

NCP Model

User Manual

Prepared by

PSR

VERSION 5.27



PSR

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1 INTRODUCTION

1.1 Description

The NCP is a mixed-integer linear programming model aimed at determining the optimal dispatch (minimum cost or maximum revenue) of an electrical system in hourly stages, either every 30 minutes, 15 minutes, or 5 minutes, for a horizon of up to two months (1488-time stages).

For the simulation of the transmission network, it uses direct current flows with quadratic losses.

The model can be used in a chained manner with Medium/Long-Term studies of longer duration (SDDP model) using the future cost function.

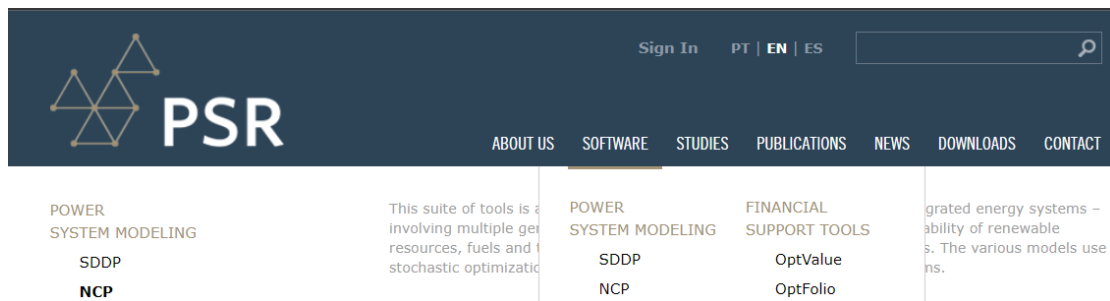
1.2 Units and abbreviations

Data and results are presented in units commonly used in the power sector:

- k Thousand
- kW Power in kilowatts (10^3 W)
- MW Power in Megawatts (10^3 kW)
- kWh Energy in kilowatt/hour
- MWh Energy in Megawatt/hour (10^3 kWh)
- GWh Energy in Gigawatt/hour (10^3 MWh)
- BTU British Thermal Units (0.2520 kilocalories)
- Hm³ Million cubic meters
- \$ Monetary unit used in this manual

1.3 Installation

NCP can be installed by downloading the setup file from our web site www.psr-inc.com selecting “Software > Power System Modeling > NCP > Download”, as shown in the figure below:



After clicking “Download”, select the version to be installed. One can alternatively save the installation file and install it later.

The program must be installed with administrator rights. The password required for the installation is sent by e-mail to the licensed users each time a new version is available. The conditions for acquiring a license can be requested at the following e-mail address: ncp@psr-inc.com.

To run the model, a hard lock key (dongle) is required. Each hard lock key is specifically programmed to identify the licensed user.

1.4 Disk space requirements

NCP requires 400 MB of free space to install the system.

1.5 Regional settings

NCP requires to set dot (.) as a decimal symbol and comma (,) as a list separator. The settings are accessed through Windows > Control Panel > Regional Configuration and Language > Additional Configuration.

1.6 Execution

NCP can be executed from its Windows graphical interface by means of the desktop icon created by the installation process or the Windows menu “Start > Programs > PSR > NCP”.

1.7 Model dimensions

Model dimensions can be seen through the menu option “Help > Dimensions” in the graphical interface.

1.8 Data and results

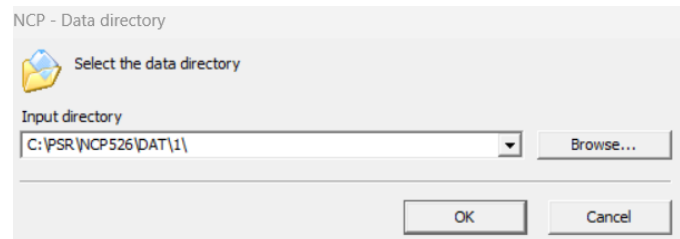
Input data are in *.dat ASCII files. Results are in CSV (comma-separated values) files.

2 WORKING DIRECTORY

When the model is executed through its Windows graphical interface by means of the desktop icon created by the installation process or the windows menu “Start > Programs > PSR > NCP”, a directory where the input data and results are located must be selected or created following this procedure:

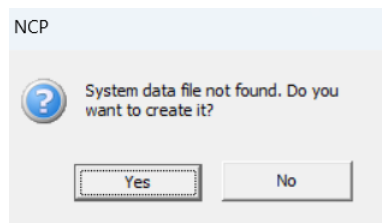
2.1 Directory selection

The first interface option is the selection of the input data directory:

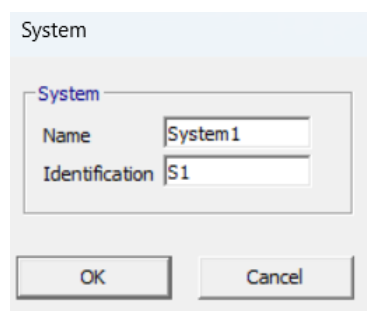


2.2 Creating a new case

If there are no data files in the selected directory, the interface will suggest the creation of new data:

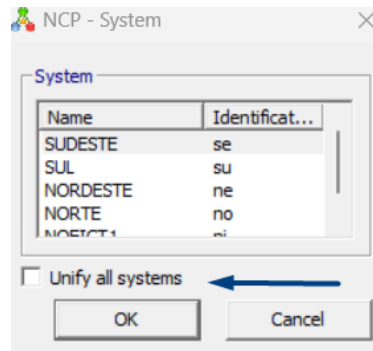


If the answer is “Yes”, a new screen requesting the name of the system and a two-character identifier will be presented:



The two characters identifier is used in the names of the files generated by the interface. For example, the name of the thermal configuration file is ctermis1.dat, where s1 is the system identifier.

Alternatively, the interface allows creating an NCP database from a medium / long-term SDDP database. For SDDP databases with more than one system, there is an option to unify the systems through an automatic import:



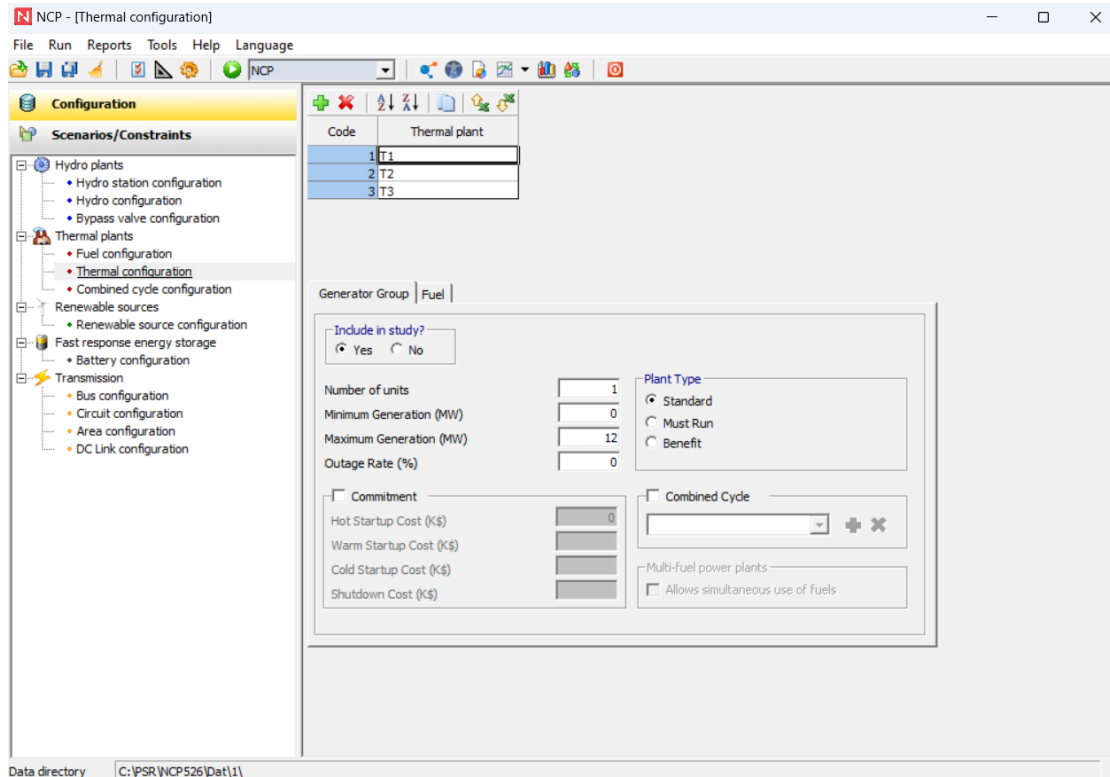
The importer will create an additional folder with "integrated" data that is fully compatible with the NCP model. In this new database, the systems are converted into "buses" and the interconnections are transformed into DC links.

3 OVERVIEW

The model is used through a graphical user interface that allows easy access to all its characteristics.

3.1 Interface structure

The interface is divided into three main sections: The Menu (located in the upper part), the Navigation tree (on the left side) and the List of elements (on the right side) as shown in the figure below:



A description of the main parts of the interface follows.

3.1.1 Main menu

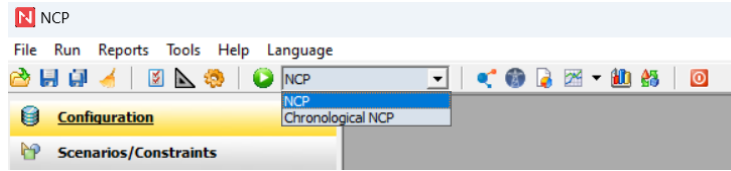
It is located at the top of the screen. Each of the options presents a series of secondary options which are described below:

a) File

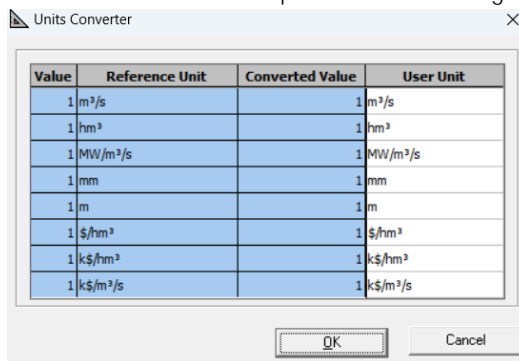
- *Directory*: selects a new data directory
- *Save*: saves changes made to the selected option
- *Save All*: saves all changes made
- *Compact case data*, compacts the input data into a .zip file
- *Exit*: exits the model

b) Run

- *Execution Parameters*: explained in part 11 of this document
- *Run*: runs the model in one of their two options: NCP or Chronological NCP.



- *View flows*: for transmission network results
 - *Graph*: explained in section 13 of this document
- c) *Reports*
- Analysis of input data
 - Execution report
 - Costs report
 - Convergence report
- d) *Tools*
- *Preferences*: modifies names and options of the navigation tree as described in section 3.2.2 of this document
 - *Units converter*: enters the screen that is presented in the figure below:












The model allows the modification of the reference units presented in the second column of the table to other units defined by the user. For example, the m³/s (cubic meters per second) reference unit in the first row has been modified to cfs (cubic feet per second).

- *Activate NCP iFeedback*, allows the automatic sending of statistics about the executed cases
 - *Activate Dashboard*
- e) *Help*: provides access to the following documents:
- *Release notes*: file that contains a brief explanation of the latest modifications and improvements made to the model.
 - *Methodology Manual*
 - *User's Manual*
 - *Chronological NCP*: option of model execution explained in section 11.10 of this document
 - *Dimensions*: presents a screen showing the limits of the model regarding the number of buses, plants, etc.
 - *Check for updates*, automatic update option of the installation components (model, graph, visualization tools, etc.)
 - *Update license*, access the latest file of licensed users of the tool

- *About*: presents the logo of the program and the name and address of PSR, proprietor of the NCP Model.
- f) *Language*: allows the user to select the language of the graphical interface:
- *English*
 - *Spanish*
 - *Portuguese*

In the second line of the menu are located the buttons with the most common options, according to the following detail:

Button	Menu	Option
	File	Directory
	File	Save
	File	Save All
	Tools	Preferences
	Tools	Units Converter
	Run	Execution Parameters
	Run	Run
	Run	Graph
	File	Exit

Note that on the right side of the Run Button the user can select either the option of running NCP or the Chronological NCP.

3.1.2 Navigation tree

On the left side, below the menu, is the Navigation Tree, which is divided in two sections:

Configuration: presents the basic system configuration information related to hydrological stations, hydroelectric plants, thermal plants, renewable resources, and transmission.

Scenarios/Constraints: presents the additional information required to represent the scenarios and constraints of the system such as inflows, fuel prices, maintenance schedules, etc.









3.1.3 List of elements

On the right side, below the menu, is the list of Elements that are defined according to the selection made in the Navigation Tree. For example, if “**Configuration > Thermal configuration**” is selected in the Navigation Tree then the number and the name of the thermal plants in the system will be presented as shown in the figure below:

Code	Thermal plant
1	The1
2	The2
3	The3
4	The4
5	The5
6	The6

The elements of the model are hydroelectric plants, hydro stations, inflows, generating units, thermal plants, areas, buses, and transmission lines.

On the top of the List of Elements there are buttons that allow adding, removing, sorting and exporting elements according to the detail presented in the table below:

Button	Function
	Add
	Remove
	Ascendent order
	Descendent order
	Export data in CSV format
	Import data in CSV format
	Launch DrawHydro Module
	Copy

3.1.4 Data editing panel

According to the selection made in the Navigation Tree and the selected element in the List of Elements, a form for data editing of the selected element will be shown below the List of Elements.

3.2 Navigation

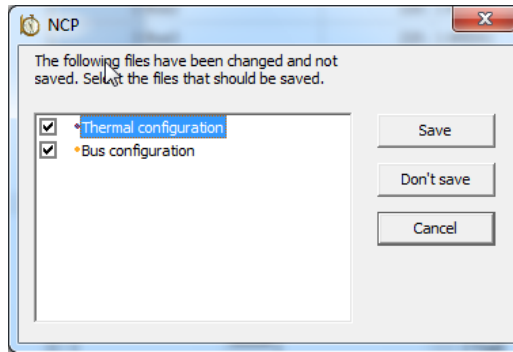
3.2.1 Editing data

The navigation tree allows the user to open and change the screens associated to each datum. When the user clicks in a branch of the navigation tree, the screen name becomes light blue and an element list associated to the selected data automatically appears in the upper right corner, below the menu. The list appears in the order these elements were added.

The user can sort the list in ascending or descending order by clicking the buttons indicated in the previous section.

A panel where the user can view and edit the data appears at the bottom right. When the screen is open, the information corresponding to the selected element is presented. Note that there are tabs the user can select to display the corresponding information. The selected tab appears framed with dotted lines.

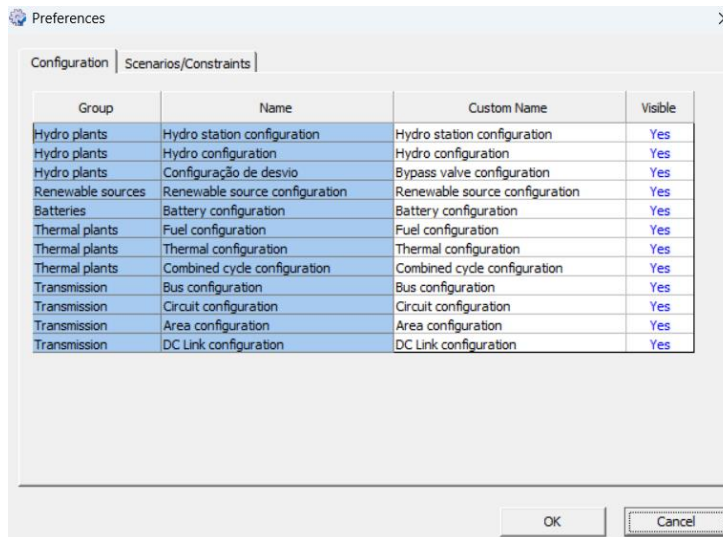
If any modification is made in the data, an asterisk (*) appears on the left side of the selected branch in the navigation tree. When the user wants to exit or run the program, the user can choose to save the modifications, ignore them, or cancel the action as shown in the figure below:



3.2.2 Customization

The navigation tree shows all the restrictions that can be represented in the NCP Model. The user can customize this list by selecting “Tools > Preferences” from the Menu. The user can modify the names of the options and simplify the navigation by disabling the options that are not required in the system under study.

The options are disabled by double clicking the option in the “Visible” column as shown in the figure below:



3.3 Selection list

Whenever needed to set a relation in a subset of elements, for example if the user needs to define the hydroelectric plants that are connected to a bus or the circuits that are associated to a constraint, the information is presented in two lists, containing the elements to be selected, separated by buttons that allow the transfer of elements between the lists. The following figure presents the case of selecting the hydroelectric plants connected to a specific bus:



The list on the right shows the elements that have been selected as part of the relationship.

3.4 Chronological data tables





Chronological information such as demand, flow rates, maintenance, etc., is organized in spreadsheets where each row corresponds to a day, while each column represents one hour (from hour 0 to hour 23)

3.4.1 Adding and removing data

The addition or removal of days is carried out using the buttons located at the upper-right part of the spreadsheet, allowing to add or to remove days at the beginning or end of the existing chronological data series as shown in the figure below:

(m ³ /s)									
Date\hh	04h	05h	06h	07h	08h	09h	10h	11h	12h
05/06/2013	10.	10.	10.	10.	10.	10.	10.	10.	10.
06/06/2013	12.	12.	12.	12.	12.	12.	12.	12.	12.
07/06/2013	14.	14.	14.	14.	14.	14.	14.	14.	14.

The buttons have the following functions:

Button	Function
	Add initial day
	Add final day
	Remove initial day
	Remove final day

Additionally, it is possible to create an interval of days by selecting the desired quantity in the following figure:

Data initial date

Initial day

Number of days

3.4.2 Data management

All chronological data screens of NCP have Excel-like sheets where the user can easily manipulate the data.

The user can prepare the data in an Excel spreadsheet and then transfer it to NCP, using the Copy and Paste Window functions.

With the same Window functions, the user can also move data from NCP to Excel

4 HYDRO PLANTS

Data management is carried out through the two options of the navigation tree: Configuration and Scenarios/Constraints. The Scenarios/Constraints option is subdivided into Scenarios/Constraints at plant level and Scenarios/Constraints at unit level.

Below is the information that must be entered into each of the three options:

4.1 Configuration

4.1.1 Hydrological station configuration

The inflows to the hydroelectric plants are recorded through hydrological stations.

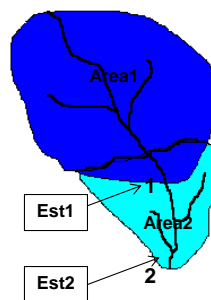
When this option is selected, the list of hydrological stations considered in the study appears on the right side of the interface in a screen like the one presented in the figure below:

Code	Hydro station	Downstream station
11	HS11	
12	HS12	
13	HS13	
14	HS14	
15	HS15	
16	HS16	

The buttons above the list of stations allow adding a new station, deleting a station and sorting them in ascending or descending order.

Each hydrological station is identified by a code and a name. Note that on the right side of the name it is also possible to define the immediately/directly downstream station code. This field should be filled only in case the downstream plant inflows are defined as total inflows not incremental ones. Inflows are defined by default as incremental.

The difference between total and incremental inflows is explained with the help of the figure below, which represents a river basin with two hydrological stations: Est1 and Est2. The catchment area of Est1 is Area1 and the catchment area of Est2 is Area1+Area2. In natural conditions (i.e., without any reservoir regulating the water flows in these rivers), the inflows registered in Est1 correspond to the rainfall that occur in Area1 and those registered in Est2 correspond to the rainfall that occur both in Area1 and Area2.



Let q_1 be the inflows in Est1 due to the rainfall in Area1 and q_2 the inflows in Est2 due to the rainfall in Area2. The total and incremental inflows for these hydrological stations are defined as follows:

For Est1: Total inflows (q_1) are equal to incremental inflows (q_1).

For Est2: Incremental inflows are equal to q_2 .

For Est2: Total inflows are equal to $q_1 + q_2$.

In case there is more than one immediately/directly upstream station to a given station (i.e., if the user defines more than one station pointing out to a given station as its downstream station), the total inflows for that station will be considered as the sum of the total inflows of all immediately/directly upstream stations.

4.1.2 Hydroelectric configuration

When this option is selected, the list of hydroelectric plants considered in the study appears at the top right of the interface; below this list, the basic data corresponding to the selected hydroelectric plant are presented as shown in the figure below:

Code	Hydro plant	Latitude	Longitude
1	H1		
2	H2		

Generator Group | Reservoir | Topology | Tables | Penstock | Hydro Unit

Include in study?
 Yes No

Number of units:

Total Installed Capacity (MW):

Unit minimum turbined outflow (m³/s):

Plant maximum turbined outflow (m³/s):

Minimum Total Outflow (m³/s):

O&M Cost (\$/MWh):

Mean Production Coefficient (MW/m³/s):

Outage Rate (%):

Minimum Generation (MW):

The buttons located above the list of hydroelectric power plants are used for adding a new plant, removing a plant, displaying the plants in ascending or descending order, displaying the topology of the plants and exporting or importing data to and from Excel.

In the middle right part are located the tabs that allow the introduction of the basic data of the hydroelectric plants. Below is the information that must be entered in each of them:

4.1.2.1 Generator Group

- a) *Consider plant?*
If the answer is yes, the plant will be considered in the study (existing plant); otherwise, the plant will not be considered in the study (future plant).
- b) *Number of Generating Units*
Represents the number of generating units in the hydroelectric plant.
- c) *Total Installed Capacity (MW)*
Is the production capacity of the hydroelectric plant. At any stage of the study, the maximum production of the plant is calculated as the minimum between the value of this field and the product of the maximum turbined outflow and the production coefficient.
- d) *Minimum turbined outflow (m³/s)*
Represents the minimum flow to be turbined by the hydroelectric plant. This flow may be required to avoid cavitation effects or other operational constraints. It is important to note that this flow results in a minimum forced generation at the hydroelectric plant must turbine throughout the simulation period.
- e) *Maximum turbined outflow (m³/s)*
Represents the maximum flow the hydroelectric plant can turbine.
- f) *Minimum Total Outflow (m³/s)*
Is equal to the sum of turbined and spilled outflows. It is used to represent constraints of water supply, navigation, etc.
- g) *O&M Cost (\$ /MWh)*
Represent the variable operation and maintenance cost associated with the plant.
- h) *Average Production Coefficient (MW/m³/s)*
Is the reference (mean) production factor of the plant, associated to reference storage level (e.g. 65% storage).
- i) *Outage Rate (%)*
This rate reduces the plant capacity, to represent the effect of outages. The reduced capacity of the plant is obtained by multiplying the capacity by $(1 - \text{Outage Rate} / 100)$.
- j) *Minimum Generation (MW)*
Represent the minimum continuous power to be generated by the plant. In a similar way to what is stated to the minimum turbined outflow, this value imposes a minimum forced generation for the plant.

4.1.2.2 Reservoir

- a) *Hydro station*
Pressing the button displays a drop-down box where the user selects the hydrological station associated with the plant.
- b) *Run-of-river*
This option must be selected in the event the plant has no storage capacity, i.e. the plant is not able to transfer water from one period to another. The information to be supplied is the following:
 - *Storage (Hm³)*, value supplied for information purposes only. It is not used by the model.
 - *Area (km²)*, value used to calculate the evaporation with the monthly evaporation coefficients presented at the bottom right of the interface.
 - *Associated Reservoir*, pressing the button it displays a drop-down box where the user can select an associated reservoir. In this case, the production factor of the

run of the river plant will be considered as variable and will be calculated based on the storage level of the associated reservoir.

c) *Regulation*

This option is selected when the plant reservoir has regulation capacity. The information that must be supplied is the following:

- *Minimum Storage (Hm³)*
- *Maximum Storage (Hm³)*
- *Spillage Type:*
 - *Controllable Spillage:* if selected, it indicates that the reservoir has bottom gates that allow the spilling at any reservoir level. The bottom gates are normally used to clean the sediments from the reservoirs, and NCP will be able to spill through these bottom gates at any time to release water to the downstream plants (this might happen when the turbinated flow is on its maximum and more water is needed for the downstream plants).
 - *Partially controllable,* indicates that the reservoir is enabled to spill from a certain storage amount.
 - *Not controllable,* it is only enabled to discharge if the reservoir is completely full.
- *Initial Condition Type:* the volume of the reservoir at the start of the simulation (at hour 0) can be reported as a fraction of the net/useful storage (maximum storage - minimum storage). In this case a value of 0 means that the reservoir is at its minimum level and a value of 1 means that the reservoir is at its maximum level. The volume may also be reported in terms of the water elevation; in this case it is necessary to define the storage x elevation table. Alternatively, the initial volume can be directly informed in Hm³.

d) *Spilling Cost (k\$/Hm³)*

Represents an economic penalty in case of spillage at the plant. This value overrides the general spilling cost located in the economic parameters screen (defined under the Execution parameters).

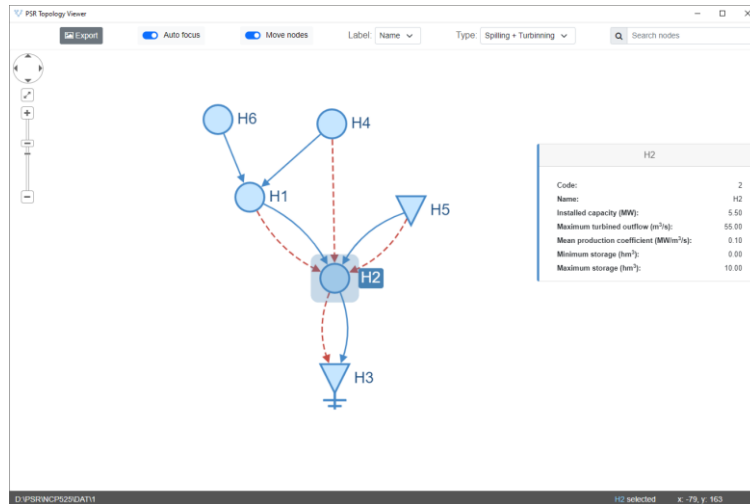
e) *Evaporation Coefficients (mm/month)*

These coefficients are expressed per km²; for their use in plants with reservoirs it is required to fill the volume x area table. For run-of- river plants, the area is informed directly (see *Area* description under *Run-of-river* item above).

4.1.2.3 *Topology*

For the selected hydroelectric plant, the user can define the downstream plant that will receive the selected plant turbinated outflow and the downstream plant that will receive the selected plant spilled outflow.

The Topology Viewer option, located in the list of buttons below the menu, allows the visualization of the topology, as shown in the figure below:



The blue lines represent turbined water, and the red lines are spilled water. Note for example that the H2 is a run-of-river station that turbines and spills to H3, while the H5 is a central with a reservoir. The H4 is a run-of-river station that turbines to H1 and spills to the H2. The spillage of the H6 plant does not go to any other plant.

4.1.2.4 Tables

There are four tables in which the user can enter variable parameters. In the model these tables are represented by means of piecewise linear functions. The tables are as follows:

- Storage x Production*
Represents the variation of the production factor as a function of the storage.
- Storage x Area*
Represents the variation of the reservoir surface area as a function of storage. This variation is used in the calculation of evaporation.
- Storage x Elevation*
Represents the variation of the reservoir elevation (in meters above the sea level) as a function of the storage.
- Storage x Infiltration*
Represents the variation of the infiltration (in m³/s) as a function of the storage.
- Outflow x Tailwater Elevation*
Represents the variation of the tailwater elevation (m.a.s.l.) as a function of the outflow (turbined outflow plus spilled outflow). In this table, the user can consider or not the influence of the spillage in the tailwater level elevation.
- Head x Maximum Turbined Flow*
Represents the maximum turbined flow of the power plant by varying with the gross head of the reservoir (difference between the forebay and tailwater elevation).

4.1.2.5 Penstock

Enable the calculation of hydraulic losses in the penstock that delivers water to the generating units. Losses are estimated as a loss coefficient α_1 multiplied by the square of the turbined outflow.

For each of the penstocks of a plant the user must enter the following information:

- a) *Code*: identifies each penstock.
- b) *Penstock*: the penstock name.
- c) *Capacity* (m^3/s)
- d) *Loss Coefficient* α_1 : is the coefficient used to calculate the hydraulic losses.

There are two possible penstocks configurations that the user can define in NCP:

- i. With one main penstock that feeds the individual penstocks connected to each generating unit. In this situation, the user must create one single penstock, which will be the main penstock, and the values of *Capacity* and *Loss Coefficient* α_1 defined in this screen will be related to the main penstock. The hydraulic losses in the main penstock will be calculated as the product of the *Loss Coefficient* α_1 multiplied by the square of the total turbined outflow of the plant (i.e., the sum of the turbined outflows of all generating units). Then the user must associate this single defined penstock to all generation units (see item *Unit* under section 4.1.2.6). The calculation of the hydraulic losses in each of the individual penstock will be done using the individual *Loss Coefficient* α_2 defined for each unit (see item *Unit* under section 4.1.2.6). The minimum and maximum outflows at each individual penstock will be, respectively, the first and last values in the table of outflow vs efficiency (see item *Table* under section 4.1.2.6).
- ii. With no main penstock, i.e., when the penstocks of each generating are directly connected to the reservoir and, therefore, have their own individual gates. In this situation, the user must create as many penstocks as the number of generating units and will latter associate each penstock to its corresponding generation units (see item *Unit* under section 4.1.2.6). The value of *Capacity* defined in this screen will be related to each individual penstock and the *Loss Coefficient* α_1 must be defined as zero. The calculation of the hydraulic losses in each of the individual penstock will be done using the individual *Loss Coefficient* α_2 defined for each unit (see item *Unit* under section 4.1.2.6). Furthermore, the maximum outflow of the individual penstocks of each generating unit will be the minimum between the penstock *Capacity* and the last value in the table of outflow vs efficiency (see item *Table* under section 4.1.2.6) for the generating unit.

4.1.2.6 Hydro Unit

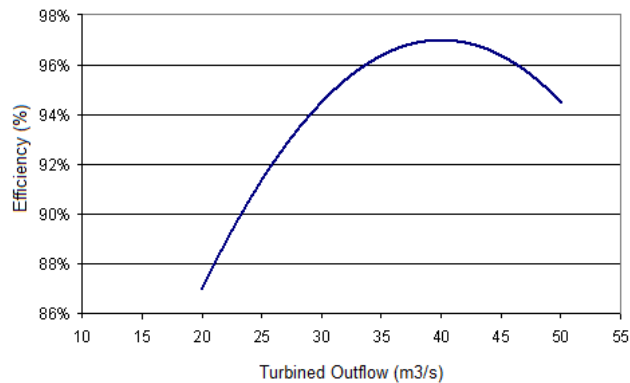
NCP enables the representation of hydroelectric production at the generating unit level using a production function for each generating unit.

If the *Constant forebay elevation* option is selected, there is no need to fill in the Storage x elevation table. In the same way, if the *Constant Tailwater Elevation* option is selected, there is no need to fill in the Outflow x Tailwater elevation table.

The information that must be provided for each generating unit is as follows:

- a) *Code*
- b) *Name of the Generating Unit*
- c) *Unit*: in this tab the user must enter the following information:
 - *Penstock*: the button allows the selection of the penstock connected to the generating unit.
 - *Minimum Generation (MW)*
 - *Maximum Generation (MW)*

- *Loss Coefficient α_2* : the hydraulic losses assigned to the generating unit (associated to the unit's individual penstock) are equal to the loss coefficient multiplied by the square of the turbined outflow of the unit. Total hydraulic losses are equal to the main penstock losses plus the losses assigned to all generating units.
 - *Commitment*: if the generating unit is selected as commitment, the user can inform a startup cost in k\$.
 - *Pumped Storage*: if the user wants to model a pumped storage as a hydro unit, this option should be enabled.
- d) *Table*: where the user enters the efficiency of the turbine/generator set as a function of the turbined outflow. A typical relation is shown in the figure below:



- e) *Allowed generation zone*: defines the minimum and maximum turbined outflows for each generating unit. If for example a plant has two equal generating units with a minimum flow of 150 m³/s and a maximum of 200 m³/s, the plant will have two forbidden generation zones: between 0 and 150 m³/s and between 200 and 300 m³/s.

4.1.3 Hydro bypass configuration

The water deviations can be represented in this configuration. The user defines the origin and the water destination, as well as the minimum / maximum limits of bypass operation.

Additionally, hourly / sub-hourly operation limits can be defined in the scenarios / restrictions section of the graphical interface.

4.2 Scenarios/Constraints of hydro plants

This part of the interface is where the user defines the complementary information at the level of hydroelectric plants. The left side of the interface presents all the options the model has for representing the hydroelectric plants.

When an option is selected, then the list of hydroelectric plants or hydrological stations is displayed on the right-hand side of the screen, with summarized information entered in the configuration option.

At the bottom of the screen appears the additional information that must be entered. If the information relates to chronological data, on the right side there are buttons that allow the user to add or delete days at the beginning or end of the existing information period.

Below is the detail of this information:

4.2.1 Inflow forecast

For each hydrological station, the user enters the chronological data of inflow forecast for each day of the simulation period. For the stochastic option it's possible to define a higher number of inflow scenarios to be considered all together in the optimization process (execution options).

4.2.2 Maintenance

The objective of this data is to define a maintenance schedule for the hydroelectric plants.

At the top right of the interface there are two options that allow the user to select the type of maintenance and the unit in which the maintenance will be expressed.

The user must choose one of the following two types:

- Available value: defines the value that remains after the maintenance.
- Reduction: defines the value that will be subtracted from the plant capacity.

Maintenance can be expressed in one of the following measurement units:

- # of units
- % of plant capacity
- MW
- m³/s

The plant in which the hourly chronological information will be informed is selected from the list of elements. It is not necessary to indicate a maintenance schedule for all plants.

The maintenance scenario can be informed in time steps of 60, 30, 15 or 5 minutes.

4.2.3 Initial status

The user must enter the operating status of the plants at the beginning of the simulation period. This information is related to the operation of the plant in the stages prior to the initiation of the study to consider startups, ramps, etc., which will be explained in the following items.

When this option is selected, the list of hydroelectric plants appears on the right side of the interface, in a screen like the one shown in the figure below:

Hydro Plant	Plant initial status	Number of hours	Previous generation (MW)
HY11	On	5	5.00
HY12	Off	24	
HY13	On	24	11.00
HY14	Off	24	
HY15	Off	24	
HY16	Off	24	

As shown in the figure, the information that must be provided for each hydroelectric plant is the following:

a) *Plant initial status*

Indicate whether the plant was operating in hour prior to the beginning of the study horizon. The prior condition of the plant (**On** or **Off**) is changed by double-clicking on the cell.

b) *Number of hours*

Is the number of hours the plant has been in its initial status (**On** or **Off**) prior to the beginning of the study horizon.

c) *Previous Generation (MW)*

If the plant was **On** in the hour prior to the beginning of the study horizon, the user should enter its generation at that previous hour.

4.2.4 Target storage

This option is used when the user wants to define a target storage for the reservoirs at the end of the simulation period.

When this option is selected, it appears on the right side of the interface the list of all hydroelectric power plants with reservoirs. To activate the data entry, click on the checkbox to the left side of *Use Target Storage* label, as shown in the figure below:

Code	Hydro Plant	Activate ?	Minimum target storage (p.u.)	Maximum target storage (p.u.)
11	HY11	<input checked="" type="checkbox"/>	0.6	0.62
12	HY12	<input checked="" type="checkbox"/>	0.8	0.81
13	HY13	<input type="checkbox"/>		
14	HY14	<input type="checkbox"/>		
16	HY16	<input type="checkbox"/>		

The user can define the target storage of the reservoir by means of a fraction of the useful volume (between 0 and 1) or by means of an elevation (meters above the sea level). In the latter case, it is necessary to define the Storage x Elevation table for all the plants in which the target storage will be activated.

The target storage can be defined as a range in which the storage must be at the end of the simulation horizon. The user can define only a minimum target or only a maximum target or both.

Each constraint can be represented as a hard one (without slack variables) or as a soft one (automatic penalties or user-defined).

4.2.5 Reservoir operation

This option displays a series of tabs that allow using the reservoirs to meet special requirements: irrigation, flood control, etc. These requirements are expressed as storages or inflows entered in chronological tables.

To allow feasibility, slack variables are used in the constraints. Each slack variable is associated with a penalty coefficient in the objective function. The user has the option to override the default penalty values used by the model.

The constraints that can be represented in the model are the following:

1) Flow constraints:

a) *Maximum total outflow*

The user defines a penalty expressed in $\text{k}\$/\text{m}^3/\text{s}$. The chronological table is filled in with the hourly values of the maximum total outflow (turbined outflow plus spilled outflow) that the model must meet. Whenever it is not possible to meet this constraint, its slack variable will assume the value of the violation.

b) *Minimum total outflow*

This screen is like the *Maximum total outflow* one but referred to the Minimum total outflow.

c) *Minimum spillage*

This screen is like the previous one but only referred to the minimum spillage.

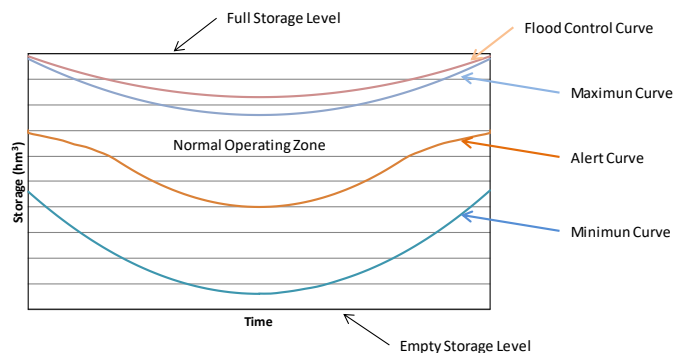
d) *Irrigation*

The hourly values for irrigation, in m^3/s , are subtracted from the plant water balance and leave the system, not being able to be used to energy production. In a similar fashion to the above two options, there is a slack variable that enforces this constraint. There are three options to define the penalty coefficient:

- *Irrigation is a priority*; in this case the automatic penalty cost is equal to 110% of the rationing cost. The rationing cost (non-served energy cost) is defined in the Economic parameters screen under the Execution Parameters of the main menu. Note that in this case, the model will only violate this constraint if it is physically impossible to avoid the violation. This happens for example if the reservoir is empty, and the inflow is not enough to meet the irrigation requirement.
- *Energy is a priority*; in this case the penalty cost is 1.1 times the variable cost of the most expensive thermal plant.
- *Fixed Penalty*, in this case the penalty cost is defined by the user and is expressed in $\text{k}\$/\text{Hm}^3$.

2) Storage constraints:

The hourly values of the flood control storage, maximum storage, alert storage and minimum storage define operating areas for the reservoirs, restricting the operation range of the water stored in reservoirs, as shown in the figure below:

a) *Minimum Storage*

There are two options for defining the penalty coefficient, to be applied when the reservoir is operating below the minimum storage (Minimum curve):

- *Automatic Calculation*: the penalty cost is 1.1 times the rationing cost, i.e., the model will only violate this constraint if it is physically impossible to avoid the violation. This occurs for example if the minimum curve boundary increases from one stage to the other and the inflow is not enough to meet the new volume.
- *Fixed Value*: in this case the user must enter a fixed value in k\$/Hm³.

The chronological data are expressed in units of volume (Hm³).

b) *Alert Storage*

The alert storage, together with the minimum storage (see previous section), defines the normal operating zone of the reservoir.

There are two options for defining the penalty cost, to be applied when the reservoir is operating below the alert storage curve:

- *Automatic Calculation*: the penalty cost is 1.1 times the variable cost of the most expensive thermal plant. That is, the model will violate this constraint to avoid rationing only after all thermal plants are dispatched.
- *Fixed Value*: in this case the user must enter a fixed value in k\$/Hm³.

The chronological data are expressed in units of volume (Hm³).

c) *Flood control storage*

Flood control storage is used to limit the upper storage of the reservoir in order to maintain a storage slack to accommodate high unexpected inflows in the real operation, which would result in severe downstream flooding. The chronological data are expressed in units of volume (Hm³). The model will use the minimum value between the full storage value informed and the flood control storage values informed in this section to define the new maximum reservoir storage, which is equivalent to stating that the reservoir is physically smaller. When the flood control storage is reached, the reservoir must spill.

d) *Maximum Storage*

This option is used to reduce the upper limit of the normal operating zone of the reservoirs.

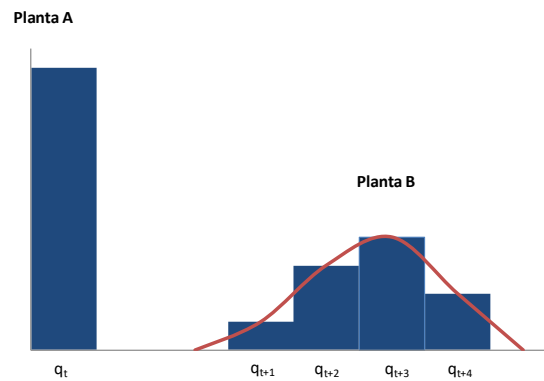
The user enters a penalty cost to be applied in case the reservoir is operating between the maximum storage and the flood control storage levels defined in this chronological data table. Unlike the flood control storage, the plant is not obliged to spill when reaches the maximum storage; it will simply violate the maximum storage constraint, with a penalty being applied to this violation.

4.2.6 Travel time

Suppose there are two hydroelectric plants in cascade: plants A and B, so that the turbined outflow of plant A goes to the reservoir of plant B. Depending on geographical conditions, the turbined outflow in plant A will take a certain amount of time to reach the reservoir of plant B; this time is defined as the turbined travel time.

Because of the wave propagation effect, the turbined outflow in plant A will reach plant B reservoir distributed over time. Consider, for example, that the turbined outflow in plant A is q , that the travel time is 4 hours and that the wave propagation factors are 0.1, 0.3, 0.4 and 0.2. In

this case, a flow of 15 m^3 will reach at the plant B reservoir distributed as follows: 1.5 m^3 ($0.1q$) in the first hour, 4.5 m^3 ($0.3q$) in the second hour, 6 m^3 ($0.4q$) in the third hour and 3 m^3 ($0.2q$) in the fourth hour as shown in the figure below:



The use of this kind of constraint will make the simulation dependent on the operational conditions existing in the plant before the start of the study. In the example presented, the user must enter the outflows of the plant for the 4 hours that precede the beginning of the study horizon.

For the cases where the initial conditions were not reported, the model can assume (optionally) as initial condition the turbine / spill flows in the final hours of the optimization horizon. For example, in a daily dispatch the initial condition for T_{o-4} will be the turbined / spilled outflow by the upstream plant at 8:00 p.m. and so on.

When this option is selected, the list of hydroelectric plants appears on the right side of the interface in a screen like the figure below:

Turbined outflow travel time		Spilled outflow travel time	
Plant	Downstream plant for turbinning	Travel time (hours)	value water in transit?
HY11	HY12	4.0	<input checked="" type="checkbox"/>
HY12	HY14	0.0	<input checked="" type="checkbox"/>
HY13	HY12	0.0	<input checked="" type="checkbox"/>
HY14	HY16	0.0	<input checked="" type="checkbox"/>
HY15	HY14	0.0	<input checked="" type="checkbox"/>
HY16			

	Turbined outflow (m^3/s)	Travel time (hours)	Wave Propagation Factor (p.u.)
To - 1	5.0	1	0.1
To - 2	4.0	2	0.3
To - 3	4.5	3	0.4
To - 4	5.5	4	0.2

There are two options for data entry:

a) *Turbined outflow travel time*

When the user selects this option, the following information must be entered for the plants with turbined outflow travel time different from zero:

- *Travel Time (hours)*: enter the total time the water takes to reach the downstream reservoir when turbined. A travel time of 0 is equivalent to indicate that water turbined by the upstream plant in each time t , reaches the downstream reservoir at the same time t . Note that the travel time can be expressed in fractions of an hour (e.g., 2.5 hours); in this case, the model enables the data entry for 3 hours.
- *Value water in transit*: this option assigns a (future) value to the water turbined in the final stages of the study horizon, which will arrive in the downstream plant after the end of the horizon due to the travel time effect.
Suppose for example that plant B is located downstream of plant A and that the travel time is 5 hours. In this case in the last 5 hours of the study period it could happen that the model will not consider economic to generate in plant A because its turbined outflow will not have the added value of generating in plant B considered.
When this option is enabled, the value for the turbined water in the final stages is equal to the higher water value of the SDDP future cost function. Alternatively, the user can calibrate the valorization with the customized option.
- *Turbined outflow (m^3/s)*: this option is enabled when the user enters turbined outflow travel times values different from zero. The number of rows enabled is equal to the travel time. Plant turbined outflows are entered for the hours that precede the beginning of the study horizon. The first value corresponds to the first hour prior to the beginning of the study horizon, the second value to the second hour prior to the beginning of the study, and so on.
- *Wave Propagation factor (p.u.)*, enter the factors according to the travel time indicated on the left side. Note that the sum of these factors must be equal to 1.

b) *Spilled outflow travel time*

When the user selects this option, the following information must be entered for plants having spilled outflow travel time different from zero:

- *Travel Time (hours)*: enter the total time the water takes to reach the downstream reservoir when spilled. A travel time of 0 is equivalent to indicate that water spilled by the upstream plant in a given time t , reaches the downstream reservoir at the same time t . Note that the travel time can be expressed in fractions of an hour (e.g., 2.5 hours); in this case, the model enables the data entry for 3 hours.
- *Spilled outflow (m^3/s)*: this option is enabled when the user enters spilled outflow travel times values different from zero. The number of rows enabled is equal to the travel time. Plant spilled outflows are entered for the hours that precede the beginning of the study horizon. The first value corresponds to the first hour prior to the beginning of the study horizon, the second value to the second hour prior to the beginning of the study, and so on.
- *Wave Propagation factor (p.u.)*, enter the factors according to the travel time indicated on the left side. Note that the sum of these factors must be equal to 1.

c) *Bypass outflow travel time*

When the user selects this option, the following information must be entered for plants having bypass outflow travel time different from zero:

- *Travel Time (hours)*: enter the total time the water takes to reach the downstream reservoir. A travel time of 0 is equivalent to indicate that water deviated

by the upstream plant in each time t , reaches the downstream reservoir at the same time t . Note that the travel time can be expressed in fractions of an hour (e.g., 2.5 hours); in this case, the model enables the data entry for 3 hours.

- *Bypass outflow (m^3/s):* this option is enabled when the user enters deviated outflow travel times values different from zero. The number of rows enabled is equal to the travel time. Bypass outflows are entered for the hours that precede the beginning of the study horizon. The first value corresponds to the first hour prior to the beginning of the study horizon, the second value to the second hour prior to the beginning of the study, and so on.

4.2.7 Ramps

A ramp is defined as the change of the value of a variable between two consecutive periods of time. In the model, ramps can be defined for the generation, total outflow and forebay levels. The aim of these constraints is to avoid abrupt changes between two consecutive periods of time, in generation, total outflow and elevation.

When the variable is the generation, the ramp is expressed in MW/min; if the variable is the total outflow (turbined outflow plus spilled outflow), the ramp is expressed in $m^3/s/min$; if the variable is the forebay level, the ramp is expressed in m/h.

When this option is selected, the upper right-hand side of the interface presents the following selection options:

- Generation maximum ramp-up:* this selection enables data entry for the hydroelectric power plants generation maximum ramp-up.
- Generation maximum ramp-down:* this selection enables data entry for the hydroelectric power plants generation maximum ramp-down.
- Total outflow maximum ramp-up:* this selection enables data entry for the hydroelectric power plants total outflow maximum ramp-up.
- Total outflow maximum ramp-down:* this selection enables data entry for the hydroelectric power plants total outflow maximum ramp-down.
- Turbined outflow maximum ramp-up:* this selection enables data entry for the hydroelectric power plants turbined outflow maximum ramp-up.
- Turbined outflow maximum ramp-down:* this selection enables data entry for the hydroelectric power plants turbined outflow maximum ramp-down.
- Spilled outflow maximum ramp-up:* this selection enables data entry for the hydroelectric power plants spilled outflow maximum ramp-up.
- Spilled outflow maximum ramp-down:* this selection enables data entry for the hydroelectric power plants spilled outflow maximum ramp-down.
- Forebay fill-up:* this selection enables data entry for the hydroelectric power plants total forebay maximum ramp-up.
- Forebay drawdown:* this selection enables data entry for the hydroelectric power plants forebay maximum ramp-down.
- Daily forebay fill-up:* this selection enables data entry for the hydroelectric power plants total forebay maximum daily ramp-up.
- Daily forebay drawdown:* this selection enables data entry for the hydroelectric power plants forebay maximum daily ramp-down.

4.2.8 Maximum number of start-ups

The start-up is the process by which a plant is connected to the system, i.e., it begins to deliver power to the system.

In the model it is possible to limit the number of start-ups of the hydroelectric plants since for both technical and economic reasons a plant cannot be connected and disconnected an unlimited number of times.

To consider constraints on the number of start-ups the plant must be defined as commitment. When a commitment plant is connected, it must generate a minimum amount of energy for technical reasons (e.g., to avoid cavitation or due to system requirements, as reactive power compensation). In the hydroelectric plants, this generation constraint is defined by a minimum value of the turbined outflow if the plant is connected, then it must turbine at least the minimum value required by the constraint.

To enter information regarding the number of start-ups, it is first necessary to define the plant as commitment. In the figure below, the HY13 and HY14 plants are defined as commitment. This selection makes the minimum turbined outflow defined in the “**Configuration > Hydroelectric configuration**” section to change from a forced condition (it must turbine at least this value all the time) to a commitment condition (if the plant is connected then the turbined outflow must be at least equal to the defined minimum turbined outflow).

Code	Hydro Plant	Hydro commitment ?	Maximum number of start-ups		
			Activate ?	Study Horizon	Daily
11	HY11	<input type="checkbox"/>			
12	HY12	<input type="checkbox"/>			
13	HY13	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	10	2
14	HY14	<input checked="" type="checkbox"/>	<input type="checkbox"/>		
15	HY15	<input type="checkbox"/>			
16	HY16	<input type="checkbox"/>			

Selecting the Hydro commitment option enables the option of selecting "Activate". If this option is selected (as for plant HY13 in the above figure), the user must define the maximum number of start-ups for both the whole period and for each day of the simulation; if this option is not activated (as for plant HY14 in the above figure), then the plant can be connected and disconnected an unlimited number of times.

4.2.9 Single reserve

In real time operation it is necessary to always satisfy the equilibrium equation “**generation = demand + losses**” because the energy produced by the generating units cannot be stored.

The spinning reserve is a value that is subtracted from the maximum generating capacity of a plant which is in the connected state, to provide an operating margin to satisfy the equilibrium equation. The reserve is composed of two parts: the single (primary) reserve to be activated almost instantly to satisfy the equilibrium equation due to demand changes, outages of the generating units or outages of the transmission elements; and the joint (secondary) reserve that has a higher activation time.

For each selected hydroelectric plant, the hourly values with which this plant must contribute to the system single reserve is entered in the chronological data tables located on the right side of the interface.

At the top right of the interface, a drop-down menu will appear where the user defines the units in which the single reserve hourly values will be informed. The single reserve can be expressed as a percent of the nominal power, in MW, as a percentage of the available power (considering maintenance) or as a percentage of the generation.

The single reserve is a value that decreases the maximum generating capacity of the plant.

It is important to notice that this is a “hard” constraint, i.e., the model will satisfy this constraint even if it causes load shedding. This constraint can only be violated if the single reserve is given as a percentage of the generation; in such case, the user can enable the use of a penalty coefficient indicating its value.

When the representation of the single reserve is made in terms of percentage of generation it is possible to define the direction of the single reserve, where it can be assigned to both senses, upward and downward.

4.2.10 Joint reserve

The joint reserve plus the single reserve, supplied by the plants in operation, constitute the spinning reserve of the system as explained in section 4.2.9.

The system requirements of joint reserve are met with the bids made by the plants and generating units considered in the study.

The joint reserve bid consists of a minimum amount, a maximum amount, and a bid price (\$/MW) for every stage of the study period.

The **system's** joint reserve requirements are defined for every stage (hourly or sub-hourly) of the study horizon through joint reserve constraints. The model allows the definition of multiple joint reserve constraints to be met.

When, for technical or economic reasons, it is not possible to meet all the joint reserve requirements at a certain stage, the model increases the cost of the objective function with the amount of joint reserve not served multiplied by a penalty cost coefficient, which can be an automatic value defined by the model or a user-defined one.

When the user selects the joint reserve option, the information to be provided for the study appear on the right side of the interface as shown in the figure below:

The screenshot shows the 'Bid type' set to 'Single' and 'Unit' set to 'MW'. The table below shows two hydro plants, H1 and H2, both with a reference value of '0 - 5.5'. The 'Power for Assignment' section includes 'Minimum (MW)', 'Maximum (MW)', 'Direction', and 'Number of Levels'. The 'Direction' is set to 'Both' and the 'Number of Levels' is 1. Below the table, there are fields for 'Minimum Reserve', 'Maximum Reserve #1', 'Bid Price #1', 'Maximum Reserve #2', and 'Bid Price #2'. At the bottom, there are tabs for '60 minutes', '30 minutes', '15 minutes', and '5 minutes', and a time selection grid from 00h to 09h.

Code	Hydro plant	Reference Value	Control Range (MW)	Minimum (MW)	Maximum (MW)	Direction	Number of Levels
1	H1	0 - 5.5				Both	1
2	H2	0 - 5.5				Both	1

At the top, the user must select the unit in which the hourly reserve values will be expressed for the selected hydroelectric plant presented in the central part. As shown in the figure, these values can be expressed either in MW or as a percentage of the generation.

The tabs at the bottom allow entering chronological data for the supply of joint reserve for the selected hydroelectric plant. The Minimum Reserve and Maximum Reserve define the range of reserve that can be assigned to the selected plant, in case it is assigned to be one of the plants providing joint reserve. In the "Bid Price" tab the user must enter the bid prices (\$/MW) for the joint reserve.

It is possible to define two bid levels with their respective prices and maximum amount of reserve. Negative prices are also allowed. The amounts are incremental, where the allocation of joint reserve on the second level is dependent on the allocation of the first level. The minimum reserve requirement does not vary with the number of bid levels, and it is unique for any option.

The bid definition can vary according to the reserve direction. The constraints will be applied, as standard procedure, with the same assigned reserve values for both ways, but it is possible to define different bid values (limits and prices) for each one the directions (upward / downward).

The generators can also be limited optionally according to the supply direction, attributing exclusive directions (upward / downward) for the reserve supply. The definition of the control range (total amount of reserves allocated in both ways) is an optional input as well.

It is possible to set a minimum / maximum power limit for allocation of joint reserve, in addition to the minimum / maximum capacity of the plant. This limit is related to power ranges where frequency regulation is not feasible due to power variation impossibility.

4.2.10.1 Multiple joint reserve bids

Alternatively, the definition of multiple joint reserve bids for a given generator is available, where the minimum / maximum limits and bid prices can be different for each joint reserve requirement.

The offers can be of the spinning and non-spinning type and are used to supply joint reserve requirements of each type, as well as the reserve requirements that accept both operation modes.

4.2.11 Generation constraint

When this option is selected, the list of hydroelectric plants appears on the right side of the interface. The buttons located at the top of the list allow the user to display the plants in ascending or descending order.

Below the list of hydro plants, it is shown the type of generation constraint (less than, equal to, greater than) that the generation of the selected plant must fulfill for each hour, according to the values defined in the chronological data table.

It is possible to define the status (Enable / Disable) of each generation restriction defined by generator. With this option, it is not necessary to edit the data so that the restriction is not considered.

The penalty for non-compliance can be defined automatically (1.1 x cost of energy not supplied) or through the definition of a custom value (\$/MW).

4.2.12 Self-consumption

Self-consumption decreases the maximum capacity of generation of hydro plants.

When this option is selected, the list of hydro plants appears on the right side of the interface as shown in the figure below:

Code	Hydro Plant	Self consumption (% of nominal power)
1	H1	2.
2	H2	0.

At the right of each hydro plant appears the “self-consumption” auxiliary column in which the user must enter the losses, in percent of nominal power, attributed to this consumption. Self-consumption includes transformation losses.

4.2.13 Energy bid

When this option is selected, the list of hydroelectric plants belonging to the study appears in the upper right-hand side of the interface. The information must be supplied only to the hydroelectric plants that sell their generation through energy bids.

Below the list, a chronological data table is presented. This table should be filled with the hourly bid prices (\$/MWh) for the generating energy of the selected hydroelectric plant.

This constraint is used only in systems where hydroelectric plants sell their energy to the system through energy bids.

4.2.14 Compensation chamber

The compensation chamber is used to establish a linear relationship between the power of a hydroelectric plant and the volume stored in its reservoir. For a given stage, the capacity of the hydroelectric plant would be equal to its maximum capacity multiplied by a fraction (between 0 and 1) that relates the reservoir stored volume with its maximum volume. If the reservoir is

at its maximum volume, the capacity of the hydroelectric plant would be equal to its maximum capacity (fraction equal to 1) and if the reservoir is at its minimum volume the capacity of the plant will be equal to zero (fraction equal to 0).

When this option is selected, the list of hydroelectric plants along with Activate and Reservoir columns appears at the top right of the interface, as shown in the figure below:

Code	Hydro Plant	Activate ?	Reservoir
11	HY11	<input type="checkbox"/>	
12	HY12	<input checked="" type="checkbox"/>	HY12
13	HY13	<input type="checkbox"/>	
14	HY14	<input type="checkbox"/>	
15	HY15	<input type="checkbox"/>	
16	HY16	<input type="checkbox"/>	

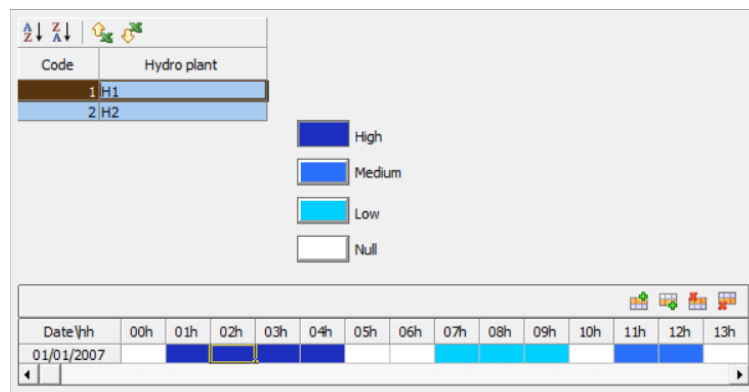
The column "Activate?" allows the user to select the hydroelectric plants for which the compensation chamber option will be activated.

The "Activate" option enables the selection of a reservoir to be used as a compensation chamber.

4.2.15 Generation boost

This option is used to stimulate the generation of hydroelectric plants in cases where the results of the optimization may indicate a lower use of water resources. With the objective that the user can "interfere" in the optimization, it is possible to create a generation boost for hydroelectric generation to increase the use of water resources regardless of the operating conditions of the case.

When this option is selected, the hydroelectric power plants belonging to the study appear in the upper right part of the interface, as shown in the following figure:



Below the list of hydroelectric plants, there is a data table where, for each of the hydroelectric plants that will use this option, the stages in which the generation boost will be applied are identified.

The identification of the stages is done by clicking on one of the colors above the data table (blue and its variations for stages with generation boost, white for null) and selecting with the mouse the stages in which this option will be used.

4.2.16 Cold ramp

When this option is selected, the list of hydroelectric plants considered in the study appears on the right side of the interface. To the right of each plant there are 2 columns in which the following information must be entered for plants which will use this feature:

- a) *Maximum ramp-up (MW/min)*: the user enters the value of the maximum slope (MW/minute) for the loading process of the hydroelectric plants that have been disconnected for a period longer than the cooling time.
- b) *Cooling time (hrs.)*: is the minimum time that a hydroelectric power plant should be disconnected to be considered as "cold" for start-up.

When a plant has been disconnected for a shorter time than the cooling time, the startup is considered as "hot". In this case the Maximum ramp-up value to be used is defined in section 4.2.7.

4.2.17 Discrete generation

This feature applies to hydroelectric plants that can only be dispatched at certain discrete values. For example, if the possible discrete generation values of a plant are 15, 30 or 45 MW, then at any stage of the study this plant will be allowed to generate only 15, 30 or 45 MW.

This constraint is only applied to the plants considered as commitment.

4.2.18 Minimum turbined flow

When this option is selected, the list of hydroelectric plants appears on the right side of the interface. The buttons located at the top of the list allow the user to display the plants in ascending or descending order.

Below the list of hydro plants, it is possible to define minimum turbined flow requirements different for each stage in the chronological data table.

4.2.19 Maximum number of daily cycles

It is possible to define a maximum number of cycles (start-up / shutdown) between all the generating units of the plant. The defined value will determine the maximum number of stops and start-ups for each day of operation of the plant.

4.2.20 Tailwater level

If the tailwater level varies based on effects such as the ones from tides, its height can be defined on an hourly basis with this option.

4.2.21 Bypass limits

In this screen it is possible to define the minimum / maximum operating limits of the bypass (water diversion) in m^3/s , as well as the penalties ($k\$/m^3/s$) associated with the defined constraints.

4.2.22 Average limits

For certain variables, it is possible to determine average operation limits, as well as the type of the operational constraint (greater than / equal to / less than) in a period of the execution horizon. The available options are: turbined outflow, spilled outflow, total outflow, forebay

elevation, stored water and tailwater elevation. Each constraint can be represented as a hard one (without slack variables) or as a soft one (automatic penalties or user-defined).

4.2.23 Spillway rating curve

The spillage limits of the hydro power plants can be defined according to the forebay elevation. The available constraints are greater than, equal to and less than. The definition of hourly changing factors of the spilled outflow is possible, where they will be applied to the values determined by the forebay elevation x spilled outflow table.

4.2.24 Terminal function

In addition to the link alternatives with the long/medium term schedules (FCF, target storage and target generation) available, it is possible to define individual terminal functions for the reservoirs, where for each storage level an associated future cost is attributed to the amount of water stored. In other words, lower storage levels are expected to have higher future costs and vice versa.

4.3 Scenarios/Constraints of hydro units

In this section the user enters the information for the hydroelectric plants for which the units are specifically represented. The hydro units are defined in the tab "Generating Unit" in the "Configuration > Hydro Configuration" section.

The information to be supplied is like the one presented in section 4.1.3.

4.3.1 Maintenance

When the user selects this option, the list of hydroelectric units appears on the right side of the interface. The name of the hydroelectric plant to which the unit belongs appears on the right.

At the top of the list there are two buttons for sorting the list in ascending or descending order.

The maintenance data for each hydro unit is entered in the chronological data table (hourly or sub-hourly) located at the bottom of the screen.

The data expressed in terms of available capacity can be informed in MW or as a percentage.

4.3.2 Joint reserve

When this option is selected, the list of hydroelectric units appears on the right side of the interface. The name of the hydroelectric plant to which the unit belongs appears on the right.

A detailed explanation is presented in section 4.2.10.

4.3.3 Generation constraint

When this option is selected, the list of hydroelectric units along with the name of the hydroelectric plant to which the unit belongs appears on the right side of the interface, as shown in the figure below:

Code	Generating Unit	Hydro Plant
1	unit 1	HY12
2	unit 2	HY12

Constraint type

(MW)

Date\hh	00h	01h	02h	03h	04h	05h
05/06/2013	0.5	0.6	0.4	0.4	0.4	0.4

At the top of the list there are two buttons for sorting the list in ascending or descending order.

Below the list of hydro units, it is shown the type of generation constraint (less than, equal to, greater than) that the generation of the selected unit must fulfill for each hour, according to the values defined in the chronological data table located below the list.

It is possible to define the status (Enable / Disable) of each generation restriction defined by generator. With this option, it is not necessary to edit the data so that the restriction is not considered.

The penalty for non-compliance can be defined automatically (1.1 x cost of energy not supplied) or through the definition of a custom value (\$/MW).

4.3.4 Initial status

When this option is selected, the list of hydroelectric units appears on the right side of the interface. The name of the hydroelectric plant to which the unit belongs appears on the right.

A detailed explanation is presented in section 4.2.3.

4.3.5 Ramps

When this option is selected, the list of hydro units appears on the right side of the interface as shown in the figure below:

Selected constraints

Maximum ramp-up

Maximum ramp-down

Hydro Plant	Generating Unit	Maximum ramp-up (MW/min)	Maximum ramp-down (MW/min)
HY12	unidad 1		
HY12	unidad 2		

In this screen the user enters the maximum ramp-up and ramp-down values for the hydro units that have this restriction.

A detailed explanation is presented in section 4.2.7.

4.3.6 Maximum number of start-ups

When this option is selected, the list of hydro units appears on the right side of the interface as shown in the figure below:

		Maximum number of start-ups	
Hydro Plant	Generating Unit	Study Horizon	Daily
HY12	unidad 1	5.	1.
HY12	unidad 2		

The maximum number of start-ups can be set both for the Study horizon and for each day of the simulation.

To declare the maximum number of start-ups, the hydro unit must have a minimum turbined flow and must also be declared as commitment (section 4.1.2.6).

A detailed explanation is presented in section 4.2.8.

4.3.7 Forbidden zone

When this option is selected, the list of hydro units appears on the right side of the interface as shown in the figure below:

A ↓ Z ↓ Z ↓ A ↓			
Code	Generating Unit	Hydro Plant	# Zones
1	unidad 1	HY12	2
2	unidad 2	HY12	0

	Elevation (m)	Minimum Limit (MW)	Maximum Limit (MW)
1	100.	15.	30.
2	150.	40.	60.

On the right side of the list of hydro units the user defines the number of forbidden zones of generation. When the user sets the number of zones, a table with the number of zones is enabled at the bottom. In this table the user must enter the elevation, in meters, and the minimum and maximum limits, in MW, that define the range of each forbidden zone of generation.

The minimum and maximum limits define the range in which the generation is forbidden, i.e. the hydro unit must generate less than the minimum limit or more than the maximum limit.

The forbidden zones associated to other elevation levels (not the ones defined in the table) at the beginning of the study are obtained by interpolation using the zones defined in the table and the reservoir initial elevation.

To use this option, the storage x elevation table in the configuration part of hydroelectric power plants must be defined.

4.3.8 Generation limits per elevation

When this option is selected, the list of hydro units appears on the right side of the interface as shown in the figure below:

Code	Generating Unit	Hydro Plant	# Constraints
1	unit 1	HY12	0
2	unit 2	HY12	2

	Elevation (m)	Minimum Limit (MW)	Maximum Limit (MW)
1	100.	15.	30.
2	150.	40.	60.

On the right side of the list of hydro units, the user defines the number of constraints that will limit the generation. Once the number of constraints is set, a table with the number of constraints is enabled at the bottom. In this table the user must enter the elevation, in meters, and the minimum and maximum generation limits, in MW.

The minimum and maximum limits define the zone in which generation is allowed, i.e., the hydro unit should generate between the minimum and the maximum limits.

The limits correspond to the values reported in the table with respect to the storage level of the reservoir at the beginning of the study. For example, if the storage level of the reservoir at the beginning of the study is between 100 and 150 meters, the minimum and maximum limits will be 15 and 30 MW respectively. If the storage level of the reservoir is above 150 meters, the minimum and maximum limits will be 40 and 60 MW respectively.

The limits associated to other elevation levels (not the ones defined in the table) at the beginning of the study are obtained by interpolation using the limits defined in the table.

To use this option, information must be previously entered in the storage x elevation table in the configuration part of hydroelectric power plants.

4.3.9 Cold ramp

This option is like the one presented in section 4.2.16. The only difference is that in this screen the user must enter the information for each hydro unit instead of for each hydroelectric plant.

4.3.10 Precedence constraint

This option is used to define the loading order of operation of the hydro units belonging to a hydroelectric power plant.

This constraint has been included in the model since in general all the hydro units belonging to a hydroelectric plant have the same technical characteristics, so the operation of any unit is indifferent for the model from an economic point of view. With this constraint, the user can explicitly define the order of dispatch of the units of a given hydroelectric plant.

4.3.11 Exclusion constraint

This option allows the user to define a list of units that can operate exclusively. In other words, the dispatch of a unit is conditioned by the non-dispatch of one or more other unit(s).

4.3.12 Hill curve

The representation of the efficiency variation of the turbine-generator set as a function of the head and turbine flow can be made using the definition of the hill curve of each hydroelectric unit.

4.3.13 Inertia

In the traditional unit commitment model for hydroelectric units, there are two operational states: off, in which the generating unit is not supplying power to the grid and its turbine is stopped, or committed (on), in which the unit is providing energy to the grid. -supplying power to the network (between its minimum and maximum capacities).

With this representation, a new operating state is added in which the generating unit is connected to the network and its turbine rotates in a motorized way, consuming energy and providing inertia to the network. This constitutes the role of a synchronous condenser for the system.

The start-up costs associated with the transition between the operating states are possible to represent, as well as the definition of the energy consumption in the synchronous condenser mode. The inertia requirement by the system is presented in section 9.11.

5 THERMAL PLANTS

The thermal plants data are defined through two options in the navigation tree: Configuration and Scenarios/Constraints.

5.1 Configuration

In this part the user enters the basic information of fuels, thermal power plants and combined cycle plants, according to the following detail:

5.1.1 Fuel configuration

When this option is selected, the list of fuels appears at the right side of the interface as shown in the figure below:

Code	Fuel	Unit	Price (\$/Unit)
1	Fue1	TPC	7.
2	Fue2	Liters	5.
3	Fue3	Heat	0.

The buttons located above the list of fuels allow the user to add and/or delete a fuel and display fuels in ascending or descending order.

Note that the unit in which the price of each fuel is expressed (\$/unit) changes according to the unit assigned to the selected fuel. The user has the option to define the unit associated to each fuel, which can be a physical unit (tons, liters, etc.) or an energy unit (BTU, kcal, etc.).

It is possible to define the emission factors of CO₂, SO_x and NO_x for each fuel. The factors are measured in tons of gases per unit of fuel.

5.1.2 Thermal configuration

When this option is selected, the list of thermal plants appears at the upper right-hand side of the interface as shown in the figure below:

Code	Thermal plant
1	The1
2	The2
3	The3
4	The4
5	The5
6	The6

Generator Group | Fuel |

Consider plant ?
 Yes No

Number of Generating Units:
 Minimum Generation (MW):
 Maximum Generation (MW):
 Outage Rate (%):

Plant Type:
 Standard
 Must Run
 Benefit

Commitment
 Hot Startup Cost (K\$):
 Warm Startup Cost (K\$):
 Cold Startup Cost (K\$):
 Shutdown Cost (K\$):

Combined Cycle

The buttons located above the list of thermal plants allow the user to add and/or delete a thermal plant, display plants in ascending or descending order and export or import information to and from Excel.

Below the list of thermal plants there are two tabs: generator group and fuel. The information that must be entered when selecting these tabs is presented below:

5.1.2.1 *Generator Group tab of thermal plants*

The detail of the information to enter is the following:

a) *Consider Plant (Yes, No)*

When No is chosen, the plant is considered as a future plant. Therefore, it is not considered in the study.

b) *Number of generating units*

The user must enter the number of units that the thermal plant has.

c) *Minimum generation (MW)*

Represent the minimum dispatch level of the plant during the stages of the study period. If the plant is not declared as commitment (see item (g) below), this value represents the minimum forced generation of the plant in each stage of the study period.

d) *Maximum generation (MW)*

Represent the maximum generation capacity of the plant.

In the model there are constraints that decrease the maximum capacity, such as single reserve, maintenance, and auxiliary consumption:

$$\text{Available Capacity} = \text{Maximum Capacity} - \text{Maintenance} - \text{Single Reserve} - \text{Auxiliary Consumption}$$

The user should note that for the plants that supply joint reserve, the generation will be at most equal to the available capacity subtracted by the assigned joint reserve.

e) *Outage rate (%)*

The outage rate (OR) reduces the maximum capacity of generation. The maximum capacity of generation is multiplied by the factor: $(1 - \text{OR}/100)$.

f) *Plant type*

It presents the following selection options:

- *Standard*, the generation is given directly by the results of the optimization.
- *Must run*, the plant generates at its maximum available capacity during all stages of the study.
- *Benefit*, represents elastic demands. The plant has negative generation which is equivalent to an energy sale. The cost of operation is also negative and represents the revenues from the energy sale. The fuel cost of benefit plants represents the elastic demand's willingness to pay for the energy.

g) *Commitment*

When this option is selected, the minimum generation indicated in item (c) above is no longer regarded as forced and, instead, is considered as commitment, which is the condition by which the plant must generate at least the minimum generation indicated in item (c) if the plant is in operation.

Additionally, the model allows the user to enter information of start-up costs (hot, warm and cold) and shutdown costs for the thermal plants that have been declared as commitment.

h) Combined Cycle

This option is used when the user wants to associate each operating state of a combined cycle plant to a specific thermal plant. In general, a combined cycle plant consists of two open cycle gas turbines and a steam turbine that works with the exhaust heat of the natural gas turbines, i.e. without fuel costs.

To create a combined cycle, the user must create as many plants as states of operation of the combined cycle. Suppose for example that there is a combined cycle composed of two gas turbines (GT1 and GT2) and a steam turbine (ST), under these conditions the following 6 plants that represent the possible states of operation of the combined cycle must be created:

1. GT1
2. GT2
3. GT1+GT2
4. GT1+ST
5. GT2+ST
6. GT1+GT2+ST

Once the user creates the thermal plants (one for each possible state of operation of the combined cycle), the following process must be implemented to create the combined-cycle plant:

- Select one of the thermal plants which will form part of the combined cycle and click on the combined cycle option located at the bottom right of the interface.
- Create the combined cycle plant by pressing the add button and enter a name for the combined cycle.
- Select each of the remaining thermal plants that are part of the combined cycle and associate them with the combined cycle. Notice that the model allows for the creation of several combined cycle plants.

Besides the option described in this item, NCP also has another way to define combined cycle plants. This alternative method, described in section 5.1.3, is more detailed and does not require that the user creates several fictitious thermal plants corresponding to each possible state of operation of the combined cycle.

i) Simultaneous fuels usage

This option should be enabled for the thermal units that can burn more than one fuel type simultaneously. If this option is not enabled, only one fuel can be used at each stage, which can be either the main fuel or any of the alternative ones.

5.1.2.2 Fuel tab for thermal plants

When the user selects this tab, a screen like the one shown in the figure below appears at the bottom of the right-hand side of the interface:

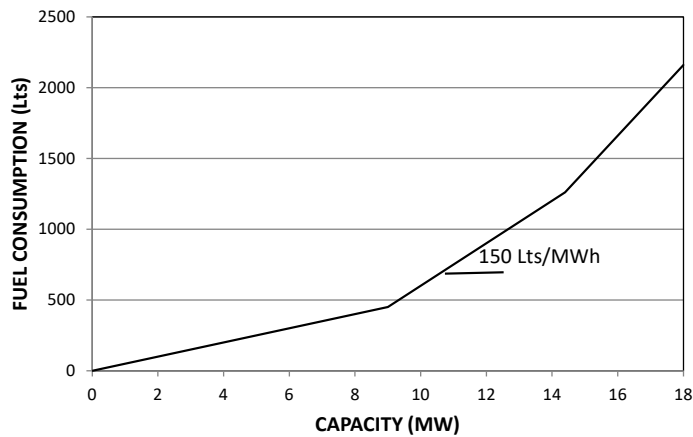
Segment	1	2	3
Curve (%)	50	30	20
Specific Consumption (Lts/MWh)	50	150	250

The first time the user selects this tab, the number of alternative fuels is set to 0 (zero), as default. When the number of alternative fuels is zero, only the “Main Fuel” tab appears.

If the user selects the number of alternative fuels different from zero (one alternative fuel in the above figure), as many tabs as the number of alternative fuels appear to the right of the "Main Fuel" tab. The figure shows the information that has been entered for Alternative Fuel #1.

The information to be entered for the main and alternative fuels are the following:

- a) *Fuel*
Displays the list of fuels and allows the selection of the fuel to be used.
- b) *Variable O&M cost (\$/MWh)*
Represents the variable cost with operation and maintenance. The O&M cost is directly added to the plant's total variable cost.
- c) *Transportation cost (\$/unit)*
Represent the cost of transporting the fuel to the plant site. Note that the "unit" of fuel presented in the interface automatically changes according to the selected fuel.
- d) *Segment*
The interface presents a table for entering the specific fuel consumption factor, which is defined as the amount of fuel (in physical units or energy units) required for producing each MWh.
The fuel consumption curve is a piecewise linear curve with up to three segments. Each segment requires the following information:
 - *Curve (%)*, which represents the validity range of the corresponding specific consumption. Note that the sum of these percentages should be equal to 100 %.
 - *Specific consumption (unit/MWh)*, a value must be entered for each defined segment. For the example shown in the previous figure, three segments have been defined: (50%; 50 Lts/MWh), (30%; 150 Lts/MWh), (20%; 250 Lts/MWh). If, for example, the plant has a maximum output of 18 MW, the fuel consumption (which is a function of the dispatch) would be as follows:



Note that the specific consumption is the value of the slope of each linear segment: for a load of 50% (=9 MWh), the fuel consumption is $9 \times 50 = 450$ Lts/hour. For a load of 80% ($9 + 5.4 = 14.4$ MWh), the fuel consumption is $450 + 5.4 \times 150 = 1260$ Lts/hour. For the 100% load ($14.4 + 3.6 = 18$ MWh), the fuel consumption is $1260 + 3.6 \times 250 = 2160$ Lts/hour. Note that since the unit of time is 1 hour in this example, the value of the energy is equal to the power.

e) *Dummy thermal plant*

The user enters the Code and Name of a dummy thermal plant that is used in the outputs of the program to identify the information associated with each of the alternative fuels declared. For example, if the output is the generation of the thermal plants, the generation associated with the main fuel is presented under the name of the plant and the generation associated with each alternative fuel is presented under the name of the corresponding dummy thermal plant.

f) *Emission coefficient*

It is the emission coefficient of thermal plants. If equal to 1, it means that the thermal power plant emits all the CO₂ from fuel burning. Values between 0 and 1, indicate that there is a filter that reduces the emission of CO₂. For example, 0.8 indicates that the thermal power plant emits only 80% of CO₂ from fuel burning. The same procedure applies to other types of gases (SO_x and NO_x).

g) *Emission cost*

It is the direct cost of emission of thermal plant. This cost is multiplied by the respective gas emission computed through consumption and fuel emission factor.

5.1.3 Combined cycle configuration

This option is used when the user wants to define the combined cycle plant by identifying the turbines associated to it. In this case, the generation of the steam turbine depends on the generation of the natural gas turbines of the plant.

Note that this option for representing combined cycle plants is different from the one presented in section 5.1.2.1, in which it is necessary to define as many thermal plants as operating states of the combined cycle.

When the user selects this option, the list of combined cycle plants appears on the right side of the interface as shown in the figure below:

Code	Combined Cycle	CHP ?	Only Coupled ?	Minimum Coupling Generation (MW)
1	CC1	<input type="checkbox"/>	<input type="checkbox"/>	0.

Thermal plants

Thermal Unit	Thermal Unit	Steam ?	Min. Coupling Time (h)	Min. Uptime Coupled (h)	Coupling Cost (k\$)
T1	T4	<input type="checkbox"/>	2.	3.	2.
T2	T5	<input type="checkbox"/>	2.	3.	2.
T3	T6	<input checked="" type="checkbox"/>			

Generation Tables

	Total Generation Open Cycle (MW)	Steam Turbine Generation (MW)
1	0.	0
2	10.	5.
3	20.	10.
4	30.	15.
5	40.	20.
6		
7		

Reduction factor (MW/ton/h)

	Total Generation Open Cycle (MW)	Maximum Steam Production (ton/h)
1		
2		
3		
4		
5		

The buttons located above the list of combined cycle plants allow the user to add or delete a combined cycle plant and to display the plants in ascending or descending order.


The *CHP* checkbox (Combined Heat and Power), that is located to the right of the name of the combined cycle, should be selected if the plant is free to decide on using the produced steam to feed a steam turbine or to other uses (such as heating, industrial use, etc.) or both. When the CHP option is not selected, all produced steam is used to produce electrical energy (the table on the left under "Generation tables" defines the relationship between the total generation of the gas turbines with the generation of the steam turbine).

When the CHP option is selected, part of the steam can be assigned by the optimization to other uses (the table on the right under "Generation tables" defines the relationship between the total generation of the gas turbines with the maximum amount of steam that can be extracted for other uses). In this case the power production of the steam turbine is decreased because of the extraction of steam for other uses. The reduction factor (MW/ton/hour) entered in the box located above the table defines the amount of MW that the steam turbine is prevented from generating for each ton of steam that is extracted for other uses.

The values entered in these two tables must cover the entire range of operation and must begin with the value of 0 (zero).

When the "Only Coupled?" checkbox located on the right side of the "CHP" checkbox is selected, the gas turbines can only operate if they are connected to the steam turbine. If this checkbox is not selected, then the gas turbines can operate even if they are not connected to the steam turbine (i.e., in open cycle mode).

At the "Minimum Coupling Generation", the user can enter the minimum value for which the combined cycle plant must be generating while it is connecting to the steam turbine.

The list of thermal plants is presented at the central part of the interface, under the "Thermal Plants" heading. The buttons  allow the user to select the thermal plants (turbines) belonging to the selected combined cycle plant.

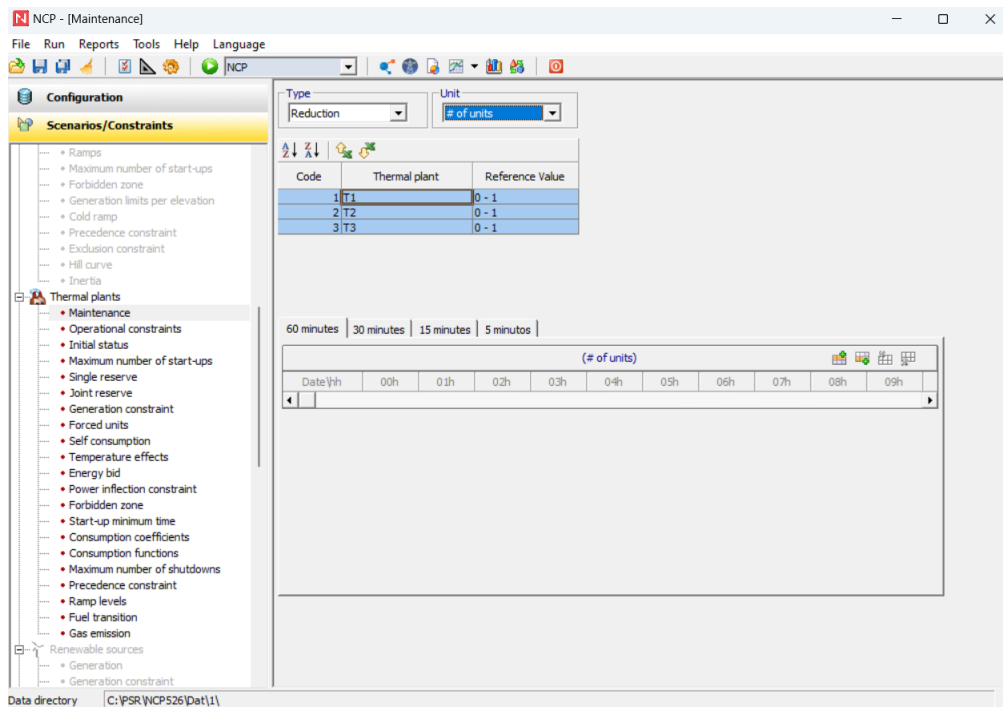
In the example shown in the last figure, the CC1 combined cycle plant is composed of two gas turbines (T4 and T5) and one steam turbine (T6).

To the right-hand side of the selected thermal turbines the user enters the following information:

- a) *Steam?*
This option must be checked for the steam turbine.
- b) *Minimum coupling time (h)*
This information is entered for the gas turbines. It represents the time that it takes for the gas turbine to change from open cycle mode (disconnected from the steam turbine) to closed cycle mode (producing steam that feeds the steam turbine).
- c) *Minimum uptime coupled (h)*
Defines the minimum number of hours that the gas turbine must be kept connected to the steam turbine (i.e., operating in closed cycle mode) once it changes from open cycle mode to closed cycle mode.
- d) *Coupling Cost (k\$)*
Is the cost incurred in the coupling process of the gas turbine to the steam turbine.

5.2 Scenarios/Constraints of thermal plants

In this part of the interface the user completes the data entry for the thermal plants. As shown in the figure, all the additional options that exist in the model for representing the operating characteristics of the thermal plants are on the left-hand side of the interface.



Depending on the selected option, the interface displays at the upper right side the list of thermal plants defined in the configuration part and on the bottom the complementary information to be supplied.

Below is the detail of the information:

5.2.1 Maintenance

The purpose of this data is to define a maintenance schedule for each of the thermal plants considered in the study.

When this option is selected, the list of thermal plants appears on the right side of the interface along with the information that must be entered to define the maintenance schedule for each of the thermal plants as shown in the figure below:

Code	Thermal plant	Reference value
1	Ther1	0 - 2
2	Ther2	0 - 1
3	Ther3	0 - 1
5	Ther4	0 - 1
6	Ther6	0 - 1
7	Ther7	0 - 1

Date/hh									
00h	01h	02h	03h	04h	05h	06h	07h	08h	

At the top, there are two options that allow the user to select, for all thermal plants, the type of maintenance and the unit in which it will be expressed.

There are two types for the definition of maintenance:

- Available value: defines the value that remains after the maintenance.
- Reduction: defines the value to be subtracted from the capacity of the plant

Maintenance can be expressed in one of the following options:

- # (Number) of units
- Percentage
- MW

The list of thermal plants is presented in the central part. On the right side of the thermal plant name column there is a "reference value" column in which the interface automatically presents the range of possible values that can be entered for the maintenance of each of the thermal plants. These values are expressed in the selected unit. For the example in the previous figure, the maintenance is expressed in # of units, so that the minimum and maximum values allowed for the plant Ther1, which has 2 units, will be 0 and 2 respectively.

At the bottom of the screen the user must enter the chronological data for the selected thermal plant. The user must enter the information according to the type and unit defined at the top of

the screen. For the example in the previous figure, the information is based on the number of units that will remain available for each day and hour of the study.

The information must be filled only for the plants with scheduled maintenance. The maintenance scenarios can be entered in time steps of 60, 30, 15 or 5 minutes.

5.2.2 Operating constraints

Constraints related to the thermal plants operating times are entered in this section. The model allows the use of the following constraints:

- a) *Min. Uptime (hours)*, is the minimum time each thermal plant must remain in operation once started.
- b) *Min. Downtime (hours)*, is the minimum time each thermal plant must remain off-line after being shut down.
- c) *Maximum ramp-up (MW/min)*, is the maximum increment of generation between two consecutive stages.
- d) *Maximum ramp-down (MW/min)*, is the maximum reduction of generation between two consecutive stages.
- e) *Max. Uptime (hours)*, is the maximum time a thermal plant can stay connected.

When the desired option is selected, the corresponding column in the table of operating constraints becomes active for entering the data for the thermal plants as shown in the figure below:

Selected constraints

Min. Uptime Maximum ramp-up Max. Uptime
 Min. Downtime Maximum ramp-down

Operating constraints

Thermal plant	Min. Uptime (hours)	Min. Downtime (hours)	Maximum ramp-up (MW/min)	Maximum ramp-down (MW/min)	Max. Uptime (hours)
Ther1					
Ther2		2			
Ther3					
Ther4					
Ther6					
Ther7					

The user can select as many operating constraints as relevant for the study and can enter the corresponding data only for the thermal plants that are subject to them, leaving the cells for the other plants as blanks.

5.2.3 Initial status

It represents the operating status of thermoelectric plants prior to the start of the study and is used to maintain the continuity (initial conditions) of the operational constraints.

When this option is selected, the list of thermal plants appears on the right side of the interface. To the right of each thermal plant the model presents the initial conditions that can be entered for each thermal power plant as shown in the figure below:

Thermal plant	Plant initial status	Number of hours	Previous generation (MW)	Period with constant power (h)	Previous load condition
Ther1	Off	24			
Ther2	On	2	8.00	1	Power increase
Ther3	On	1	5.00	1	Power decrease
Ther4	Off	24			
Ther6	Off	24			
Ther7	Off	24			

A brief explanation of the conditions follows:

- Plant initial status*: which can be "On" or "Off". The change between the options is done by double clicking on the option.
- Number of hours*: the user must enter the number of hours that the plant was in the initial condition indicated in part (a) before the first hour of the study.
- Previous generation (MW)*: the user must enter the generation of the thermoelectric plant in the hour preceding the start of the study, so that the model can correctly apply the ramp constraints for the first hours of the study horizon.
- Period with constant power (h)*: the user enters the time in hours at which the thermal plant operated with constant power prior to the start of the study. This initial condition is relevant for the thermal plants that must meet a power inflection constraint (see section 5.2.12).
- Previous load condition*, which can be "Power increase" or "Power decrease". The change between the options is done by double clicking on the option. This initial condition is also relevant for the thermal plants that must meet a power inflection constraint (see section 5.2.12).

5.2.4 Maximum number of start-ups

When this option is selected, the list of thermal plants defined as commitment in the Configuration part appears on the right-hand side of the interface as shown in the figure below:

Maximum number of start-ups				
Code	Thermal plant	Activate ?	Study Horizon	Daily
1	Ther1	<input type="checkbox"/>		

When the "Activate" option is selected, the user can define the maximum number of start-ups for the study horizon and for each day of the simulation.

5.2.5 Single reserve

For a detailed explanation, please refer to section 4.2.9, which is the same for hydro and thermal plants.

5.2.6 Joint reserve

For a detailed explanation, please refer to section 4.2.10, which is the same for hydro and thermal plants.

5.2.7 Generation constraint

When this option is selected, the list of thermal plants appears on the right side of the interface. The buttons at the top of the list allow the user to display the plants in ascending or descending order.

Below the list of thermal plants appears the type of constraint (less than, equal to, greater than) the generation of the selected thermal plant must comply according to the values entered in the chronological data table shown at the bottom of the interface.

It is possible to define the status (Enable / Disable) of each generation restriction defined by generator. With this option, it is not necessary to edit the data so that the restriction is not considered.

The penalty for non-compliance can be defined automatically (1.1 x cost of energy not supplied) or through the definition of a custom value (\$/MW).

5.2.8 Forced units

When this option is selected, the list of thermal plants defined as commitment in the Configuration part appears in the right-hand side of the interface as shown in the figure below:

The screenshot shows a software interface. At the top, there is a table with two columns: 'Code' and 'Thermal plant'. The first row contains '1' and 'Ther1'. Below this table, there are two legend items: a blue square labeled 'Forced generation' and a white square labeled 'Not forced'. At the bottom, there is a chronological data table with columns for 'Date\hh' and hours from '00h' to '10h'. The date '27/06/2013' is entered in the first row. The cells for '01h', '02h', and '03h' are highlighted in blue, indicating forced generation. There is a scroll bar at the bottom left of the table.

Date\hh	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h
27/06/2013											

Below the list of thermal plants, there is a chronological data table to be used for identifying the stages in which the selected thermal plant must generate.

The identification of the stages is performed by clicking on one of the colored buttons located above the data table (blue for forced generation, white for not forced generation) and selecting with the mouse the stages in which this option will be used.

5.2.9 Self-consumption

Self-consumption decreases the maximum capacity of generation of thermal plants.

When this option is selected, the list of thermal plants appears on the right side of the interface as shown in the figure below:

Code	Thermal plant	Self consumption (% of nominal power)
1	Ther1	2.
2	Ther2	0.
3	Ther3	0.
5	Ther4	0.
6	Ther6	0.
7	Ther7	0.

At the right of each thermal plant appears the “self-consumption” auxiliary column in which the user must enter the losses, in percent of nominal power, attributed to this consumption. Self-consumption includes transformation losses.

5.2.10 Temperature effects

The user can consider thermal plants in which both the capacity and the consumption depend on the temperature.

When this option is selected, the list of thermal plants appears on the right side of the interface as shown in the figure below:

Code	Thermal plant	Maximum Generation (MW)
1	Ther1	18
2	Ther2	20
3	Ther3	15
5	Ther4	20
6	Ther6	20
7	Ther7	20

Temperature variation table | Hourly temperature

To the right of the plants name the model presents the plants maximum generation, which was entered in the Configuration part.

Below the list of thermal plants there are two tabs: Temperature variation table and Hourly temperature in which the user must enter the following information:

a) Temperature variation table

When the user selects this tab, the interface shows a screen like the one presented in the figure below:

Temperature variation table		Hourly temperature			
Number of Levels		Minimum Generation			
3		60 (% Maximum Generation)			
Level	Temperature (°C)	Max. generation (MW)	Incremental Specific Consumption (MPC/MWh)		
			Seg 1	Seg 2	Seg 3
1	0.	11.	15.	8.	
2	10.	10.	16.	8.5	
3	20.	9.	17.	9.	

At the top the user enters the number of levels; each level corresponds to a temperature. Notice that when the user selects the number of levels, they appear in the table at the bottom. For each level, the user must enter the following information:

1. *Temperature*, enter the temperature in degrees Celsius in ascending order. Note that the range of temperature variation in the area where the plant is located must be between the minimum and maximum temperatures entered in this screen.
2. *Maximum Generation*, enter the generation capacity corresponding to the temperature indicated in point 1: For example, for gas turbines the capacity decreases as the temperature increases.
3. *Incremental Specific Consumption*, enter the Incremental Specific Consumption that corresponds to the percentages defined in section 5.1.2.2. Observe that these values override those defined in the thermal configuration. For example, for gas fired thermal plants the specific consumption increases as the temperature increases. The model allows the representation of concave or convex curves for the specific consumption.

To the right of the number of levels the user must enter the minimum generation expressed as a percentage of the maximum generation. Note that this is an additional way to declare the unit as commitment.

b) *Hourly temperatures*

When this tab is selected, a chronological data table appears at the bottom of the interface in which the user enters the temperature of the area where the thermal plant is located, for each hour and day of the study period.

5.2.11 Energy bid

When this option is selected, the list of thermoelectric plants belonging to the study appears in the upper right-hand side of the interface. The information must be supplied only to the thermoelectric plants that sell their generation through energy bids.

Below the list, a chronological data table is presented. This table should be filled with the (hourly or sub-hourly) bid prices (\$/MWh) and total available amount (MW) for each energy bid level.

The definition of the no-load cost, expressed in \$/h, is also available in market environments where this value is considered in the thermal operating costs.

Once the energy bids are defined, the user must change the representation of the costs of the plants for "energy supply" instead of considering them based on fuel costs (standard representation).

5.2.12 Power inflection constraint

This constraint is used in the thermal plants that should remain running at a steady load for a minimum number of hours before being able to modify the direction of load variation. For example, the plants have the constraint of not being able to reduce the production at a stage if the production has been increasing in the previous stage. There are two possibilities to define this minimum operation time with steady load:

- a) *If the plant was in a process of increasing its output*, in this case the plant should remain a minimum time with steady state load before starting the process of decreasing its load.
- b) *If the plant was in a process of decreasing its output*, in this case the plant should remain a minimum time with steady load before starting the process of increasing its load.

When this option is selected, the list of thermal plants appears on the right side of the interface as shown in the figure below:

Thermal plant	Power increase (hours)	Power decrease (hours)	Number of max. load variations
Ther1			
Ther2			
Ther3	3	4	1
Ther4			
Ther6			
Ther7			

For each of the thermal plants with this type of constraint, the following information must be supplied:

- a) *Power increase (hours)*, is the minimum time the plant should remain with a steady load before it can raise its output in case the plant was previously in a load reduction process.
- b) *Power decrease (hours)*, is the minimum time the plant should remain with steady load before it can reduce its output in case the plant was previously in a load increasing process.
- c) *Number of maximum load variations*; is the maximum number of load direction variation changes allowed in the study period.

5.2.13 Forbidden zone

This constraint is used in thermal plants that have forbidden operating zones.

When this option is selected, the list of thermal plants along with the lower and upper limits of the forbidden zone appears on the right-hand side of the interface as shown in the figure below:

Code	Thermal plant	Lower limit (MW)	Upper limit (MW)
1	Ther1		
2	Ther2		
3	Ther3	4	8
5	Ther4		
6	Ther6		
7	Ther7		

The lower and upper limits define the range in which the generation is forbidden, i.e., the generation of the plant must be less than the lower limit or greater than the higher limit. In the figure, the generation of plant Ther3 must be less than 4 MW or greater than 8 MW for all stages in the study period.

5.2.14 Start-up minimum time

When this option is selected, the list of thermal plants declared as commitment along with the start-up information appears on the right-hand side of the interface as shown in the figure below:

Code	Thermal plant	Hot state (hours)	Warm state (hours)	Cold state (hours)	Total cooling time (hours)	Partial cooling time (hours)	Initial condition for synchronism (hours)
1	Ther 1	2.	2.5	3.	4.	2.	1.

As presented in the figure, the user must enter the following information for the thermal plants having this kind of constraints:

- Hot State (hours)*, is the time the thermal plant requires for a hot start-up. A plant is in “hot state” if it has been disconnected for a time shorter than the “partial cooling time”.
- Warm state (hours)*, is the time the thermal plant requires for a “warm” start-up. A plant is in “warm state” if it has been disconnected for a time greater than the “partial cooling time” and smaller than the “total cooling time”.
- Cold state (hours)*, is the time a thermal plant requires for a cold start. It is considered that a plant is in “cold state” if it has been disconnected for a time greater than the “total cooling time”.
- Total cooling time (hours)*, is the minimum time a thermal plant must remain disconnected before a “cold” start-up.
- Partial cooling time (hours)*, is the minimum time a thermal plant must remain disconnected before a “warm” start-up.
- Initial Condition for synchronism (hours)*, information is supplied for the plants that are in the start-up process at the beginning of the study. The information corresponds to the number of hours the plant was in the start-up process prior to the beginning of the study. For the example shown in the figure, the plant began the start-up process one hour before the beginning of the study.

5.2.15 Consumption coefficients

The user can represent the fuel consumption function by means of a second-degree equation:

$$F = A * G^2 + B * G + C$$

Where A, B and C represent the coefficients of the second-degree equation, G represents the generation in MW and F represents the fuel consumption expressed in units/hour. It is important to note that the fuel unit has already been entered in the “**Configuration > Thermal Plants > Fuel configuration**” section.

The information is entered only for the plants that will use this representation of fuel consumption.

5.2.16 Consumption functions

The user can optionally represent the consumption function through a piece-wise linear approximation represented by up to 10 pairs of points that relate generation and consumption.

The following table presents an example of this representation:

Capacity (MW)	Unit Consumption (TCF/MWh)	Total Consumption (TCF/hour)
0	0	0
1	20	20
2	20	40
3	20	60
4	20	80
5	10	90
6	10	100
7	10	110
8	10	120
9	6	126
10	6	132

When this option is selected, the list of thermal plants along with the number of points that will be used to represent the consumption function appears on the right side of the interface.

For the selected plant, a table in which the number of rows is equal to the number of points appears at the bottom of the interface. In this table the user enters the power and the total consumption. For the above example, it is enough to define 4 pairs of values as shown in the following table:

	Power (MW)	Consumption (MPC/h)
1	0	
2	4	80
3	8	120
4	10	132

Note that the consumption unit is the same as the fuel unit defined for the selected thermal plant in the Configuration Section.

5.2.17 Maximum number of shutdowns

When this option is selected, the list of thermal plants defined as commitment in the Configuration part appears on the right-hand side of the interface as shown in the figure below:

Code	Thermal plant	Maximum number of shutdowns	
		Study Horizon	Daily
6	T6		
7	T7		

The user can define the maximum number of shutdowns for the study horizon and for each day of the simulation.

5.2.18 Precedence constraint

This option is used to define the loading order of operation of the thermal generators.

This constraint has been considered in the model due to the possibility of some thermal generators having the same technical characteristics and therefore, the dispatch is economically indifferent to the model.

5.2.19 Ramp levels

This option allows to define different levels of power ramp up / down associated with the current generation of the thermal power plant.

5.2.20 Fuel transition

This option is applied to thermal plants that can use more than one alternative of fuel. The user can define the transition minimum time to change from one type of fuel to another. It is also possible to define the operational cost associated with this change.

5.2.21 Gas emission

It is possible to limit the emission of gases through operational restrictions (greater than / equal to / less than) in a period of the execution horizon. The available gas options are CO₂, SO_x and NO_x, where each constraint can be represented as hard (no slack variables) or soft (automatic/user-defined penalties).

5.3 Scenarios/Constraints of fuels

In a way like the hydroelectric and thermal plants, this part of the interface is used to complete the information entered in the fuel configuration section.

The additional information entered relates to the price and availability of fuels whose detail is presented below:

5.3.1 Fuel price

When this option is selected, the list of fuels along their corresponding unit appears on the right of the interface as shown in the figure below:

The screenshot shows a software interface for fuel configuration. At the top, there are icons for sorting (A-Z, Z-A) and data exchange (import/export). Below this is a table with three columns: Code, Fuel, and Unit. The table contains three rows of fuel data. Below the table is a price table with a header row for hours (00h to 08h) and a data row for the date 27/06/2013. The price table is titled '(\$/MPC)'.

Code	Fuel	Unit
1	Comb1	MPC
2	Comb2	Lts
3	Comb3	Calor

Date\yh	00h	01h	02h	03h	04h	05h	06h	07h	08h
27/06/2013	7.1	7.	7.	6.5	6.5	6.5	6.5	6.5	

The buttons above the list allow the user to sort the list in ascending or descending order and export or import the data to and from Excel.

Below the list there is a chronological data table in which the user supplies the hourly prices for the selected fuel.

5.3.2 Fuel constraints

When this option is selected, the list of fuels along their corresponding unit appears on the right-hand side of the interface as shown in the figure below:

The screenshot shows a software interface for defining fuel constraints. At the top, there is a 'Constraints' section with a list containing '1 - Constraint 1'. To the right of this list are 'Add' and 'Remove' buttons. Below the list, there are input fields for 'Type' (set to 'Availability'), 'Amount (Ton)' (set to '1000'), 'Initial hour' (set to '1'), and 'Final hour' (set to '24'). At the bottom, there is a 'Fuels' section containing a table with two rows, both checked:

Code	Name	Unit
1	Fuel 1	Ton
2	Fuel 2	Ton

Below the list of constraints, the user must enter the interval (initial / final hour) of the horizon in which there will be a fuel constraint (availability / minimum usage) and the total amount of the constraint expressed in the unit of the fuel or set of fuels was/were defined. The buttons on the right allow the user to add a new interval or delete an existing one.

5.3.3 Fuel contracts

The representation of fuel contracts is possible through the definition of availability x fuel price curves. The user defines for each fuel the number of contract levels, as well as the associated thermal power plants and the duration (daily / integral), as presented in the following figure:

The screenshot shows a software interface for defining fuel contracts. At the top, there is a table with the following data:

Code	Name	# Levels	Associated Fuel
1	Contract 01	1	1 Fuel 1
2	Contract 02	3	2 Fuel 2

Below the table is a 'Thermal plants' section with two lists: 'Non selected' and 'Selected'. The 'Selected' list contains 'T1' and 'T2'. At the bottom, there is a table showing availability and price for different days and levels:

Day	Level	Availability (Ton)	Price (\$)
01/01/2007	1	10000.	4.
02/01/2007	1	5000.	6.

6 RENEWABLE SOURCES

The model allows the user to represent sources of renewable energy such as wind plants, solar plants, small-scale hydro plants, biomass plants, etc. In the model these plants are represented by a predefined generation with 0 (zero) operating cost. The information is supplied by means of the two options in the navigation tree: Configuration and Scenarios/Constraints. Below is the information to be entered in each of these two options:

6.1 Configuration

Here the user enters the basic information of the renewable sources.

6.1.1 Renewable source configuration

When this option is selected, the list of renewable sources appears on the right side of the interface as shown in the figure below:

Code	Renewable source
1	R1
2	R2

Renewable source data

Include in study?
 Yes No

Number of units:

Installed Capacity (MW):

Operation Factor (p.u.):

Spilling Cost (\$/MWh):

O&M Cost (\$/MWh):

The buttons above the list of renewable sources allow the user to add or remove a renewable source and to sort them in ascending or descending order.

The data to be entered for the selected renewable source is under the renewable source data heading located at the lower part of the interface. These data are the following:

- Consider source*, when the user selects the option "No", the renewable source is not considered in the study.
- Number of Generating Units*
- Installed capacity (MW)*
- Operation factor (p.u.)*, the generation of the renewable source, at each stage, is equal to the installed capacity multiplied by this operation factor. This value is overridden if the user enters detailed generating information in the scenarios/constraints section.

- e) *Spilling cost (\$/MWh)*, this value is used to penalize the renewable energy sources that cannot be injected into the system.
- f) *Cost of operation and maintenance (\$ / MWh)*, which represents the variable cost of operation and maintenance associated with the plant.

6.2 Scenarios/Constraints of renewable sources

6.2.1 Generation

This option is used to enter the generation for the selected energy source. When this option is selected, the list of renewable sources appears on the right side of the interface as shown in the figure below:

Date\hh	00h	01h	02h	03h	04h	05h	06h	07h
01-01-2021	0.5	0.4	0.4	0.4	0.5	0.5	0.6	0.7

The buttons at the top of the list allow the user to sort them in ascending or descending order.

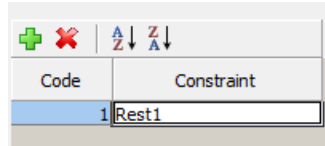
Below the list of renewable sources are two alternative ways in which the user can enter the selected renewable source generation information for each of the stages considered in the study. When the user selects the p.u. generation option the generation at each stage is equal to the installed capacity of the renewable source multiplied by this value.

The generation can be entered in time steps of 60, 30, 15 or 5 minutes. For the stochastic option it's possible to define a higher number of generation scenarios to be considered all together in the optimization process (execution options).

6.2.2 Generation constraint

These restrictions apply if the sum of the generation of a set of renewable power plants must be lower/greater than or equal to a given value (MW) or limited by a percentage of the system demand.

When this option is selected, the list of generation constraints defined for the study appears on the upper right side of the interface as shown in the figure below:



The buttons at the top allow the user to add or remove a restriction and sort the list in ascending or descending order.

For the selected generation constraint, the middle part of the interface presents a dialog box with a selection list in which there are two buttons that allow the user to move the items from the list on the left to the list on the right and vice versa. The renewable sources which will be part of the selected energy constraint are in the list on the right, as shown in the figure below:



At the bottom of the interface there is a chronological data table in which the user enters the percentage of demand for each hourly stage of the study period. This percentage applied to the system demand represents the total maximum generation of the renewable sources that form part of the constraint.

6.2.3 Single reserve

For a detailed explanation, please refer to section 4.2.9, which is the same for renewable sources.

6.2.4 Joint reserve

The joint reserve for renewable sources includes definitions of minimum reserve, maximum reserve, and bidding prices, in upward, downward, or both directions. It can be defined up to a 5-minutes resolution.

For a detailed explanation, please refer to section 4.2.10, in which the joint reserve is explained, and the same logic applies to renewable sources.

7 BATTERIES

The NCP model can represent energy storage devices such as batteries, flywheels and other fast response storage technologies.

7.1 Configuration

Here the user enters the basic information of the batteries.

7.1.1 Battery configuration

When this option is selected, the list of batteries appears on the right side of the interface as shown in the figure below:

The buttons above the list of batteries allow the user to add or remove a battery and to sort them in ascending or descending order.

The data to be entered for the selected battery is under the battery data heading located at the lower part of the interface. These data are the following:

- a) *Consider battery*, when the user selects the option "No", the battery source is not considered in the study.
- b) *Minimum Storage (MWh)*
- c) *Maximum Storage (MWh)*
- d) *Maximum Capacity (MW)*
- e) *Initial Storage*, the user can either input the initial storage manually (p.u.) or select the option "Optimized", and the model will optimize and choose the best initial storage to end the horizon with the same charge as the one from the start.
- f) *Charge maximum ramp (MW/min)*
- g) *Discharge maximum ramp (MW/min)*

- h) *Operation and Maintenance Cost (\$/MWh)*, is applied to either the total power injected / withdrawn in / of the network or just the total power injected in the network.
- i) *Maximum regulation time (hours)*, is the maximum operation cycle duration.
- j) *Efficiency*, efficiency data can be defined through:
 - a. *Round Trip Efficiency (p.u.)*, is the ratio between the energy injected into the network from the battery and the energy taken from the network to charge the battery.
 - b. *Charge / Discharge Table (p.u.)*, is the relationship between energy consumption / injection from / to the network versus battery charging / discharging. The reference (1 p.u.) for the table is the maximum capacity of the battery.

7.2 Scenarios/Constraints of batteries

In this part, the user completes the entry of the information related to the batteries according to the following detail:

7.2.1 Maintenance

When this option is selected, the list of batteries belonging to the study is displayed on the right side of the interface.

At the top of the battery list there are two buttons that allow you to sort the list in ascending or descending order.

The maintenance information for each of the batteries is entered in the chronological data table (hourly or sub-hourly stages) located at the bottom of the screen. The available power of the selected battery expressed in MW is entered in the data table.

7.2.2 Single reserve

For a detailed explanation, please refer to section 4.2.9, which is the same for batteries.

7.2.3 Joint reserve

The joint reserve for batteries includes definitions of minimum reserve, maximum reserve, and bidding prices, in upward, downward, or both directions. It can be defined up to a 5-minutes resolution.

For a detailed explanation, please refer to section 4.2.10, in which the joint reserve is explained, for the same logic applies to batteries.

7.2.4 Generation constraint

When this option is selected, the list of batteries appears on the right side of the interface. The buttons at the top of the list allow the user to display the batteries in ascending or descending order.

Below the list of batteries appears the type of constraint (less than, equal to, greater than) the generation of the selected battery must comply according to the values entered in the chronological data table shown at the bottom of the interface.

It is possible to define the status (Enable / Disable) of each generation restriction defined by generator. With this option, it is not necessary to edit the data so that the restriction is not considered.

The penalty for non-compliance can be defined automatically ($1.1 \times$ cost of energy not supplied) or through the definition of a custom value (\$/MW).

7.2.5 Energy bid

When this option is selected, the list of batteries belonging to the study appears in the upper right-hand side of the interface. The information must be supplied only to batteries that sell their generation through energy bids.

Below the list, a chronological data table is presented. This table should be filled with the (hourly or sub-hourly) bid prices (\$/MWh) and total available amount (MW) for each energy bid level.

Once the energy bids are defined, the user must change the representation of the costs of the plants for "energy supply" instead of considering them as the standard representation.

7.2.6 Target storage

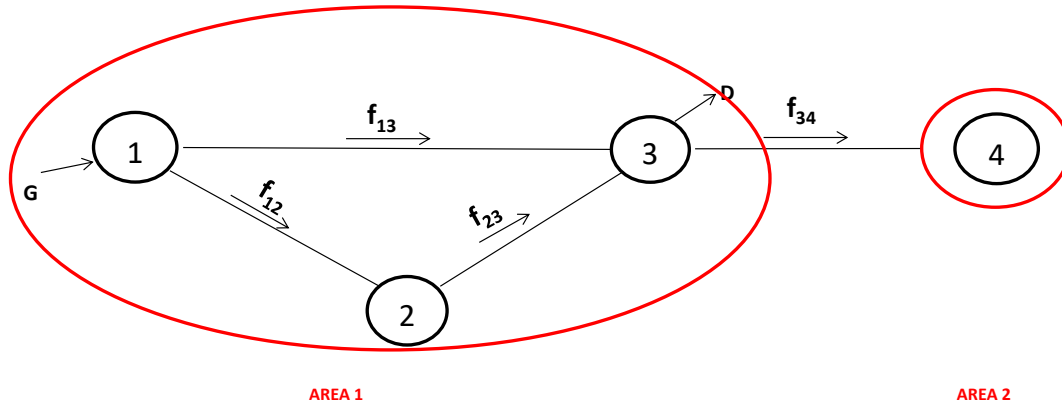
This option is used when it's **necessary** to define the final energy storage level (MWh) in batteries, instead of the standard procedure (final storage = initial storage) applied for these devices.

The definition of the target storage values replaces this terminal condition of the batteries in the optimization problem.

8 TRANSMISSION

Electrical power transmission is the bulk transfer of electrical energy from generating power plants to electrical substations located near demand centers.

The transmission network system consists of a set of buses in which the generators and demands are connected and a set of circuits (transmission lines) which interconnect the buses and allow transfers of energy between them. The figure below shows an example of a network system:



The system is composed of 4 buses and 4 transmission lines. The arrows in the figure represent the positive direction of the flow in the transmission lines, for example, the flow between buses 2 and 3 is positive if it goes from bus 2 to bus 3.

Buses 1, 2 and 3 are assigned to AREA1 and bus 4 to AREA2. AREAS are used for defining zones with special features and/or to make energy exchanges. For example, let AREA1 be the electrical system of country1 and area2 be the electrical system of country2, in this case a positive flow between buses 3 and 4 will be the energy purchases of country2 or alternatively the energy sales of country1.

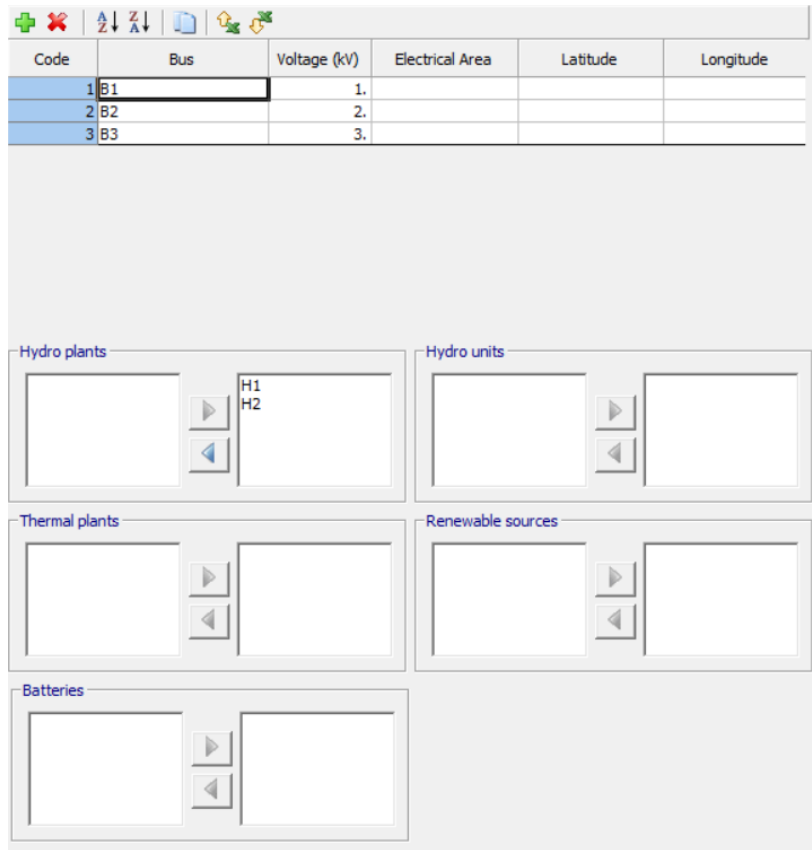
The transmission data are supplied through two options of the navigation tree: Configuration and Scenarios/Constraints.

8.1 Configuration

In this part the user enters the basic information that defines the topology of the network: buses, circuits, and areas according to the following detail:

8.1.1 Bus configuration

When this option is selected, the list of buses along with the voltage, which should be entered by the user, and the area to which the bus belongs appears on the right side of the interface as shown in the figure below:



The buttons located above the list let the user add and remove buses, sort them in ascending or descending order, and copy the information to and from Excel. The copy button allows the user to take the information from the selected bus to a new bus. When the user clicks this button, the interface shows a form in which the user must enter the number and name of the new bus that will be added to the system with the selected bus information.

At the bottom there are 5 selections lists that allow the user to associate hydroelectric plants, thermal plants, renewable sources, batteries, and hydro units to the selected bus.

The right-hand side lists contain all the generating plants associated with the selected bus: For example, in the figure, hydroelectric plants H1 and H2 are associated with bus 1.

The left-hand side lists contain the generating plants not yet associated with any bus. For example, in the figure, the renewable source and the thermal plants have not been associated with the buses. It is important to note that all the generators must be associated with the buses before processing the model.

8.1.2 Circuit configuration

When this option is selected, the list of the circuits along with the busses at which the circuit is connected appears on the right-hand side of the interface as shown in the figure below:

Code	Circuit	From Bus	To Bus
1	C1	1B1	2B2
2	C2	1B1	3B3
3	C3	2B2	3B3

Circuit Data
Geographical Location

Include in study?

 Yes No

Resistance (%)

Reactance (%)

Flow limit (MW)

Selected for monitoring

Represents contingency

Type

 AC Line DC Link

Phase-shifting transformer

 Constant Variable

Losses penalty ?

 (\$/MWh)

Setpoint(°)

Minimum(°)

Maximum(°)

Allow overload ?

 (\$/MWh)

The buttons above the list let the user add and delete circuits, sort them in ascending and descending order, and copy the information to and from Excel. The copy button allows the user to take the information from the selected circuit to a new circuit. When the user clicks this button, the interface shows a form in which the user must enter the number and name of the new circuit that will be added to the system with the selected circuit information.

At the bottom of the screen the basic information to be provided for the selected circuit is presented. The user must enter the following information:

8.1.2.1 Circuit data for AC line

The following information corresponds to AC circuits (lines and transformers):

- *Consider Circuit (Yes, No)*
If the “No” option is selected the circuit is considered as “future”, i.e., it is not considered in the study.
- *Resistance (%), Reactance (%)*
The calculations must be performed considering a power base of 100 MVA. Below is a sample calculation of the reactance of a 230 kV, 100 km line that has a reactance equal to 0.5 ohms/km.
The reactance base is defined as:

$$\text{reactance base [ohm]} = \frac{(\text{voltage base [kV]})^2}{\text{Power base [MVA]}}$$

The reactance base is equal to 529 ohm = 230 [kV]² / 100 [MVA]

The reactance of the line is equal to $50 \text{ Ohm} = 100 \text{ [km]} * [0.5 \text{ Ohm/km}]$

This value in p.u. is equal to $0.0945 \text{ [p. u.]} = 50 \text{ [Ohm]} / 529 \text{ [Ohm]}$

This value in percentage is 9.45 %.

- *Flow limit (MW)*
- *Flow limit monitoring*
If this option is selected the flow limits will be monitored by the model for the selected circuits. Section 11.5.2 of the document will present an option for monitoring all the circuits.
- *Represents contingency?*
It allows the selection of a subset of circuits in which it is possible to do a violation analysis (ex-post) using the results of the base case.
- *Phase-shifting transformer (degrees)*
 - *Setpoint*
 - *Variable*, it requires the minimum and maximum operating limits.
- *Circuit status*
 - *On*
 - *Off*, it allows the user to identify the circuits that will not be considered in the study period.
- *Losses penalty (\$ /MWh)*
This value is used to avoid inconsistencies in the results when the price in a bus is zero or negative (see the Methodology Manual).
- *Allows overload?*
This value is used to penalize flow violations in the monitored circuits, but which allows overloading of the transmission line flows (flow greater than the circuit capacity).

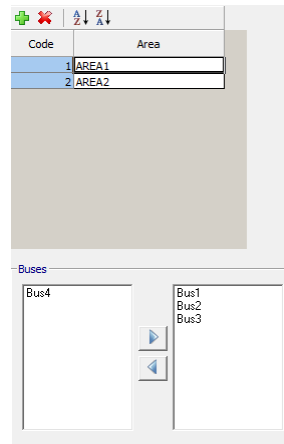
8.1.2.2 Circuit data for DC link

The DC links are represented as independent decision variables because the flow is not subject to the second Kirchhoff's law.

The information to be entered is the same as for AC circuits except for the reactance field and the AC information fields that are disabled. In this approach quadratic losses will be applied.

8.1.3 Area configuration

This part of the model is used to define the buses that belong to a particular area. When this option is selected, the list of areas appears on the right side of the interface as shown in the figure below:

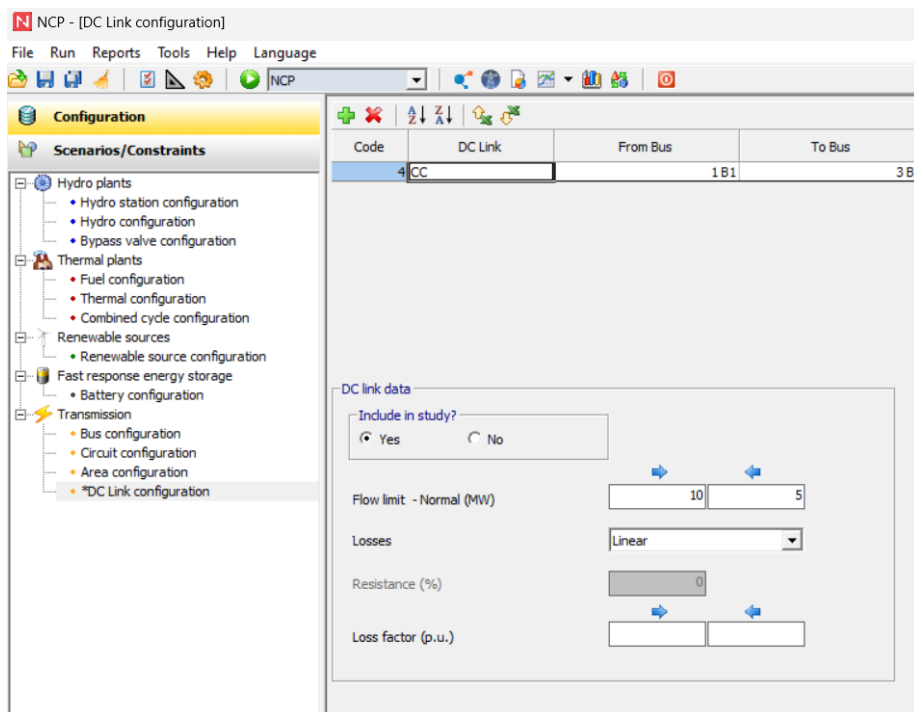


The buttons above the list let the user add and remove areas and sort them in ascending or descending order.

As shown in the figure, at the bottom of the interface there is a selection list in which the user assigns the buses that belong to the selected area. For the example in the previous figure, bus Bus4 has not been assigned to any area and busses Bus1, Bus2 and Bus3 belong to AREA1 area.

8.1.4 DC link configuration

When this option is selected, the list of the DC links along with the busses at which the DC link is connected appears on the right-hand side of the interface as shown in the figure below:



The buttons above the list let the user add and delete DC links and sort them in ascending and descending order. At the bottom of the screen the basic information to be provided for the selected DC link is presented. The user must enter the following information:

8.1.4.1 Circuit data for DC link

The following information corresponds to DC links, for both directions:

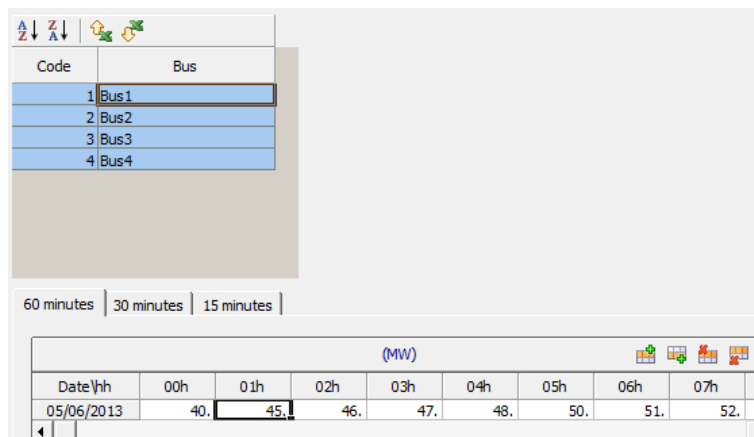
- *Consider DC link (Yes, No)*
If the “No” option is selected the DC link is considered as "future", i.e., it is not considered in the study.
- *Flow limit (MW)*
- *Losses (Linear / Quadratic)*
The losses will be calculated linearly based on the factors or quadratically using the resistance data provided in the DC link definition.
- *Loss factor (p.u.)*
- *Resistance (%)*

8.2 Scenarios/Constraints of transmission

In this part the user completes the entry of the information related to the transmission system according to the following detail:

8.2.1 Bus demand

When this option is selected, the list of busses appears on the right side of the interface as shown in the figure below:



The buttons above the list allow the user to sort the busses in ascending and descending order and to copy the information to and from Excel.

At the lower part of the screen the interface presents, for the selected bus, a chronological data table in which the user must enter the demand, in MW, for the selected bus. The tabs located above the table allow entering the demand in stages of 60, 30, 15 or 5 minutes.

For the stochastic option it's possible to define a higher number of demands by bus scenarios to be considered all together in the optimization process (execution options).

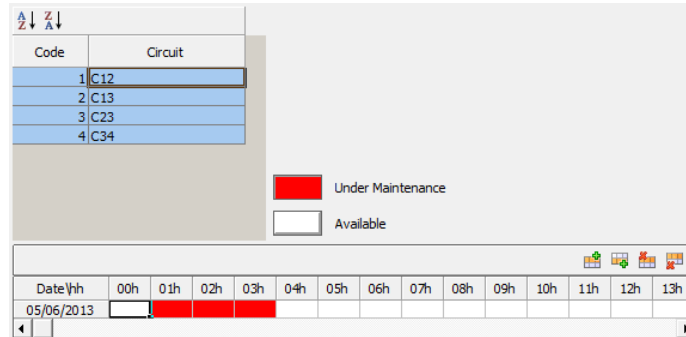
8.2.2 Electrical area import/export

This option allows the user to define, for each time step of the simulation period, the maximum amount of energy that can be imported and exported from each of the areas considered in the study.

8.2.3 Circuits maintenance

This option is used to enter for each circuit having maintenance in the study period, the hours in which it is unavailable.

When the user selects this option the list of circuits appears on the right side of the interface as shown in the figure below:



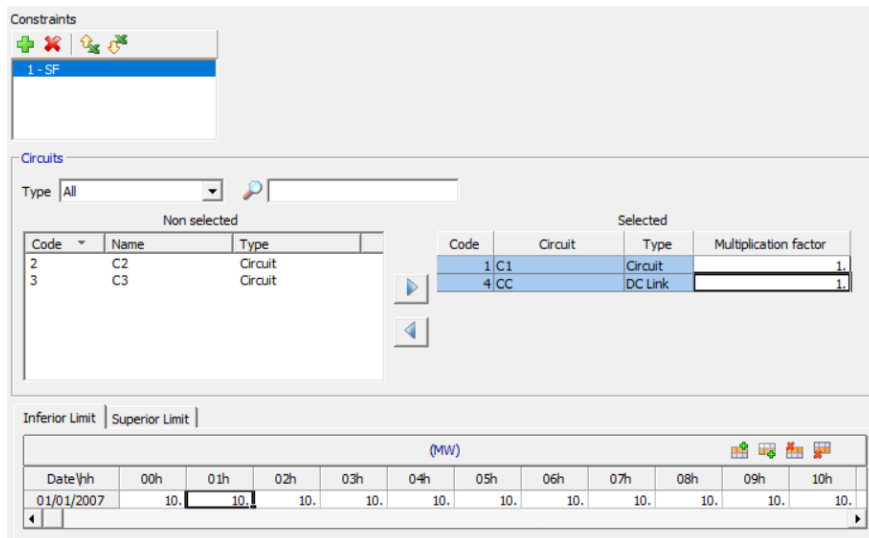
The buttons at the top allow the user to sort the circuits in ascending or descending order.

At the bottom there is a chronological data table in which the user enters for the selected circuit, the hours in which it is in maintenance. In this case the hours in which the circuit is in maintenance are entered selecting the red button "Under Maintenance" and clicking on the corresponding hours.

8.2.4 Sum of circuit flows

This option is used when, due to system constraints, it is necessary to limit the flow passing through a set of circuits during certain hours of the simulation period.

When the user selects this option, the list of circuit flow constraints appears on the right side of the interface as shown in the figure below:



The buttons located on the right of the list of flow constraints allow the user to add or remove a flow constraint.

Below the list of flow constraints appears a selection list. The left list presents the circuits / DC links not subjected to the selected flow constraint and the right list presents the circuits subjected to the selected flow constraint. To the right of the selected circuits the user must enter a multiplication factor to be used for calculating the amount of the circuit flow that will be added to satisfy the constraint. For example, a value equal to 1 indicates that the direction of flow is equal to its definition while a factor of -1 reverses the direction of flow in the calculation of the restriction.

Under the selection list there are two tabs that enable chronological data tables in which the user must enter the lower and upper limits for the selected flow constraint. The lower limit indicates that the sum of flows in the set of selected circuits must be greater than or equal to the values entered in the lower limit table; in a similar way, the upper limit indicates that the sum of flows in the selected circuits must be less than or equal to the values entered in the upper limit table.

8.2.5 Circuit losses representation

Circuit losses can be represented using a series of linear segments or with integer variables. For a detailed explanation, the user is referred to the methodology manual.

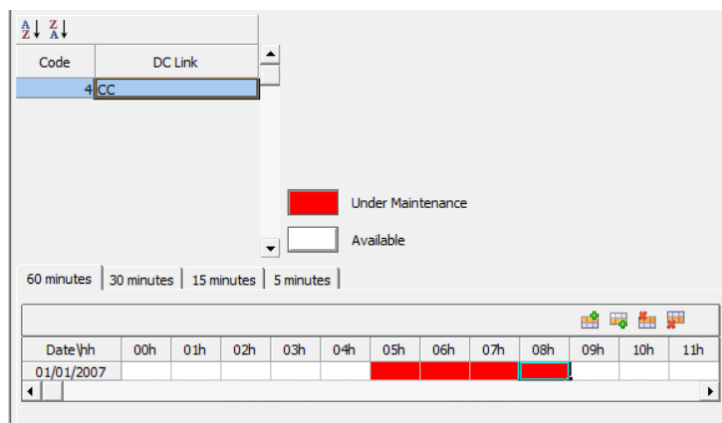
8.2.6 Circuit losses penalty

Circuit losses can be penalized only for a specific set of circuits and/or stages. For a detailed explanation, the user is referred to the methodology manual.

8.2.7 DC link maintenance

This option is used to enter for each DC link having maintenance in the study period, the stages (hourly or sub-hourly) in which it is unavailable.

When the user selects this option the list of DC links appears on the right side of the interface as shown in the figure below:



The buttons at the top allow the user to sort the DC links in ascending or descending order.

At the bottom there is a chronological data table in which the user enters for the selected DC link, the stages in which it is in maintenance. In this case the stages in which the DC link is in maintenance are entered selecting the red button "Under Maintenance" and clicking on the corresponding stages.

8.2.8 DC link transmission cost

This option is used to enter an hourly "toll" (\$ / MWh) for the use of the DC link.

8.2.9 Bus energy price

The bus energy price is used when the optimization criterion is to maximize net revenues and the execution is representing the network constraints, so that it is possible to define different prices for each node. For an explanation about revenue maximization the user is referred to the Methodology manual.

When this option is selected, the interface shows chronological data in which the user enters the bus energy price (\$/MWh) for every stage (hourly or sub-hourly) of the study period.

For the stochastic option it's possible to define a higher number of bus energy price scenarios to be considered all together in the optimization process (execution options).

9 SYSTEM

This part of the interface is used to enter scenarios/constraints that affect the system such as load, reserve and the generation constraints that are detailed below:

9.1 Load

This part of the interface is used to enter total system demand. If the system has a transmission network, then demand must be entered explicitly at the buses as explained in section 8.2.1.

When the user selects this option, the interface will display a chronological data table in which the user enters the total system demand in 60, 30, 15 or 5 minutes.

For the stochastic option it's possible to define a higher number of load scenarios to be considered all together in the optimization process (execution options).

9.2 Elastic load/supply

The elastic demand corresponds to a demand sensitive to price levels. Each elastic demand function is represented by up to 5 blocks: for the price level of the first block the user must specify the total energy amount that this demand is willing to purchase at this system price, i.e., how much energy will be purchased if the system price (load marginal cost) is at the first price level of the elastic demand or immediately below. Analogously, the other blocks for the elastic demand are defined, respecting the following conditions: (i) the price at a given block must be necessarily greater than the price of the preceding block and (ii) the energy amount of a given block must be necessarily greater than the energy amount of the preceding block.

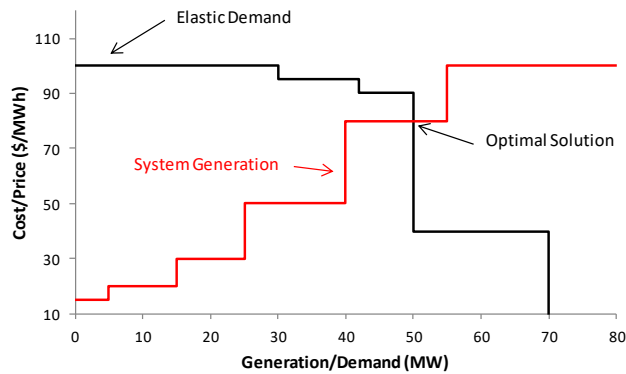
In a similar way, the elastic supply corresponds to a generation willing to sell energy which is sensitive to price levels. Each elastic supply function is represented by up to 5 blocks. In the construction of the elastic supply blocks the following conditions must be respected: (i) the price at a given block must be necessarily smaller than the price of the preceding block and (ii) the energy amount of a given block must be necessarily smaller than the energy amount of the preceding block.

The following example considers a system composed of a single elastic demand defined with 4 blocks and a generating system composed of 6 generating units whose features are the following:

Elastic Demand		Generating Units	
Demand (MW)	Purchase Price (\$/MWh)	Capacity (MW)	Gen. Cost (\$/MWh)
30	100	5	15
42	95	10	20
50	90	10	30
70	40	15	50
		15	80
		25	100

Note that as the price drops the quantity demanded grows. The generating units are sorted from lowest to highest cost.

This information is shown in the figure below:



As seen in the figure, the optimal solution is to supply a 50 MW demand.

When this option is selected, the list of elastic load/supply bids along with the type of bid, the # of blocks and the associated bus appears on the right side of the interface as shown in the figure below:

Represent Network

+ - ↕ ↕ ↕ ↕ ↕

Code	Name	Type	# Levels	Associated Bus
1	Dem1	Demanda	4	1 B1

Amount
Price

60 minutes	30 minutes	15 minutes	5 minutes	(MW)						
Date\hh	Block	00h	01h	02h	03h	04h	05h	06h	07h	08h
01/01/2007	1	0.	0.	30.	0.					
01/01/2007	2	0.	0.	42.	0.					
01/01/2007	3	0.	0.	50.	0.					
01/01/2007	4	0.	0.	70.	0.					

If the user enables the Represent Network option located at the top, then it will be necessary to associate each elastic load/supply bid to a bus.

The buttons above the list of the elastic load/supply bids allow the user to add or remove elastic load/supply bids and sort them in ascending or descending order. When the user adds a new bid, the user must specify if the bid corresponds to a demand or a supply. If the option "Represent Network" is selected, then the user must associate the bid to a bus of the system.

Below the list of bids there are two tabs that enable chronological data tables in which the user enters the quantity and the purchase price of the energy if the bid corresponds to an elastic demand; or the quantity the selling price of the energy if the bid corresponds to an elastic supply.

9.3 Joint reserve

The joint reserve system requirements are met through a set of joint reserve constraints which are satisfied with the joint reserve bids made by the generators.

When this option is selected, the list of joint reserve constraints appears on the right side of the interface reserve defined for the system, in a screen like the one presented in the figure below:

The buttons located to the right of the list of reserve constraints allow the user to add or remove a joint reserve constraint.

Above the list of reserve constraints, the user can select the unit in which the values (hourly or sub-hourly) of the reserve requirements will be expressed. The units are MW or p.u.; in the latter case the joint reserve requirement is calculated as the system total demand multiplied by this factor.

Below the list of reserve constraints, the user must enter the penalty cost for the non-supplied reserve. There are 4 options for expressing this value:

- a) *Automatic Calculation*
The cost of the non-supplied reserve is 1.1 times the variable cost of the most expensive thermal plant.
- b) *Fixed Value*
The cost of the non-supplied reserve equals a user supplied value expressed in \$/MW.
- c) *Joint reserve price*
The user must enter, for every stage (hourly or sub-hourly) of the simulation period, the price of the joint reserve in the chronological data table detailed in section 9.10.
- d) *Do not allow violation*
In this case the joint reserve must necessarily be met. The user must consider that this type of constraint could make the problem unfeasible.

The standard definition of joint reserve requirements is related to both ways (upward / downward), but the user can define different reserve requirements, optionally, based on an exclusive direction.

For each of the defined joint reserves the user can choose between requirement types:

- a) *Standard*: No further restrictions on whether power or plants can be shared between this reserve and other *Standard* reserves.
- b) *Not Shared*: The amount of power that a plant is providing for this reserve cannot be shared with any other reserves.
- c) *Exclusive*: If a plant is assigned to this reserve, it cannot be assigned to any other reserves.

The constraint type allows to the user to change the mathematical sign (\geq or $=$) of the reserve requirement.

The service type (spinning / non-spinning / both) filters the reserve offers eligible to supply the selected joint reserve. With that, it is possible to create exclusively spinning or non-spinning services, as well as allowing both types of services to be provided. The minimum number of generators assigned to attend the reserve can also be defined through the Minimum Number of Generators field. It is important to note that these two options are only available for the multiple joint reserve bids.

Below the non-served reserve cost there are five lists which allow the user to select the set of hydroelectric plants, thermal plants, hydro units, batteries, and renewable sources eligible to satisfy the requirements of the selected joint reserve constraint.

At the bottom of the interface there is a chronological data table in which the user must enter the requirements of the selected joint reserve constraint. The user can enter the values in hourly or sub-hourly time steps.

9.4 Joint reserve group

The attendance of joint reserve constraints can be done through individual generators or groups of generators defined in this screen. The groups can be mixed where hydraulic, thermal generators, batteries and renewable sources can belong to the same service group.

The joint reserve bid made by the groups of generating units consists of a minimum quantity, a maximum quantity, and a price (\$/MW) for each hourly or sub-hourly stage of the study period.

The definition of the offers may vary according to the service direction. For the standard offers, the model will use the same values for both directions, while it is possible to define different values and limits for each one (upward / downward).

There is the option of symmetric allocation between the components of the reserve group, where the total reserve amount assigned to the group must follow a uniform distribution among the group participants.

9.5 Reserve nesting

This option allows joint reserve requirements that nest other requirements to be partly/fully supplied by accepted bids from nested reserves.

In other words, nested services can be reused in other services, where root services can contain one or more nested services.

It is important to note that this reserve nesting option is only available for multiple of the multiple joint reserve bids.

9.6 Generation constraints

This part of the model is used to represent the constraints all generating plants must meet to satisfy the system requirements. For example, the minimum generation that must exist to avoid a "black out" in case of a transmission outage.

When this option is selected, the list of generation constraints appears on the right side of the interface as shown in the figure below:

Date\hh	00h	01h	02h	03h	04h	05h	06h	07h	08h
01-01-2007	15.	15.	15.	15.	15.	15.	15.	15.	1

The buttons above the list of constraints allow the user to add or delete a constraint, sort them in ascending or descending order and import data from Excel files.

At the top is presented the option for selecting the unit (MW or % of system demand) in which the constraint hourly values will be expressed. The hourly values are entered in the chronological data table located at the bottom of the interface.

Below the list of generation constraints there are three possibilities for the constraint type definition:

- ($<$) the sum of the hourly generation values of all the plants belonging to the selected constraint must be less than the value indicated in the chronological data table located at the bottom of the interface.
- ($=$) the sum of the hourly generation values of all the plants belonging to the selected constraint must be equal to the value indicated in the chronological data table located at the bottom of the interface.
- ($>$) the sum of the hourly generation values of all the plants belonging to the selected constraint must be greater than the value indicated in the chronological data table located at the bottom of the interface.

Aside the constraint type, the user can choose between penalty types, either having them automatically calculated or setting a fixed value for it.

Below the constraint type there are selections lists that allow the user to select the generation plants that will belong to the selected generation constraint.

9.7 Generic constraint

Generic constraints are constraints that allow you to create linear relationships between decision variables of the mathematical model. To create a generic restriction, the procedure is as follows:

- Add a generic constraint;
- Define a code and name for the constraint;
- Select the agent (hydro, thermal, renewable source, battery, AC circuit, DC link, bus, demand);
- Select the corresponding agent's decision variable (for example, turbined outflow for a given hydroelectric plant);
- Define the coefficient (and its unit) that will be multiplied by the selected decision variable;
- Define the penalty for violation (in k\$/unit);
- Select the type of requirement (constant or variable);
- Enter the requirement. If the requirement is constant, it must be entered in the "Value" field that is located next to the type of requirement. If it is variable, the values must be entered in the "Chronological requirement" tab.

9.8 Target generation

These restrictions are used to establish the generation boundaries of a set of hydroelectric and thermal power plants within a time interval.

When this option is selected, the list of target generation constraints appears at the top right side of the interface as shown in the figure below:

The example in the figure is interpreted as follows: between hours 4 and 10, total generation of plant HY12 must be greater than or equal to 25 MWh and must be less than or equal to 30 MWh.

The buttons located to the right of the list of target generation constraints allow the user to add or remove a constraint.

Below the list of target generation constraints, the user must enter the limits (upper and lower) between which the total generation of the plants belonging to the selected constraint must lie. On the right side the user must enter the constraint time interval (initial and final time).

At the bottom there are two selections lists that allow the user to define the set of hydroelectric and thermal plants belonging to the selected target generation constraint.

The user should be aware that these are hard constraints that could cause the problem to be unfeasible.

9.9 Market energy price

The market price of energy is used when the optimization criteria is to maximize net revenues. For an explanation the user is referred to the Methodology manual.

When this option is selected, the interface shows chronological data in which the user enters the market energy price (\$/MWh) for every stage (hourly or sub-hourly) of the study period.

For the stochastic option it's possible to define a higher number of market energy price scenarios to be considered all together in the optimization process (execution options).

9.10 Joint reserve price

The price is an alternative option that allows the user to set the cost of the not-served joint reserve requirements detailed in section 9.3.

When this option is selected, the interface shows a chronological data table for entering the (hourly or sub-hourly) price values (\$/MWh) of the non-served joint reserve.

9.11 Inertia

The inertia requirement can be defined in terms of hourly or sub-hourly resolution. The hydroelectric units that can provide inertia are eligible to meet the system requirement.

10 FREQUENCY CONTROL ANCILLARY SERVICE

The power system requires that both generation and load are in balance in order to operate safely. If there is a variation in generation without a corresponding variation in load then the frequency of the power system will deviate, which can lead to instability or, at extreme levels, cascading failure and blackouts.

The Frequency Control Ancillary Service (FCAS) is a process used by the power system operator to maintain the system frequency within the normal operating band.

In short, FCAS provides a rapid injection of energy, or a rapid reduction of energy, to manage supply and demand.

10.1 Configuration

The main characteristics of each ancillary service are defined on this screen. The available parameters are:

- Requirement type (absolute, largest generator contingency, system inertia, interconnector flow, multi-objective)
- Penalty type (no violation, deficit cost, FCAS price)
- Assignment direction (upward, downward, both)
- Selection of hydroelectric units eligible to supply the service
- Selection of DC links (applicable for the last two types of requirements)
- Participation factors (applicable only for the multi-objective requirement)

10.2 Limits

The FCAS assignment limits may be determined on an individual basis and by service type. It is a “generation x maximum service assignment” function defined through points (maximum of 4) that constitute assignment **limiting** “trapeziums”.

10.3 Requirement

The absolute FCAS requirement is defined on this screen in terms of hourly or sub-hourly resolution. It is only applicable to services with an absolute requirement type.

10.4 Price


The FCAS price is defined on this screen in terms of hourly or sub-hourly resolution. It is only applicable to services with a "FCAS price" penalty type.

10.5 Relationship

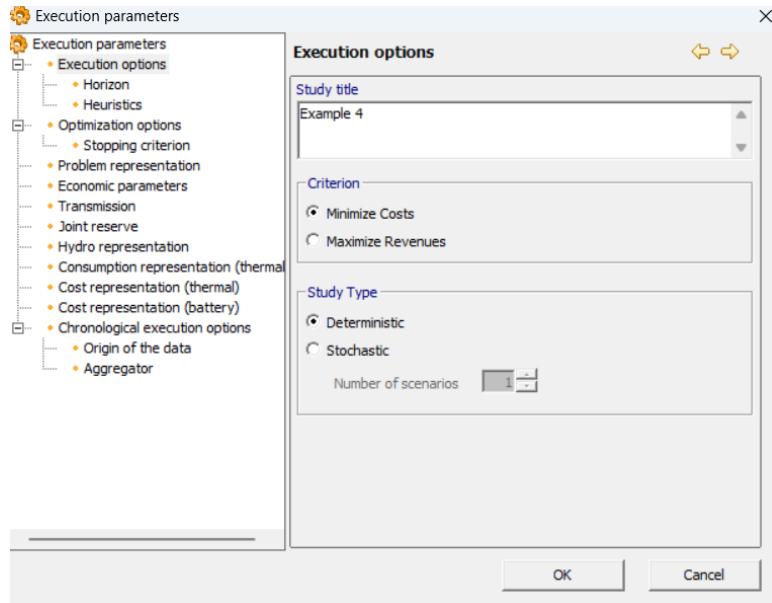
The concomitant assignment of services in the same generating unit is done in an exclusively way. In other words, the allocation of one service decreases the margin for the allocation of another service.

On this screen, it is possible to create relationships between different services allowing allocation **limits to be added and/or reduced**. By selecting the “reduce” relationship type, it indicates that the maximum assignment of the reference service is reduced with the value of the associated service assignment. The second type adds the maximum allocation capacities of the services (reference and associated) before reducing the allocation of the associated service.

11 EXECUTION PARAMETERS

This part of the interface is accessed by selecting “Run > Execution Parameters” in the Main Menu or by pressing the button  of the main menu common options.

When this option is selected, the interface shows a screen like the one in the figure below:



On the left side is presented a list of options that complete the definition of the optimization problem. When the user selects any of these options it appears on the right side the information that must be entered.

At the top right there are two yellow colored direction arrows which let the user navigate through the list of options. At the bottom there are two buttons; the "OK" button exits this screen saving all changes made, the "Cancel" button exits the screen without saving the changes.

Below is the detail of the information that must be entered to define the execution parameters.

11.1 Execution options

When this option is selected, the screen displays the figure shown above in which the user must enter the following information:

- a) *Study title*
- b) *Criterion*
The options are minimizing cost or maximizing revenue.
- c) *Study type*
The options are deterministic or stochastic. The stochastic option contains nonparticipative constraints regarding the thermal and hydro commitment status to guarantee the uncertainty of decision-making process.
- d) *Number of scenarios*
Once the stochastic was previously selected, the user must inform the number of scenarios to be considered.

11.1.1 Horizon

The horizon of the case is defined through the following data:

- a) *Resolution*
The resolution of each stage can be 60 / 30 / 15 / 5 minutes, with a maximum number of 1488 stages. That means an execution horizon of:
 - a. 62 days (60- minutes resolution)
 - b. 31 days (30- minutes resolution)
 - c. 15 days (15- minutes resolution)
 - d. 05 days (5- minutes resolution)
- b) *Initial date*
Enter the initial date of the study in day/month/year and hour/minute format.
- c) *Final date*
Enter the final date of the study in day/month/year and hour/minute format.

11.1.2 Heuristics

- a) *Activate rolling horizon*
By enabling this option, the model implements a heuristic which aims to reduce the execution time of complex cases, based on the representation of binary variables of the whole study in sub-horizons with standard duration of 24 hours. The strategy is based on the execution of sequential cases where the binary variables will be only represented in each sub-horizon execution. For example, on a weekly schedule of 168 hours, the model will run 7 weekly cases in sequence where the binary variables are considered in the first 24 hours for execution # 1, in the next 24 hours for execution #2 and so forth. The decisions taken in previous executions are fixed for the next run until the 7 cases are completed. Alternatively, the user can define the duration of the sub-horizons.
- b) *Activate intra-hourly aggregation of integer variables*
For cases with stage duration of 5, 15 or 30 minutes, the user can enable this option to reduce the size of the problem by aggregating the commitment decisions at each hour. In other words, for each complete hour of the whole horizon the model will dispatch or not the plants, not having the possibility of startups or shutdowns intra-hourly.
- c) *Hot-start*
It is possible to save the final solution of a dispatch into a .slx file and load it as initial solution through this functionality. For this, there must be compatibility between databases (number and order of the plants) and the horizon should be the same. Additionally, it was included the ability to interrupt a program through the command CTRL + C so that the model generates the results of the best solution until the moment of the interruption.
- d) *Reproduction of results*
It is possible to select the convergence report of an execution (ncpconv.csv file) to reproduce the results obtained previously based on the convergence parameters used by the base case.

11.2 Optimization options

There are five optimization options that are presented below:

- a) *Solution method*, the optimization problem can be solved with the Simplex method or the Newton Barrier method. It is recommended to use the Newton Barrier method on systems that have many plants, buses, and circuits.
- b) *Heuristics*, enables the degree of dedication in the processing of information for the search for feasible solutions. It can be done automatically or manually regulated between maximum quality and higher speed.
- c) *Parallel execution*, enables the use of multiple processors located in the same computer. The parallel process can be applied to the whole optimization problem or, alternatively, only for B&B phases.
- d) *Preprocessing level*, enables the automatic elimination of restrictions and decision variables to reduce the size of the original problem. The level of reduction can be total or partial, according to the characteristics of each case.
- e) *Relaxed solution*, enables the execution without the integrality constraints, where it is possible to have a preview of the results as well as the previous detection of possible infeasibility in the input data.

11.2.1 Stopping criterion

The stopping criterion is divided into two types (single- / multi-). In both options, the following stopping parameters are informed:

- *Maximum execution time (minutes)*, in case a feasible solution is not reached in the selected time, the model presents the best solution found.
- *Absolute convergence tolerance (k\$)*, the model converges when the difference between the best solution found, and an upper limit is less than the defined tolerance.
- *Relative convergence tolerance (%)*, this is an alternative way of defining the absolute convergence tolerance.

The difference is that in the multi-criterion it is possible to define convergence intervals that can "relax" the criterion during the execution process. For example, if the desired relative tolerance of the first interval is 0.1% up to 30 minutes of execution, but in the second interval, execution is allowed to be interrupted after the initial 30 minutes if the convergence gap is below 0.5%. The same is applied for absolute tolerance, defined in terms of thousands of monetary units.

11.3 Problem representation

In this option, the user must enter the following information:

- a) *Use terminal function*
When this option is selected, the user must use one of the following alternative forms of representation of the terminal function:
 - SDDP, in this case the user must enter the name of the file having the future cost function. The future cost function is generated by the SDDP Model developed by PSR. The future cost function files have the FCF extension. For a detailed explanation of the future cost function the user refers to the SDDP methodology manual.
 - MaxRev, a future benefit function is applied when the optimization criterion is to maximize revenues. The future benefit function is generated by the MaxRev model developed by PSR.
- b) *Maintenance*

- The model presents two options: use maintenance schedule or use unavailability factor.
- c) *Generation*
The model allows the user to select the option "electricity production smoothing" which is designed to avoid abrupt changes in hydro and/or thermal generation. The penalty associated with this feature can be defined by the user if it's needed.
 - d) *Deficit*
The model allows the user to select the option "do not allow deficits for economic reasons" with which the model does not create slack variables to represent unserved energy. This option is recommended only in situations where it might be cheaper for the model to perform a small rationing instead of starting up a thermal unit due to the associated start-up cost. The user must use this option with caution because the model could have no solution.

11.4 Economic parameters

In this option, the user must enter the following information:

- a) *Monetary unit*
It defines the currency that is used for data entry and program outputs, for example, the currency used in this manual is \$.
- b) *Discount rate (p.u.)*
A 12% annual discount rate is entered as 0.12.
- c) *Minimum flow penalty (\$ /hm³)*
It is used in the objective function as a penalization coefficient applied to the quantity of flow that violates the constraint.
- d) *Spilling penalty (k\$ /hm³)*
It is used in the objective function as a penalization coefficient applied to spilled water.
- e) *Unserved energy*
The unserved energy cost is represented in a table of up to 5 pairs of values which relates the rationing (% of unserved demand) and the corresponding unserved energy cost. The user should note that the sum of the percentages of the demand must be 100% and that the deficit costs must be in ascending order.

11.5 Transmission

The parameters related to the transmission are the following:

11.5.1 Network

It allows the representation of the transmission network in one of four alternatives: without network and DC flow with / without losses. A brief description of these options follows:

- a) *Without network*
The model does not consider the transmission system, i.e., the electrical system is represented by only one bus.
- b) *Linear power flow with no losses*
When using this option, it is a common practice to increase the demand of each node in the system with an estimate of the transmission losses. The flow through each circuit is equal to the difference of the nodal angles divided by the reactance. For a more detailed explanation the user is referred to the methodology manual.
- c) *Linear power flow with losses*

In a similar fashion to case b), the flow in each circuit is equal to the difference of the nodal angles divided by the reactance and the losses in each of the circuits are proportional to the square of the flow. For a more detailed explanation the user is referred to the methodology manual.

11.5.2 Flow limit monitoring

Depending on the alternative selected the model creates flow constraints for all circuits of the system or only for those circuits that were enabled in the flow limit monitoring option in section Circuit configuration.

11.5.3 Circuit overload

The monitored AC circuits can represent eventual overloads in the flows when this option is enabled. In these cases, a penalty to be defined by the user will be applied.

11.5.4 Circuit losses

This option is enabled when the user selects the linear power flow with losses option or the AC flow option to represent the transmission network. The representation of losses requires the following information:

- a) *Maximum number of segments*
The user must enter the maximum number of segments the model will use to represent losses. The maximum number allowed is 50.
- b) *Losses penalty (\$ /MWh)*
This value is used to avoid inconsistencies in the results of the losses when the price at a bus is zero or negative. For a detailed explanation, the user is referred to the methodology manual.
- c) *Absolute tolerance (MW)*
- d) *Relative tolerance (%)*
The relative value is calculated with respect to the maximum possible loss.
- e) *Automatic check of inconsistency in the loss model*
This option automatically detects and corrects possible inconsistencies in the quadratic loss calculation. The maximum number of iterations applied to this verification is optional. More information can be obtained in the Methodology Manual.

11.6 Joint reserve

There are three alternative options to the joint reserve market:

- a) *No reserve selling*
When this option is selected, the model does not consider the generator's offers (amount / price) to meet the reserve requirements.
- b) *Selling reserve according to plant's offers*
When this option is selected, the joint reserve requirements are met through the generator's bids.
- c) *Selling reserve at the joint reserve price*
When this option is selected, the joint reserve bid prices of the generators are replaced with the values entered in section 9.10.

11.7 Hydro representation

Allows the user to represent the hydroelectric part of the model per plant, per unit or in mixed mode according to the following detail:

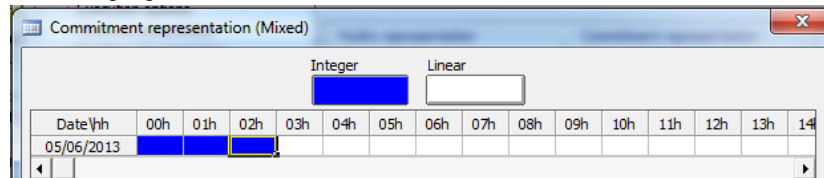
a) *Per plant*

When this option is selected, the hydroelectric representation is done by plant, i.e. the information entered at the unit level is not considered. When the user selects the option "Represent the allowed generation zone", the information submitted at the unit level is aggregated at the plant level.

b) *Per unit*

When this option is selected, the hydroelectric representation is at the level of generating units. The commitment representation is done through either of the following ways:

- *Linear*, in this case, the model does not use the binary variables associated with the commitment representation.
- *Integer*, the commitment options are represented by binary variables.
- *Mixed*, the model allows using the linear option or the integer option at each stage of the simulation period. When this option is selected, the interface presents a chronological data table in which the user selects, for every hour of the study period, if the commitment option will be linear or integer, as shown in the following figure:



c) *Mixed*

When this option is selected, the interface presents a chronological data table in which the user selects, for every hour of the study period, if the hydroelectric representation will be by generating units.

There are two additional options that enable the representation of the variation of the forebay level with the water storage which is applied for the operational constraints that involve the levels as a decision variable (spilling rating curve / forebay fill-up and drawdown ramps / generic constraints / etc.) and the representation of the forbidden zones of generation.

11.8 Thermal consumption representation

Consumption at each thermoelectric plant can be represented in any of the following three forms:

- Incremental consumption*, the model uses the incremental values entered in the fuel tab of the "Configuration > Thermal Plants > Thermal Configuration" option.
- Consumption coefficients*, the model uses the second-degree curve entered in the "Scenarios/Constraints > Thermal Plants > Consumption coefficients" option.
- Consumption coordinates*, the model uses the values entered in the "Scenarios/Constraints > Thermal plants > Consumption functions" option.

11.9 Thermal cost representation

The cost of each thermoelectric plant can be represented in any of the following two forms:

- a) *Fuel cost*, the model uses the fuel costs associated with selected the thermal consumption representation in the previous item.
- b) *Energy bids*, the model uses this option for the thermal cost representation of the selected plant the energy bid levels defined in 5.2.11.

11.10 Battery cost representation

The cost of each battery can be represented in any of the following two forms:

- a) *Standard*, the model uses the standard charge/discharge model of battery operation.
- b) *Energy bids*, the model uses for the representation of the cost of the selected battery, the energy bid levels defined in numeral 7.2.5.

11.11 Chronological execution

The NCP allows for the refinement of SDDP results using a weekly or monthly stage SDDP simulation and present the results chronologically in hourly / sub-hourly resolution.

Using this feature, for example, a SDDP 1 year run with weekly time steps can be split in 8760 hourly results obtained with 52 consecutive sequential NCP weekly executions. In this case the results from one week are passed as initial conditions to the next week, for example storage levels, commitment status of units (on/off and how many hours), water in transit (if travel time exists), etc.

11.11.1 Options

The user must enter the following information in the chronological execution option's screen:

- a) *SDDP directory*
The user must specify the directory where SDDP data and results are located.
- b) *Terminal Function*
The user must choose one of the following five options:
 - *FCF*, in this case NCP uses the SDDP future cost functions at the end of each weekly or monthly simulation period. It is important to note that in this case target generation constraints or target storage constraints are not used.
 - *Target storage*, in this case the NCP uses the SDDP results related to initial and end storage levels. It is important to note that the NCP results for total hydroelectric production (weekly or monthly) may differ from the SDDP ones.
 - *Target generation*, in this case, the SDDP hydroelectric generation (weekly or monthly) is respected by the NCP. Since the modeling of the hydroelectric plants may be different in the SDDP and NCP models, the amount of water used by each hydroelectric plant may be different in the two models and consequently, the storage levels may be different.
 - *FCF + Target storage*, in this case the model will consider a combination of the first two items listed.
 - *FCF + Target generation*, in this case the model will consider a combination of the first and third items listed.
- c) *Initial / final series*

The user must enter the SDDP scenarios interval from which the SDDP results will be extracted.

d) *Initial / final stage*

The user must enter the SDDP stages interval (monthly or weekly) from which the SDDP results will be extracted.

11.11.2 Additional information

The hourly input data must be entered for the entire simulation period or acquired directly from an execution of SDDP long/medium term case.

11.11.3 Output results

The results are presented into new directories with the description XXXX-YYYY, where XXXX corresponds to the week or month of the original SDDP executed case and YYYY is the correspondent scenario. Those partial results should be aggregated using the aggregator tool to be displayed with the graph module.

12RESULTS

The NCP provides the following output results:

Hydroelectric plants	Unit	File
Start-up decision	p.u.	arraqhcp.csv
Reservoir level	m.a.s.l.	cotrescp.csv
Opportunity cost	\$/MWh	oppchhcp.csv
Operating cost	k\$	coshidcp.csv
Production factor	MW/m ³ /s	fprodct.csv
Generation	MW	gerhidcp.csv
Gross generation	MW	ghidbrcp.csv
Pre-defined generation	p.u.	gerprhcp.csv
Joint reserve	MW	resaghcp.csv
Available capacity	MW	pothid.csv
Installed capacity	MW	pnomhd.csv
Single reserve	MW	rrodhd.csv
Turbined outflow	m ³ /s	turbincp.csv
Water value	k\$/Hm ³	watervcp.csv
Maximum turbined outflow	m ³ /s	qmaxim.csv
Minimum turbined outflow	m ³ /s	qminim.csv
Inflows	m ³ /s	inflow.csv
Spilled outflow	Hm ³	vertimcp.csv
Final storage	Hm ³	volfincp.csv
Alert storage	Hm ³	volale.csv
Flood control storage	Hm ³	volesp.csv
Maximum operative storage	Hm ³	volmax.csv
Minimum operative storage	Hm ³	volmno.csv
Minimum turbined outflow violation	m ³ /s	vturmncp.csv
Alert storage violation	Hm ³	vvalercp.csv
Minimum operative storage violation	Hm ³	vvolmncp.csv
Minimum total outflow violation	m ³ /s	vdefmncp.csv
Maximum total outflow violation	m ³ /s	vdefmxcp.csv
Irrigation violation	m ³ /s	vriegocp.csv
Evaporation	Hm ³	evaporcp.csv
Available maximum turbined outflow	m ³ /s	qmxdsp.csv
Commitment status	p.u.	commihcp.csv
Capacity margin	MW	pdhgercp.csv
Single reserve (% of generation)	%	resphhcp.csv

Single reserve (generation > 0)	MW	resprhcp.csv
Single reserve violation	MW	violrhcp.csv
Joint reserve cost	k\$	cosrshcp.csv
Energy bid cost	k\$	ofenercp.csv
Joint reserve (up)	MW	resagh_u.csv
Joint reserve (down)	MW	resagh_d.csv
Joint reserve (% of generation)	%	resaphcp.csv
Joint reserve (% of generation) (up)	%	resaph_u.csv
Joint reserve (% of generation) (down)	%	resaph_d.csv
Joint reserve cost (up)	k\$	cosrsh_u.csv
Joint reserve cost (down)	k\$	cosrsh_d.csv
Minimum spillage violation	m ³ /s	vvermncp.csv
Generation constraint violation	MW	violrhcp.csv
Tailwater elevation	m	cotjuscp.csv
Multiple joint reserve (up)	MW	rsexch_u.csv
Multiple joint reserve (down)	MW	rsexch_d.csv
Bypass flow	m ³ /s	waterway.csv
Total received outflow	m ³ /s	outotcp.csv
Minimum bypass outflow violation	m ³ /s	watermin.csv
Maximum bypass outflow violation	m ³ /s	watermax.csv
Time average constraint violation	unit	timeaveh.csv
Target storage violation	Hm ³	vmetacp.csv

Hydroelectric units	Unit	File
Start-up decision	p.u.	arraqucp.csv
Start-up cost	k\$	costuncp.csv
Generation	MW	gerunicp.csv
Penstock friction losses	MW	lossuncp.csv
Turbined outflow	m ³ /s	turbiucp.csv
Commitment status	p.u.	comitucp.csv
Available capacity	MW	potunicp.csv
Capacity margin	MW	pdugercp.csv
Opportunity cost	\$/MWh	oppucgcp.csv
Forced generation	MW	gerfuncp.csv
Single reserve (% of generation)	%	respupcp.csv
Single reserve (generation > 0)	MW	resrucp.csv
Joint reserve (% of generation)	%	resapucp.csv
Joint reserve (generation > 0)	MW	resagucp.csv

Joint reserve cost	k\$	cosrsucp.csv
Joint reserve (up)	MW	resagu_u.csv
Joint reserve (down)	MW	resagu_d.csv
Joint reserve (% of generation) (up)	%	resapu_u.csv
Joint reserve (% of generation) (down)	%	resapu_d.csv
Joint reserve cost (up)	k\$	cosrsu_u.csv
Joint reserve cost (down)	k\$	cosrsu_d.csv
Generation constraint violation	MW	violrucp.csv
Production factor	MW/m ³ /s	fprduncp.csv
Multiple joint reserve (up)	MW	rsexcu_u.csv
Multiple joint reserve (down)	MW	rsexcu_d.csv
Inertia	MWs	inertiau.csv
Start-up (off -> synchronous condenser)	p.u.	stofscpp.csv
Start-up (synchronous condenser -> on)	p.u.	stsconcp.csv
Start-up cost (off -> sync condenser)	k\$	csfscpp.csv
Start-up cost (sync. condenser -> on)	k\$	cssconcp.csv
Synchronous condenser	p.u.	synconcp.csv
FCAS (up)	MW	fcunit_u.csv
FCAS (down)	MW	fcunit_d.csv

Thermal plants	Unit	File
Start-up decision	p.u.	arranqcp.csv
Commitment status	p.u.	commitcp.csv
Fuel consumption	Unit	consumcp.csv
Operating cost	k\$	costercp.csv
Unit cost - segment 1	\$/MWh	cinte1.csv
Unit cost - segment 2	\$/MWh	cinte2.csv
Unit cost - segment 3	\$/MWh	cinte3.csv
Pre-defined generation	p.u.	gerprtcp.csv
Generation	MW	gertercp.csv
Gross generation	MW	gterbrcp.csv
Generation marginal cost	\$/MWh	cmgtercp.csv
Forced generation	p.u.	gerforcp.csv
Minimum generation	MW	pmnter.csv
Joint reserve	MW	resagtcp.csv
Available capacity	MW	potter.csv
Nominal capacity	MW	pnomtr.csv
Single reserve	MW	rrodtr.csv

Forced units	p.u.	cpunfo.csv
Steam extraction	Ton	stmextcp.csv
Steam boiler	Ton	stmboicp.csv
Steam deficit	Ton	stmdefcp.csv
Capacity margin	MW	pdtgercp.csv
Joint reserve (% of generation)	%	resptpcp.csv
Joint reserve (generation > 0)	MW	resprtcp.csv
Single reserve violation	MW	violrtcp.csv
Steam generation increase	p.u.	nvarupcp.csv
Joint reserve cost	k\$	cosrstcp.csv
Shutdown decision	p.u.	desligcp.csv
Operative average cost	\$/MWh	costmdcp.csv
Cold start-up decision	p.u.	cdstarcp.csv
Warm start-up decision	p.u.	wmstarcp.csv
Combined cycle coupling	p.u.	acoplacp.csv
Shutdown cost	k\$	cdeslgcp.csv
Cold start-up cost	k\$	cscdstcp.csv
Start-up cost	k\$	carrancp.csv
Combined cycle generator coupling cost	k\$	cacoplcp.csv
Warm start-up cost	k\$	cswmstcp.csv
CO ₂ emissions	tCO ₂	emico2cp.csv
NO _x emissions	tNO _x	eminoxcp.csv
SO _x emissions	tSO _x	emisoxcp.csv
Joint reserve (up)	MW	resagt_u.csv
Joint reserve (down)	MW	resagt_d.csv
Joint reserve (% of generation)	%	resaptcp.csv
Joint reserve (% of generation) (up)	%	resapt_u.csv
Joint reserve (% of generation) (down)	%	resapt_d.csv
Joint reserve cost (up)	k\$	cosrst_u.csv
Joint reserve cost (down)	k\$	cosrst_d.csv
Generation constraint violation	MW	violrtcp.csv
Commercial revenue	k\$	revtercp.csv
Multiple joint reserve (up)	MW	rsexct_u.csv
Multiple joint reserve (down)	MW	rsexct_d.csv
Gas emission violation	unit	emicgast.csv

System	Unit	File
Demand marginal cost	\$/MWh	cmgdemcp.csv

System deficit	MW	defcitcp.csv
Demand	MW	demand.csv
Market price	\$/MWh	pricescp.csv
Generation constraints	MW	resgen.csv
Terminal function marginal cost	p.u.	cmgcutcp.csv
Target generation marginal cost	\$/MWh	cmgmetcp.csv
Joint reserve marginal cost	\$/MWh	cmgrsecp.csv
Fuel availability marginal cost	\$/Unit	cmgdiscp.csv
Joint reserve purchase	MW	respurcp.csv
Revenue	k\$	profitcp.csv
Demand (30 min.)	MW	demand30.csv
Demand (15 min.)	MW	demand15.csv
Demand (05 min.)	MW	demand05.csv
Aggregated elastic transaction	MW	demagtcp.csv
Individual elastic transaction	MW	demelecp.csv
Stage duration	h	duraci.csv
Joint reserve purchase (up)	MW	respur_u.csv
Joint reserve purchase (down)	MW	respur_d.csv
Generation constraint violation	MW	violrgcp.csv
Elastic transaction revenue	k\$	revelecp.csv
Stage resolution	min	duracipc.csv
Generic constraint violation	unit	vgenectr.csv
Average elastic demand price	\$/MWh	prcelecp.csv

Transmission	Unit	File
Bus marginal cost	\$/MWh	cmgbusc.csv
Bus deficit	MW	defbuscp.csv
Bus demand	MW	demxba.csv
Circuit flow	MW	cirflwcp.csv
Circuit marginal cost	p.u.	cmgcircp.csv
Circuit loss	MW	lossescp.csv
Circuit loss factor	p.u.	lossftcp.csv
Bus demand (05 minutes)	MW	demxba05.csv
Bus demand (15 minutes)	MW	demxba15.csv
Bus demand (30 minutes)	MW	demxba30.csv
Sum of circuit flow marginal cost	\$/MWh	cmgsumcp.csv
Bus energy price	\$/MWh	prcbusc.csv
Bus revenue	k\$	prfbusc.csv

Circuit loading	%	usecircp.csv
Quadratic losses	MW	qdrllsccp.csv
Sum of circuit flow constraint	MW	sumcircp.csv
Net bus injection	MW	businj.csv
Phase shifter angle	grados	phshif.csv

Renewable sources	Unit	File
Net generation	MW	gergndcp.csv
Curtailment	MW	vergndcp.csv
Joint reserve	MW	resagrccp.csv
Joint reserve (up)	MW	resagr_u.csv
Joint reserve (down)	MW	resagr_d.csv
Single reserve (% of generation)	MW	resprccp.csv
Single reserve (generation > 0)	MW	resprccp.csv
Single reserve violation	MW	violrccp.csv
Multiple joint reserve (up)	MW	rsexcr_u.csv
Multiple joint reserve (down)	MW	rsexcr_d.csv
Curtailment cost	k\$	cvegndcp.csv
O&M cost	\$/MWh	oemgndcp.csv
O&M total cost	k\$	comgndcp.csv
Available capacity	MW	potgndcp.csv

Batteries	Unit	File
Net generation	MW	gerbatcp.csv
Energy storage	MWh	batstgcp.csv
Joint reserve	MW	resagbcp.csv
Joint reserve (up)	MW	resagb_u.csv
Joint reserve (down)	MW	resagb_d.csv
Generation constraint violation	MW	violgbcp.csv
Multiple joint reserve (up)	MW	rsexcb_u.csv
Multiple joint reserve (down)	MW	rsexcb_d.csv
Single reserve (% of generation)	MW	resprbcp.csv
Single reserve (generation > 0)	MW	respbccp.csv
Single reserve violation	MW	violrbcp.csv
O&M cost	\$/MWh	oembatcp.csv
Available capacity	MW	potbatcp.csv

13GRAPH

13.1 Menu

The Graph has two main menus: A top-right and a top-left side one. The top-right menu is as follows:



- *Add Chart*: Opens the *Settings* window, to define and add a new chart to the main screen, and further explained on section 13.2.
- *Update Charts*: Opens a new window to select charts for an update, and then reloads them based on the most recent case data.
- *Night/Day Mode*: Shifts between the white or black background color.
- *Display Mode*: Shifts between stacking the charts in a single or double column arrangement.

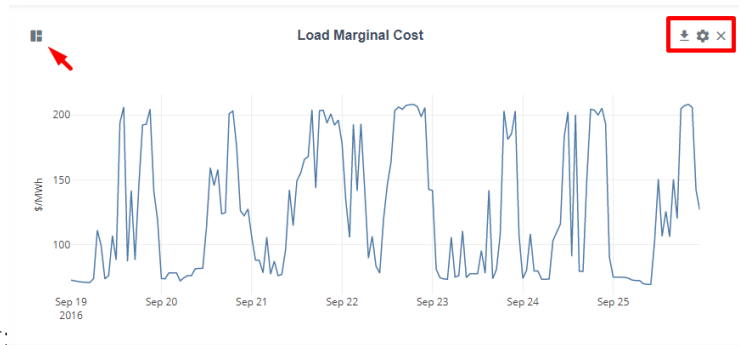
Similarly, the top-left menu is described below:

- *Charts*: Returns to the Graph main screen, where the charts are located.

13.2 Chart Settings

On clicking the *Add Chart* button, the *Settings* menu will be displayed. Then, the charting options between horizon, blocks, scenarios, and variables can be chosen. After the setup is ready, the *Update Chart* button can be used to plot the graph.

After the chart is plotted, there is a series of options included inside the graphic itself. From the

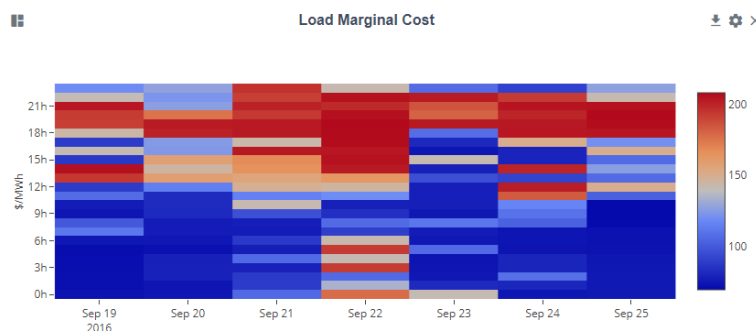


top left to the top right:

- *Chart Type*: Allows the user to change the presentation of the data between many types of charts.



Below is an example of a heatmap chart applied to the plotting of the load marginal cost of a case:



- *Download*: Allows the choice to download a chart, either as an image or as data.
- *Settings*: Re-opens the settings menu for the chart.
- *Close*: Deletes the chart from the screen.

The link to download the new versions of the graph tool is: <https://www.psr-inc.com/app/link/?t=d&f=graphmodule-setup.zip>

14 HYDRO VIEW

The Hydro View module is a visualization tool that makes it easy to show water flow and hydro related results inside the power system.

It can be opened using the button highlighted below, on the NCP's graphical interface right-side toolbar.

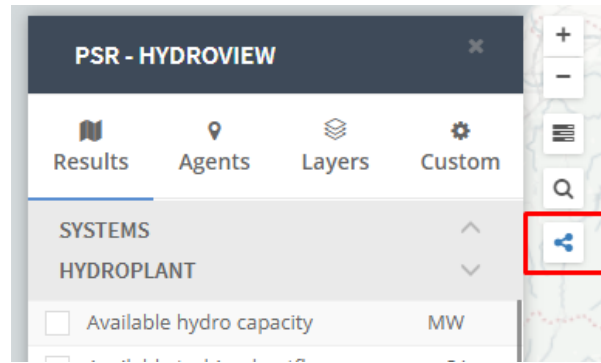


As the program opens, it will show its main screen, which consists of a zoomed in cut from a map, where the case's hydro plants are located, based on the location set on the *Hydro Configuration* screen, back at NCP's main GUI. By default, the blue and red lines are going to be drawn, and they represent the water turbined and the spillage, respectively.

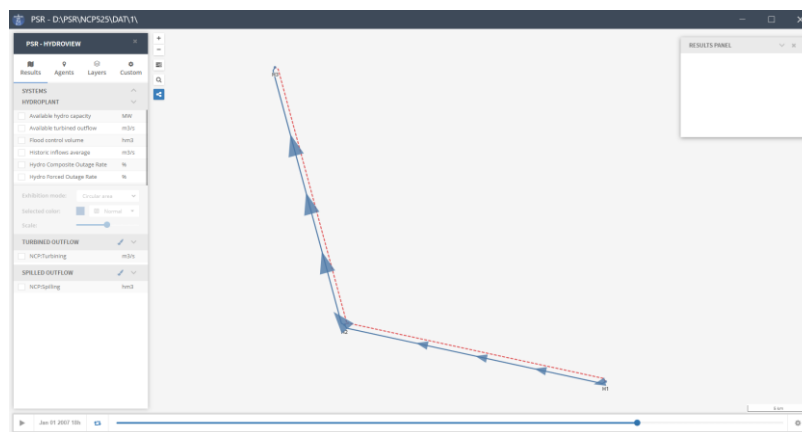


On the left side, new results can be selected for displaying. After selecting any results that weren't previously chosen, it is necessary to press the F4 key or the reload button on the bottom left to load the newly chosen results. After that, hover the mouse on each hydro plants' dot on the map to visualize the data on the top right window. The bottom timeline can be used to pin the analysis to a single stage in the study's horizon, and when the *play* button is pressed, the application will iterate through the stages in chronological order.

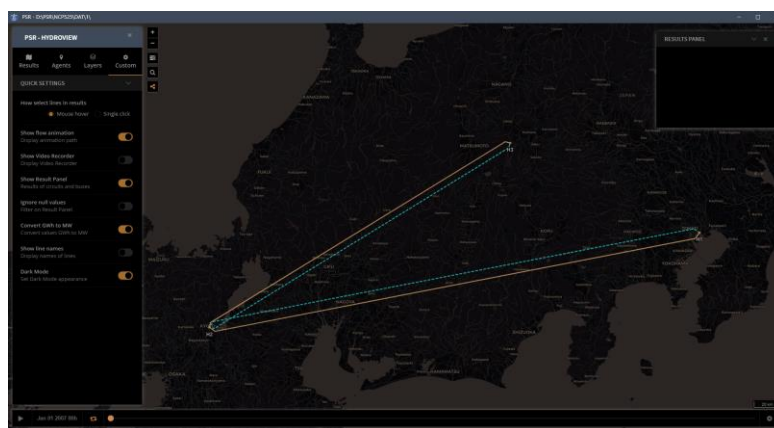
If there are no coordinates set for the system's hydro plants, the button highlighted below can be used to enter the graph mode.



In this mode, only the plant's relative positions will be considered, and the system will be displayed in a generic graph manner, but otherwise, all the other visualization features will work.



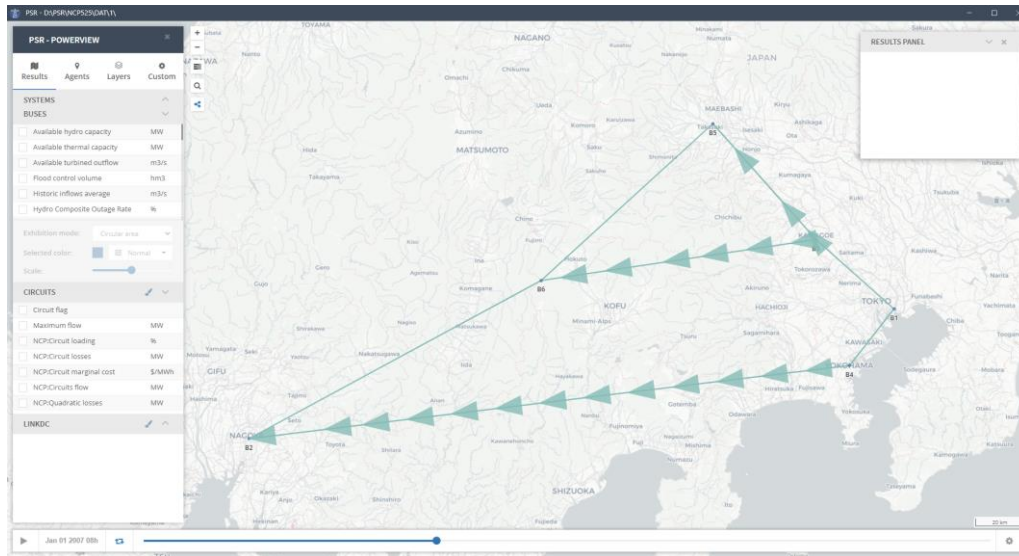
The other tabs on the left-side menu bar can be used to visualize all the agents that compose the analysis, change the background from a vectorial map to satellite view or edit settings such the dark mode.



The link to download the new versions of the Hydro View tool is: <https://www.psr-inc.com/app/link/?t=d&f=powerview-setup.zip>

15 POWER VIEW

The Power View is analogous to the Hydro View Module previously described, except that it shows the flow of power through the system's network, as opposed to water. However, all the hydro and power related results are still available for a bus-to-bus analysis. For settings and preferences, refer to section 14.



The link to download the new versions of the Power View tool is: <https://www.psr-inc.com/app/link/?t=d&f=powerview-setup.zip>