=1000;	// Célérité des ondes (m/s)
19	10	rho=1000.;	// Masse volumique de l'eau (kg/m^3)
20	10	mu=1e-6;	// Viscosité dynamique de l'eau (Pa.s)
21		;	
22	10	// Paramètres du bloc de Turbine et Adductions	
23	10	//----------	
24	10	nq=0.7;	// Coefficient d'adaptation Ouverture/Débit (s.u)
25	10	rugo=2e-5;	// Rugosité de la conduite (m)
26	10	;	
27	10	eps=1.e-10;	// epsilon - Valeur minimale (note eps>%eps)

PAR

Figure 129 : Partial view of the FR2c.xls file and column layout



Access to the Masking Zone

Data filtering column A allows the display of all or part of the parameters depending on the selected masks.

To do this, click on the "Mask" box in A1 

to display the drop-down menu of masks.

Masks available

Then select or deselect the masks to apply to the Excel sheet.

The proposed ranking is provided for informational purposes only.

The user can therefore redefine the assigned levels according to their own arrangement.

Figure 130 : Hiding in a settings sheet in EXCEL 97 2003 format

The masking levels are defined *a priori*, following an order ranging from the fundamental parameters of regulation to optional parameters of expertise.

The table below summarizes these arbitrary choices, which can be modified by changing the masks in column A.

It is of course possible to add other masks 3, 4, 20…etc.

Level	Meaning
1	Fundamental parameters derived from a stability study (Kp, Ti, etc.)
2	Signal generators and disruptors,
5	*These are, a priori, first-level system parameters, to be modified only on specific instructions.*
10	Comment lines, second-level system parameters to be modified only on specific instructions

Figure 131 : Prioritizing the arrangement of parameters in an .xls file

D. MAIN DIAGRAM OF THE FR2 MODEL

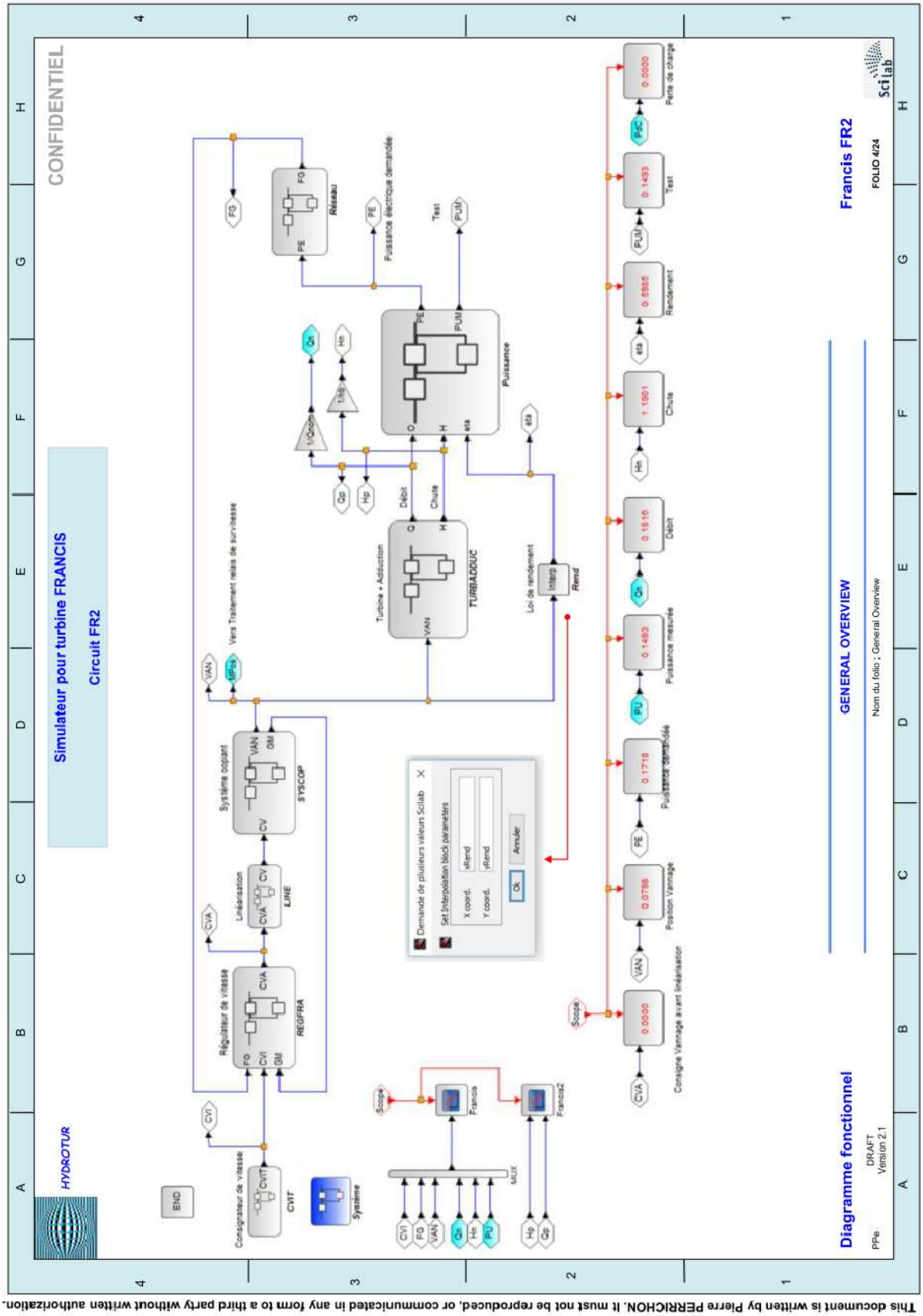
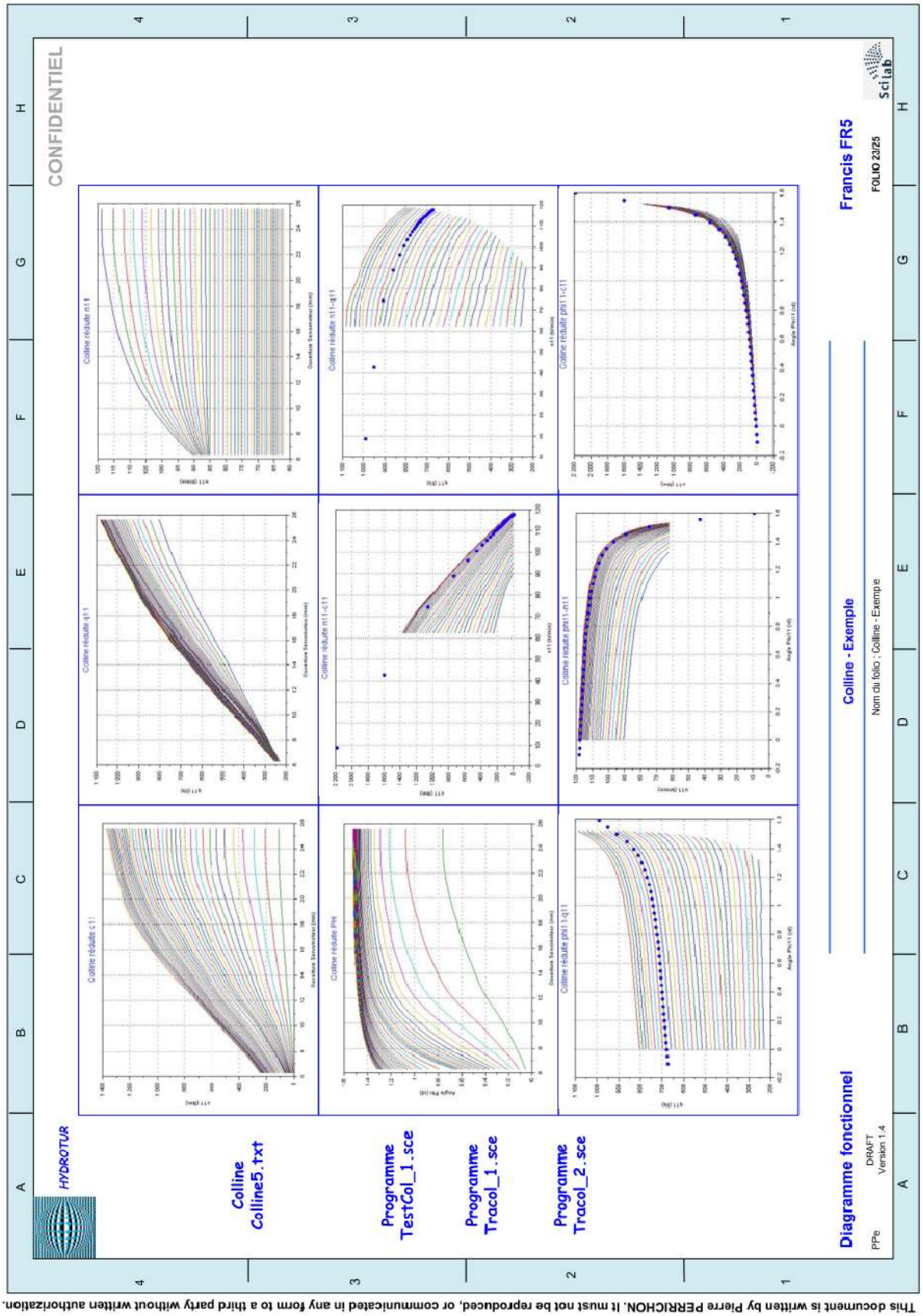


Figure 132 : FRANCIS turbine simulator - FR2 circuit

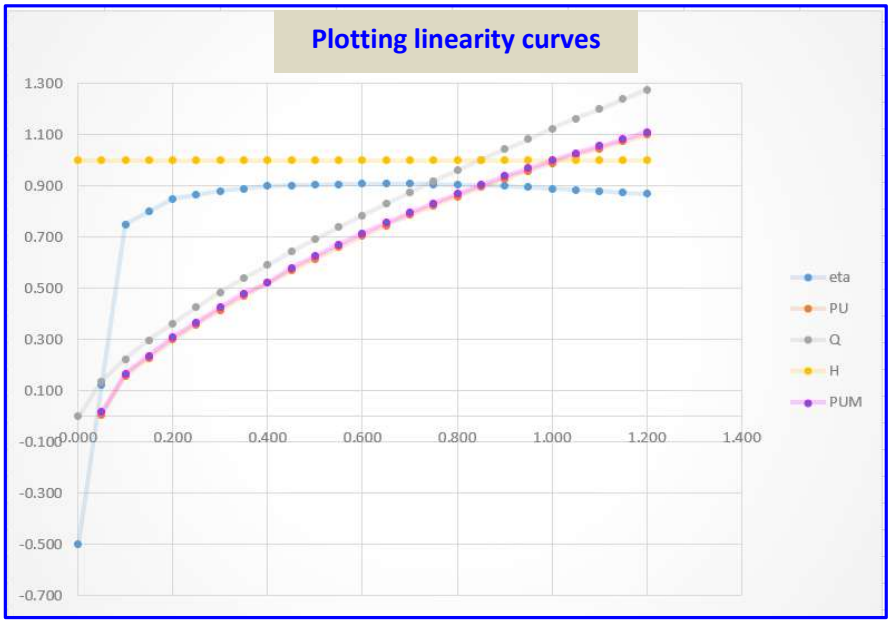
E. REPRESENTATION OF A HILL

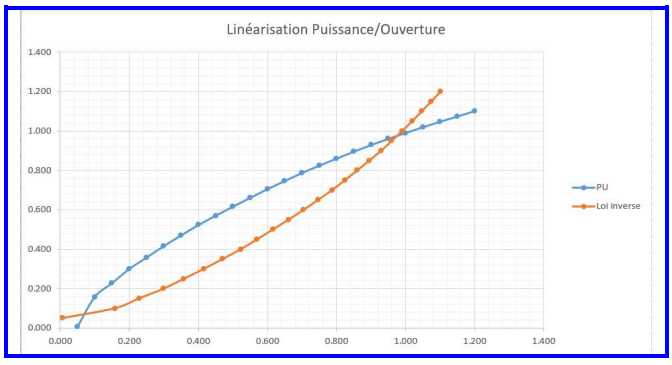


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F. PLOTTING LINEARITY CURVES – FR2 CIRCUIT – FILE FR2_LOIS.XLSX

	A	B	C	D	E	F
1	**Ouverture**	**PUM**	**PU**	**Q**	**H**	**eta**
2	0.000	0.000	-0.010	0.000	1.000	-0.500
3	0.050	0.017	0.007	0.138	1.000	0.125
4	0.100	0.168	0.158	0.224	1.000	0.750
5	0.150	0.238	0.228	0.298	1.000	0.800
6	0.200	0.310	0.300	0.364	1.000	0.850
7	0.250	0.368	0.358	0.426	1.000	0.865
8	0.300	0.426	0.416	0.484	1.000	0.880
9	0.350	0.480	0.470	0.539	1.000	0.890
10	0.400	0.523	0.523	0.592	1.000	0.900
11	0.450	0.580	0.570	0.643	1.000	0.903
12	0.500	0.626	0.616	0.692	1.000	0.905
13	0.550	0.671	0.661	0.740	1.000	0.908
14	0.600	0.715	0.705	0.786	1.000	0.910
15	0.650	0.756	0.746	0.831	1.000	0.910
16	0.700	0.797	0.787	0.875	1.000	0.910
17	0.750	0.834	0.824	0.919	1.000	0.908
18	0.800	0.870	0.860	0.961	1.000	0.905
19	0.850	0.905	0.895	1.003	1.000	0.903
20	0.900	0.939	0.929	1.044	1.000	0.900
21	0.950	0.970	0.960	1.084	1.000	0.895
22	1.000	1.000	0.990	1.124	1.000	0.890
23	1.050	1.029	1.019	1.163	1.000	0.885
24	1.100	1.057	1.047	1.201	1.000	0.880
25	1.150	1.084	1.074	1.239	1.000	0.875
26	1.200	1.111	1.101	1.277	1.000	0.870





G. GATEWAY FROM .SCG RECORDING FILES TO EXCEL

It is possible to create .TXT format files from .SCG graphic files for importing the data into Excel. (*See SaveGraph §4.3.2*)

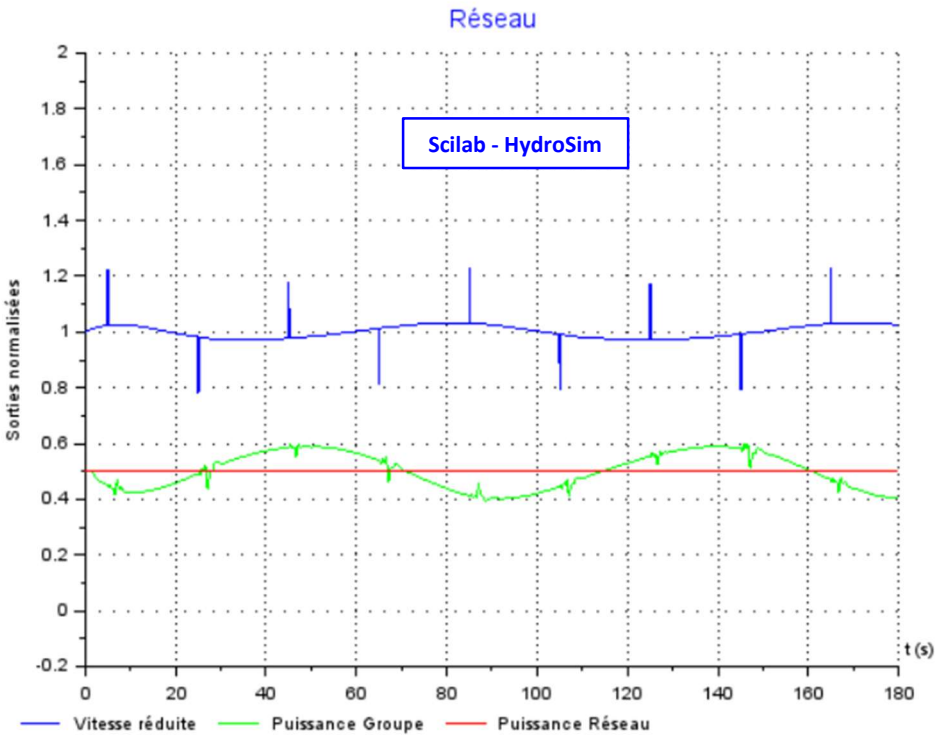


Figure 133 : File 01_Reseau -- FR2c - Pn=50% - Sinus 10% Fréquence Dirac 20%.scg

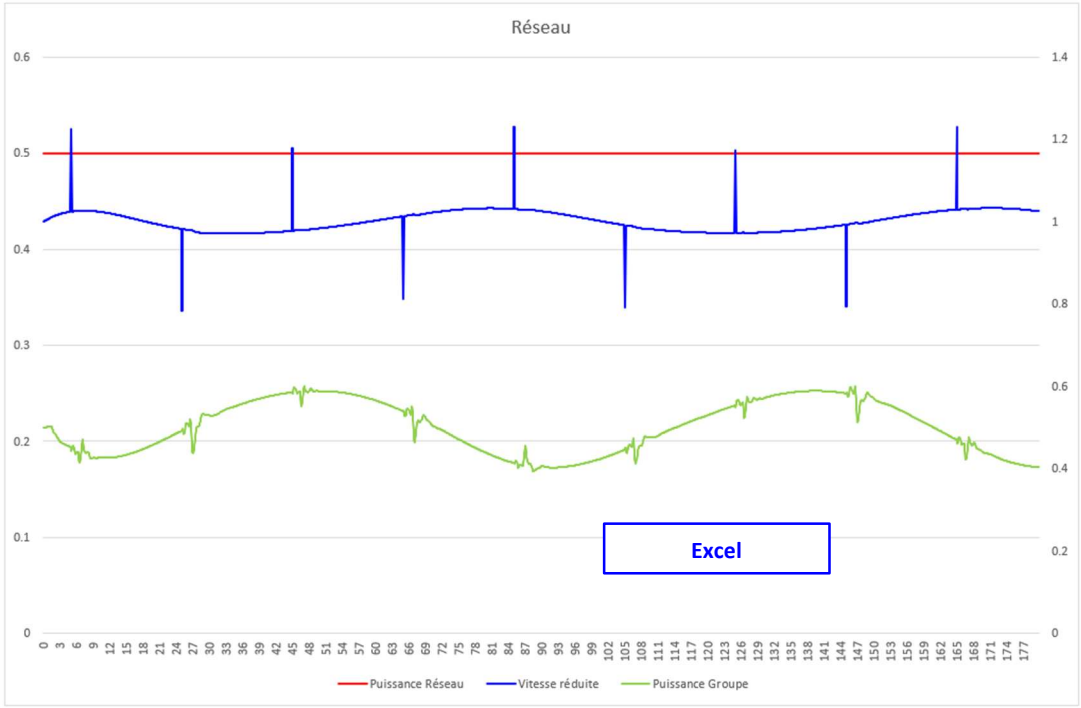


Figure 134 : File 01_Reseau -- FR2c - Pn=50% - Sinus 10% Fréquence Dirac 20%.xlsx

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Personal notes