

SDDP

User Manual

VERSION 17.2



PSR

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1 INSTALLATION NOTES AND DATA HANDLING

1.1 Installation

SDDP can be installed by downloading the setup file from our web site www.psr-inc.com. In order to do that, visit our site and select "Software > SDDP" from the menu that appears on the top of the page. Then go to *Selected downloads* on the right-hand-side where the last available version is shown. Click once with the mouse on the name and proceed with the installation. The user can also save the setup file for a future installation.

Observe that the program must be installed by a user having Administrator rights in order to install correctly all the required files.

During the installation a password is required. This password is sent by e-mail to the licensed users each time a new version is available.

The new features and the corrections made on the model are described in the document *SddpReadmeEng.pdf*. This document can be accessed from the graphical interface of SDDP in the top menu option "Help > Readme". Please read carefully this document before using the new version of the model.

To run the model a hard lock key is required. This key, sent to the user when the license is acquired, must be plugged in the parallel port.

1.2 Disk space requirements

SDDP requires 150 MB of free disk space to install the system. Note that the user-selected output files generated by the model can use a lot of additional disk space, depending on the dimensions of the study case (i.e. number of plants, number of stages, hydrological scenarios and load blocks used in the study, etc.).

1.3 System access

The program can be executed from its Windows graphical interface by means of the desktop icon or the Windows menu "Start > Programs > PSR> SDDP".

1.4 Model dimensions

To view the model dimensions and memory requirement, the user can access the menu option "Help > Dimensions" in the graphical interface. A new window will be shown containing a table with the maximum dimensions allowed by the program. Besides that, it is also possible to obtain information about the name and number of the version which has been selected during the installation process. Alternatively, it is possible to execute the command **SDDP DIM** in the DOS prompt, from the \OPER subdirectory. This command will not activate the model but will generate a file called SDDP.DIM, in the same directory, containing the required information.

1.5 MPI (Parallel execution)

SDDP algorithm can take advantage of multiple computing resources¹ to perform its calculations in parallel mode. The communication between SDDP processes in parallel execution relies on MPICH library, which is an implementation of the MPI standard (*Message Passing Interface*) supported by Argonne National Laboratory.

The computers must have SDDP installed and MPI properly configured. The SDDP installer automatically performs the MPI configuration described in the next section. This is the most straightforward way to configure SDDP for parallel executions.

1.5.1 Node configuration

The SDDP setup process will install and configure MPI automatically. MPI installation and configuration involves:

Step 1) Installation of MPICH (compatible version used by SDDP).

Step 2) Creation of a user called “sddpar” with administrative privileges. The password for this user is defined by PSR.

Step 3) Creation of a drive sharing called “sddpar”, pointing to the SDDP installation drive. This sharing is used to access the SDDP executables and its dependencies from all processing machines.

Step 4) Creation of a drive sharing for each of the computer’s physical hard disks. Each drive sharing is named as “sddpdat_<DRIVELETTER>”. In order to prevent unauthorized access, the permissions of this sharing are restricted to the current user and the “sddpar” user. This sharing is used to access the SDDP data from all processing machines.

Step 5) Registration of the “sddpar” user for MPI executions.

1.5.2 Execution

In parallel mode, SDDP needs to set up the cluster configuration and ensure that all directories are accessible by all nodes involved in the execution. At the beginning of this process, SDDP will perform the following steps depending on how the nodes and the data directory were defined:

- 1) If the execution involves only one node:
 - a. Local path will be used to define SDDP’s binaries working directory.
 - b. Data path defined in the GUI will be used directly in the execution.
- 2) If the execution involves two or more nodes:
 - a. UNC pre-defined path `\\sddpar\PSR\<SDDP_Folder>\Oper` will be used to define SDDP’s binaries working directory. This sharing is created during the SDDP’s setup

¹ several computers connected by a local network or in a multi-task computer

in all nodes (step 3) and its main objective is to ensure that this folder is visible and accessible by every node.

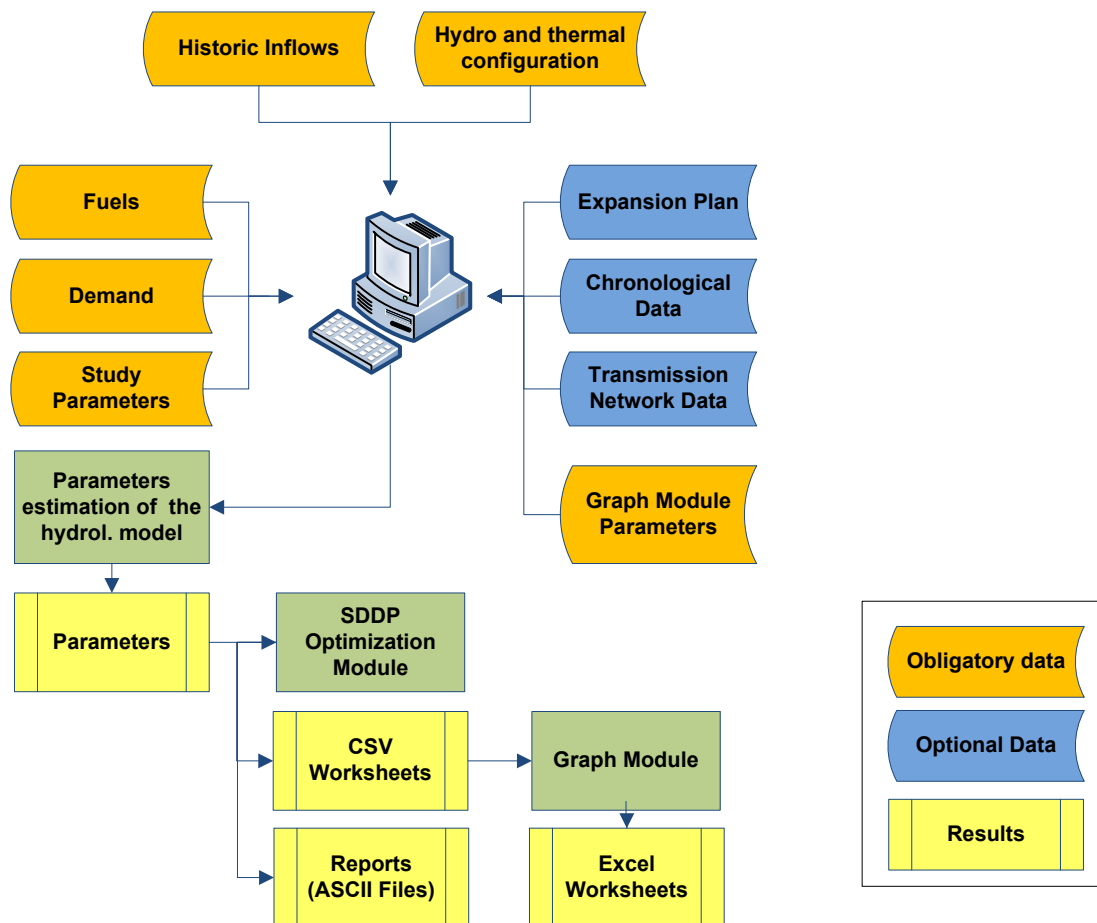
- b. If the data path is:
 - i. defined as UNC path (for example, `\\node-name\path-to-data`): it will be directly used in the execution.
 - ii. defined as local path (for example, `D:\path-to-data`): it will be converted to UNC path (`\\node-name\sddpdat_D\path-to-data`). This sharing is created during the SDDP's setup in all nodes (step 4) and its main objective is to ensure that this folder is visible and accessible by every node.

1.5.3 Performance

For better performance, we recommend that all computers have similar configuration and belong to the same network segment.

2 EXECUTION FLOW

The figure below shows the execution flow of operation planning activities, the input data, and the links between the SDDP modules.



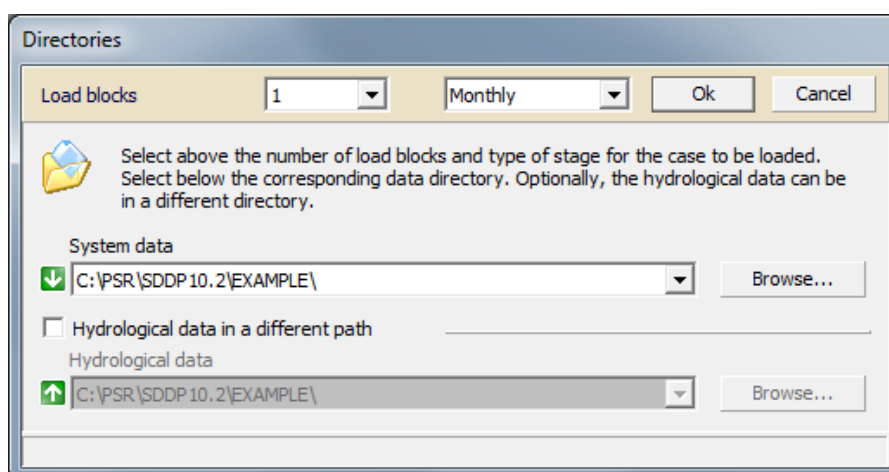
The next chapters of this document describe the input, execution, and output analysis of SDDP.



3 GETTING STARTED

3.1 Directory selection

The first user action is to select the directories where the study input data and hydrology data are located.

SDDP allows the user to keep, in the same directory, data for different load blocks configuration. For this reason, in this screen, the user must define the number of load blocks and the stage type (weekly or monthly) that wishes to consider. The following picture illustrates this screen:



Observation: the buttons  and , located next to each data directory are used to facilitate the directory specification. After specifying the directory of one of the data types (System or Hydrological), the button, if pressed, updates the adjacent directory with the same data path.

3.2 Creating a new case

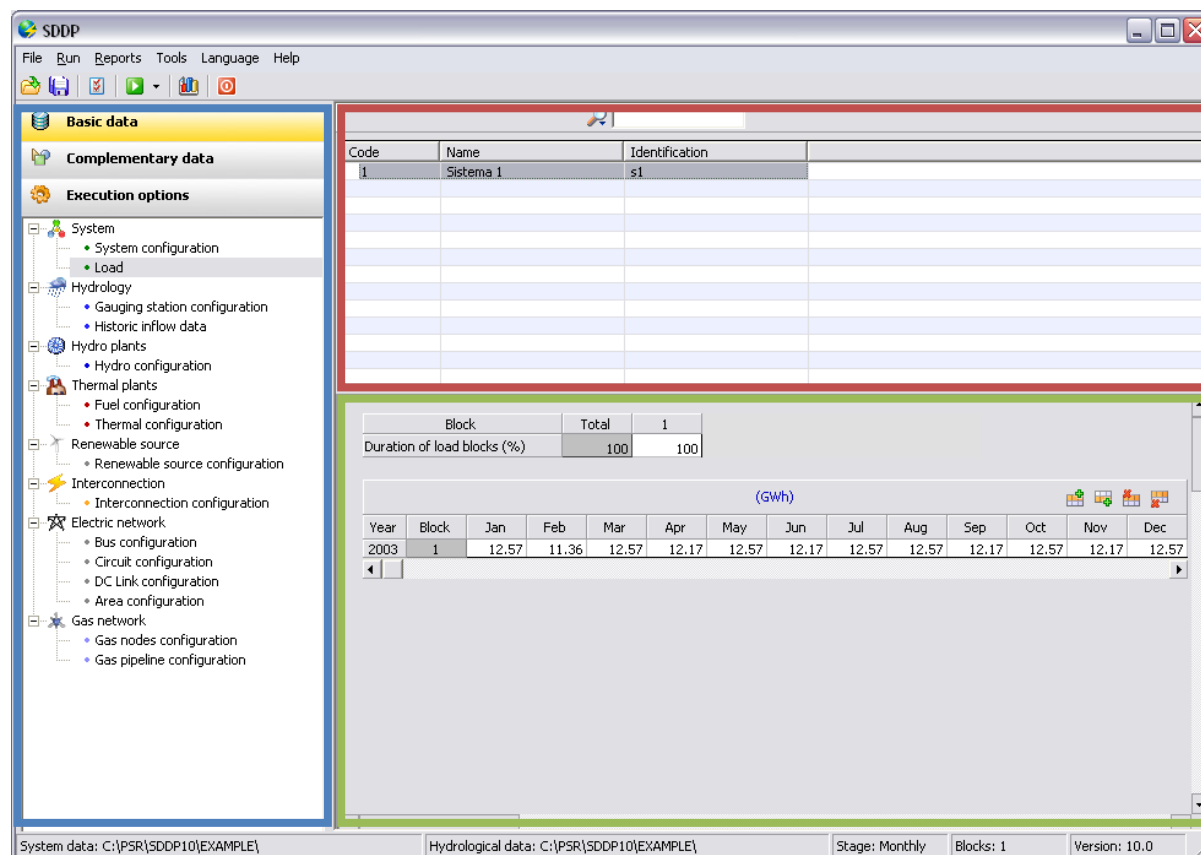
If the selected directory is empty, because no SDDP data files are defined, then the interface suggests the creation of new data. Press YES to create a new data base.

In this case the screen for system definition will appear. The user should inform a code and a name for each system and a two-character system identifier. The identifier is used in all system-related data files. For instance, the hydro configuration data file is called chidroxx.dat, where xx is the system identifier. Therefore, there will be as many hydro configuration files as there are systems. This logic works for all data files, except for the single inflow data file, which has the data for all hydro stations. The reason is that the upstream and downstream plants in the same river may belong to different systems.

4 OVERVIEW

4.1 Interface structure

The interface is divided into three main sections, as shown in the figure below:



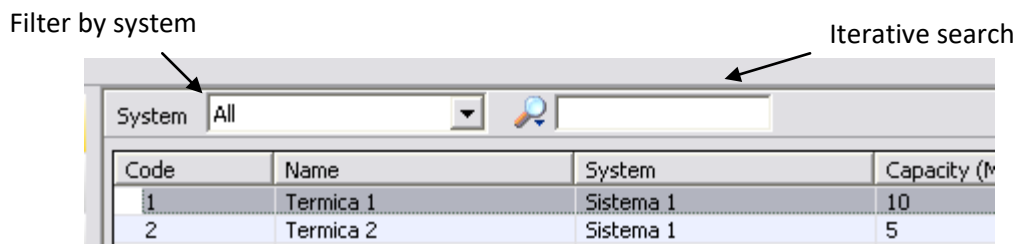
4.1.1 Navigation tree

The navigation tree is found in the left-hand side. This tree is in turn divided into three sections, according to data type and usage:

- **Basic Data:** minimum set of data required to run SDDP, such as system configuration, hydrological stations, hydro and thermal plants, load and others.
- **Complementary data:** includes the information required to represent the expansion and/or modification of the basic data, maintenance, additional constraints and scenarios.
- **Execution options:** comprises the data that define the study options, system configuration, execution strategy etc.

4.1.2 List of elements

This section contains a list of the elements defined, and some of their attributes are shown, as illustrated in the following figure:



The following features are available:

- Filters by system
- Iterative search: as text is being typed in the search box, the list of elements is filtered; i.e., only the elements that contain part of the typed text are shown.

The following buttons are used to add or remove an element of the list:



4.1.3 Panel for editing data

According to the type of data selected in the tree and the selected element is the [list of elements](#), a form for data editing is shown.

4.2 How to navigate

4.2.1 Open, edit and save data

The [navigation tree](#) allows the user to open and change the screens associated to each data. When the user clicks in a branch of the navigation tree, the screen name becomes gray and a list for the visualization of the element associated to the selected data automatically appears in the upper right corner. The cursor appears on the first element of the list, which is colored blue. This list always appears in the order that those elements were added – if it is a new case – or in the order in which the files appear. If there is more than one system, the elements appear in the order in which those systems were defined.

The user may order this list by the available attributes in the upper bar; these attributes can be adapted clicking the bar with the mouse's right button. The elements can also be filtered by system or by an input-text search.

In the right lower part there is the data edition panel, where the user can visualize and edit the data. When the screen opens, the information on the first element of the list appears. By clicking in the lower part of the screen, the focus is shifted to the first field in the editing panel and, at that moment, the list element is colored gray. All the controls (arrows, page up/down) are applied to the element under focus – marked in blue.

To select another element it is only necessary to click in the [list of elements](#) and use the filter controls, search or the arrows and page up/down. To check or edit other data, just select the desired data in the navigation tree to change the screen.

If the data were modified, a screen will appear asking for confirmation to save these modifications. The user can choose between saving and ignoring the modifications. This message allows the user to discard unwanted modifications. It is also possible to disarm this confirmation message. In this case, the modifications are stored and confirmation is only requested once, before running the model or closing the interface. The user can restore the confirmation request at any moment by clicking the upper menu at *Tools > Show warning message*.

4.2.2 Adapting the list of complementary data

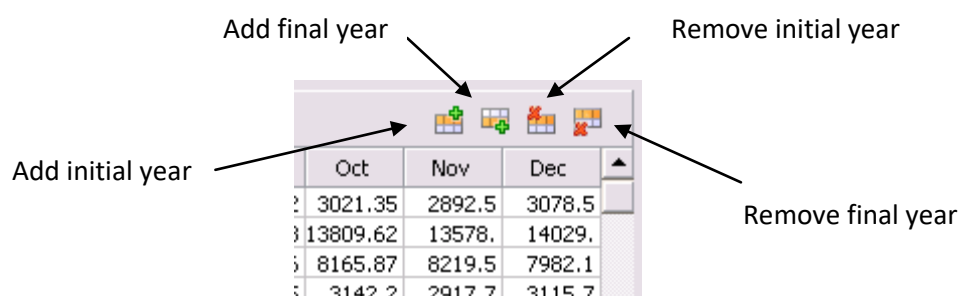
The *complementary data* section of the navigation tree shows all constraints that can currently be represented by SDDP. The user can adapt this list using the Tools/Preferences option in the upper menu, disabling those data that are not used in the system being studied. This simplifies the interface navigation.

4.3 Chronological data tables

4.3.1 Adding and removing data

The chronological data such as demand scenarios, inflows, costs, maintenance etc. are organized in spreadsheets where each row corresponds to a year, and the column represents a stage (weekly or monthly). If the data also varies by load block, there will be a row for each year and load block.

The data are informed in chronological order and should be continuous; the addition or exclusion of new rows in the table is carried out with the control located in the upper right corner of the table, as illustrated in the following figure.



The available options are:

- | | |
|----------------------|---|
| Add initial year: | adds one year to the beginning of the table |
| Add final year: | adds one year to the end of the table |
| Remove initial year: | removes the first year of the table |
| Remove final year: | removes the last year of the table |

4.3.2 Data management

SDDP now incorporates several Microsoft Excel controls which can be used in all screens that have chronological data, such as: maintenance of hydro and thermal plants, irrigation and others. This provides the user with powerful tools for editing and analyzing data. Resources in SDDP include:

- Total compatibility with MS Excel spreadsheets

The SDDP user can manage his data in an Excel file and afterwards take them to SDDP using Copy and Paste (only valid for chronological data).

- Data handling, calculations and statistics

SDDP loads the data in a part of the spreadsheet. Each row corresponds to a year, and each column represents a stage (weekly or monthly).

Some of the functions available are shown next:

- | | |
|-------------------|--|
| = Average(A1:B20) | average of a set of data values |
| = Sum(A1:B20) | sum of a set of data values |
| = Stdev(A1:20) | standard deviation of a set of data values |

5 HYDRO PLANTS

5.1 Configuration

5.1.1 Plant selection

The selection, addition and elimination of hydro plants are made from the [list of elements](#) located on the upper part of the screen.

5.1.2 Basic hydro plants data

Plant data is organized as follows:

Plant parameters:

- generator group
- reservoir
- topology
- tables
 - storage vs. production
 - storage vs. area
 - storage vs. filtration
 - storage vs. head
 - total inflow vs. turbinning outflow
 - tailwater elevation

5.1.3 Plant parameters – generator group

a) minimum turbinning (m^3/s)

Represents the minimum turbinning outflow of the plant, which may be required to cavitation effects or other technical constraint. Note that this results in a minimum forced generation at the hydro plant.

b) maximum turbinning (m^3/s)

Represents the maximum turbinning outflow of the plant.

c) minimum total outflow (m^3/s)

Represents a lower bound on the sum of turbinning and spilled outflows, required for example to control pollution or assure navigation along the river.

d) production coefficient ($\text{MW}/\text{m}^3/\text{s}$)

Represents the average production coefficient in the plant, used in the hydrothermal optimal operating policy calculation (see methodology manual). The detailed relationship between production coefficient and storage is entered as a [table](#).

e) installed capacity (MW)

This is a limit on the plant power production. The plant output in each stage and load block is given by the minimum between this value and the product of turbined inflow and production coefficient.

f) O&M cost (\$/MWh)

Represents the variable operation and maintenance cost associated with the plant power production. In some countries such as Brazil, the O&M field is also used to represent environmental “taxes”.

g) production factor depends on head difference

If this switch is selected, the following fields appear:

- turbine/generator efficiency (p.u.)

In case of a plant with **Reservoir**, the following fields appear:

- tailwater level (meters above sea level)

This switch is used in two circumstances: (i) when the storage level of the *downstream* plant may affect the current plant’s production coefficient and (ii) when the turbines of a given plant have different efficiencies or are located in different buses of the network system. The plant head is calculated in each stage as the *difference* between its reservoir storage level (in meters) and the *maximum* between tailwater level of the plant with reservoir and the downstream plant’s storage level. The production coefficient is in turn calculated from the product of plant head and turbine/generator efficiency.

For a **Run-of-river** plant, the following fields appear:

- associated reservoir

The production factor for a run-of-river plant is calculated taking the difference between the *associated reservoir* storage level and its tailwater level;

h) number of gauging station

This number is a pointer to the inflow database; it identifies which gauging station contains the historical record of the inflows to the plant.

i) number of generating units

This number is used only for the definition of hydro units maintenance schedules and for the generator outage sampling.

j) construction status

An **Existing** plant is already in operation in the beginning of the study.

A **Future** plant is not operating in the beginning of the study. Its activation date is defined in the hydro modification screen. Note that the configuration data should include *all* existing and future plants that will be used in the study.

k) Forced outage rate – FOR (%)

Represents the effect of random equipment outages on the hydro plant production capacity. *If a maintenance schedule is provided for the plant* (see Maintenance section), the plant maximum turbined capacity after maintenance is multiplied by $(1 - \text{FOR}/100)$ at each stage. Otherwise, the composite outage rate index - COR - is used, as described next.

l) composite outage rate – COR (%)

Represents the *joint* effect of equipment maintenance and equipment outage on the hydro plant production capacity. *If no maintenance schedule is provided for the plant*, its maximum turbinning capacity is multiplied by $(1 - \text{COR}/100)$ at each stage.

m) Spillage cost (k\$/hm³)

A penalty may be charged in case of spillage at the plant. This value overrides the penalty cost field of the execution screen, which is otherwise applied to all plants that do not have a specific spillage cost.

n) generator outages sampling

If this switch is selected, the model will carry out a Monte-Carlo sampling of generation availability. For each hydrological scenario and stage in the final simulation, a random number between 0 and 1 will be sampled from a uniform distribution. If the sampled value is smaller than the plant forced outage rate FOR – see item (s) – the plant will be represented as failed (capacity = 0); otherwise, the plant will be working. Note that the Monte-Carlo sampling is not used in the hydrothermal policy calculation, only in the final production simulation.

5.1.4 Plant parameters – reservoir

If the switch **Reservoir** is selected, the following fields appear:

a) minimum/maximum reservoir storage (hm³)

Minimum and maximum reservoir storage capacities. If those values are the same, the model will consider the plant as a run of river.

b) switch for controllable spillage

If **selected** then spillage is a control variable, that is, the plant can spill at any reservoir storage level.

If **not selected** then the spillage is not a control variable, that is, it is only allowed when the storage level reaches its maximum value.

c) initial condition

Amount of water stored in the hydro plant's reservoir in the beginning of the study. This information can be given in two forms, storage or head.

1. **Storage** information is given as a *fraction* (p.u.) of the net storage (maximum storage - minimum storage). Therefore, a value of 0 means that the reservoir is at its minimum level and a value of 1, that it reached its maximum level.

2. **Head** information is given in terms of the water head (in meters). Because SDDP internally works with storages, it is necessary to provide the [head vs. storage table](#) in order to use this option. SDDP will read the value in this field and interpolate from the head vs. storage table to obtain the initial storage in hm^3 .

If the switch **Run-of-river** is selected, the following fields appear:

d) regulation factor for run of the river (ROR) plants

The regulation factor is a parameter ϕ in the range $[0,1]$; it measures the *modulation capacity* of a run of the river plant, that is, the ability to use its reservoir storage to transfer power generation from off-peak to peak hours. $\phi = 1$ indicates that the hydro plant has no storage capacity; as a consequence, its power production matches exactly the inflow profile, which is assumed to be constant along the load blocks ("flat" production schedule). At the opposite end of the range, $\phi = 0$ indicates that the storage capacity is enough for full modulation, that is, the turbined outflow in a load block can differ from the inflow as long as the sum of outflows along the stage is equal to the average inflow. For example, a plant with $\phi = 0$ could concentrate all its power production in the peak hours (limited, of course, to its installed capacity) Intermediate values of ϕ indicate that part of the power can be transferred between load blocks - see the methodology manual for more details. Note that almost all run of the river plants do have a daily modulation capacity; therefore, the option $\phi = 0$ is the most adequate option; only very small plants would require different settings.

e) storage (hm^3)

Constant water volume of the run-of-the-river plant.

f) area (km^2)

Constant flooded area of the run-of-the-river plant for evaporated volume calculation.

g) monthly evaporation coefficients

The evaporation coefficients are provided for each month. If weekly stages are used, the program interpolates the values.

For both type of plants, reservoir and run-of-river configuring as future, a period for the dead storage fill up can be specified.

h) dead storage fill-up

This group of data is defined by an initial and a final period (day, month and year) and an initial condition specified in p.u., which indicates the storage level at the beginning of the dead storage filling-up process.

5.1.5 Plant parameters – topology

The data are described next:

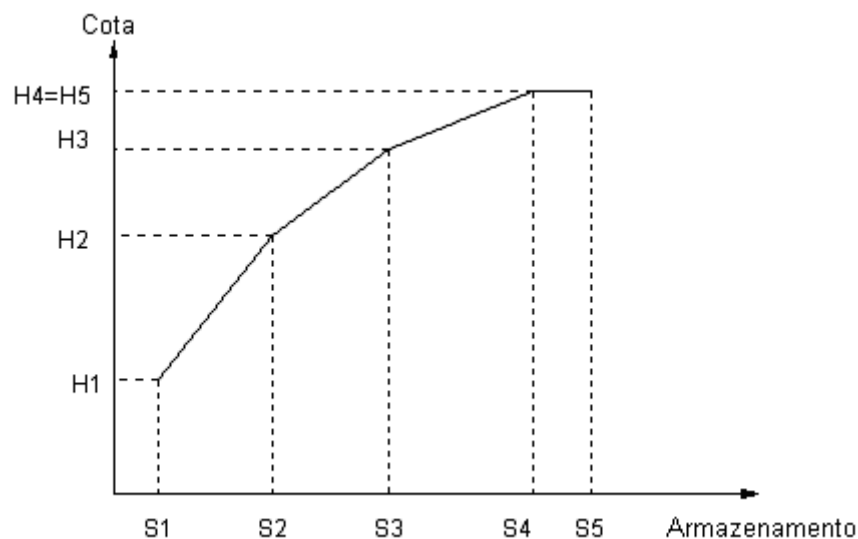
- a) **downstream plant for spillage**
- b) **downstream plant for turbinning**
- c) **downstream plant for filtration**
- d) **downstream plant for evaluation of the store and inflow energy**
- e) **switch indicating if the plant is considered (or not) to evaluate store and inflow energy**

5.1.6 Plant parameters – tables

There are six data tables, which are used to represent the variation of plant parameters with storage level:

- production factor vs. volume
- area vs. volume
- filtration vs. volume
- head vs. volume
- total inflow vs. turbinning outflow
- tailwater elevation

The table values are used to form a piecewise linear curve, as shown below:



Note: The first and the last storage points, S1 and S5, should coincide with the minimum and maximum storage values, defined in the plant data (see item (m)).

In the hydrothermal operating policy calculation, the piecewise linear functions are replaced by constant values (informed in the same screen as its respective table). This replacement is required to avoid the possibility of non-convexities in the solution procedure (see the methodology manual). Note that the piecewise functions are fully represented in the final simulation of system operation. In the beginning of each stage, the simulation program evaluates the production coefficient of the plant from an interpolation of the table data. Each curve is described next:

- **production coefficient \times storage** – represents the effect of head variation with storage.
- **production coefficient in the "backward" phase:** This option is related to the representation of head variation in the hydrothermal policy calculation. The default – and recommended – value for this field is “constant”, due to the possibility of non-convexities in the solution procedure when the “variable” option is selected (see the methodology manual for details). Note that the final production simulation always represents head variation, regardless of the value selected here.
- **area \times storage** – used to calculate the evaporated volume in each stage, given by the product of reservoir area (km²) and the unit evaporation factor for the stage (mm), defined in the evaporation table.
- **Constant value in policy calculation:** if this field is not filled, the model assumes as default for policy calculation the minimum area value defined in the table (first point).
- **filtration \times storage** – used to calculate the stored water that “seeps” through the reservoir walls and bottom to reappear in a downstream location.
- **Constant value in policy calculation:** if this field is not filled, the model assumes as default for policy calculation the maximum filtration value defined in the table.
- **head \times storage** - only used for printing reports in the simulation of system operation and in the case of representation of the production factor as a function of head (see section 5.1.4, letter p).
- **total inflow \times turbinning outflow** – It is possible to define the generation associated to hydro plants varying with respect to the total inflow, through a table informing the turbinning outflow (m³/s) as function of the total inflow (m³/s). See the methodology manual for more details.
- **tailwater elevation** – It is possible to represent the variation of the production factor with respect to the tailwater elevation, defining a table that relates the tailwater elevation (m) with respect to the total outflow (m³/s). See the methodology manual for more details.

5.2 Hydroelectric loss factor

The objective of this data is to define a loss factor for hydro plants (p.u.).

The plants are selected from the [list of elements](#) and it is not obligatory to indicate a loss factors for each plant. Also, it is possible to add multiple factors per plant by selecting different dates.

5.3 Maintenance

The objective of this data is to define a maintenance schedule for hydro and thermal plants. There are two types of hydro maintenance information:

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

Each maintenance type can in turn be expressed in terms of:

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

These maintenance options are chosen for each selected system and are valid for all plants of each system.

The plants are selected from the [list of elements](#) and it is not obligatory to indicate a maintenance schedule for each plant.

1. The creation of a maintenance schedule is made from the [chronological data table](#).
2. The maintenance values are defined for each stage of the selected years. In case of weekly maintenance, a horizontal scrollbar allows the user to access weeks 13-52.

The maintenance schedule can have a shorter duration than the study period. For example, suppose that we have a three-year study period. If the user provides a maintenance schedule for the first year alone, the program will use the composite outage rate (cor) factor in the remaining years.

5.4 Expansion/Modification

The modification screen is used for two main purposes:

- modify a parameter of an existing plant, such as the installed capacity, FOR, etc.
- specify the entrance date of a plant labeled as "future" in the configuration screen.

Procedure:

1. Press the button Add Date. Choose day/month/year and press Ok.
2. Choose or remove the plants to be modified with the (>>) and (<<) arrows.
3. Choose a plant in the selected plant list (on the right).
4. Choose the data that will be modified, in the selected date.

To remove a date, select it from the list located on the upper part of the screen and press the Eliminate Date button. Note that all the modifications scheduled for this date will be deleted. The fields that can be altered are:

- number of units
- minimum turbined outflow (m³/s)
- maximum turbined outflow (m³/s)
- minimum total outflow (m³/s)
- average production coefficient (MW/m³/s)
- maximum storage (hm³)
- installed capacity (MW)
- forced outage rate - FOR(%)
- composite outage rate - COR(%)
- total inflow vs. turbinning outflow table
- switch indicating if the plant is considered (or not) to evaluate store and inflow energy

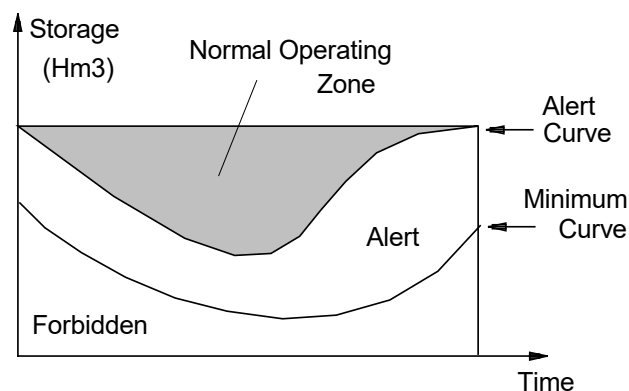
5.5 Irrigation

Select a hydro plant from the plant menu, on the superior upper of the screen, on the left. To enter with the irrigation schedule data:

1. Add an initial year with the right button of the mouse. Indicate the initial year and the number of years of the schedule. Observe that the selected years are shown in the first column of the worksheet. The values that are outside of this area (lines = number of years and columns = number of stages) will not be considered in the SDDP calculations.
2. Irrigation values (in m³/s) are subtracted from the water equation. Irrigation is not a hard constraint to the problem. Therefore, there is a slack variable associated to the irrigation demand of each hydro plant. Penalties can be assigned to these slack variables in the objectives. These penalties can be defined by the user or, alternatively, the interface automatically offers two options in the case of water rationing: irrigation is priority (meet irrigation demand first, then produce power); power is priority (meet energy demand first, and then irrigate).

5.6 Alert volume and minimum volume

The alert and minimum storage values are used to create reservoir depletion zones, as illustrated in the Figure below. The basic idea is to penalize storage if it is below the zone limits, so the system will try to avoid entering them. The penalty can be directly informed by the user ("fixed value") or, alternatively, calculated by the program ("automatic calculation").



Alert volume – the penalty cost in the automatic calculation option is 1.1 times the variable cost of the most expensive thermal plant. In other words, the program will only enter the alert zone to avoid an energy rationing, after all thermal plants are dispatched.

Minimum volume – the penalty cost in this case is 1.1 times the rationing cost. As a consequence, the program will only violate this constraint if it is physically impossible to avoid it. This happens for example if the minimum curve boundary increases from one stage to the other and the inflow is not sufficient to meet the new (and higher) minimum volume.

5.7 Maximum operative storage

In this screen, the user specifies the maximum reservoir storage allowed for operation. The penalty cost in the automatic calculation option is 1.1 times the rationing cost. As a consequence, the program will only violate this constraint if it is physically impossible to avoid it. The procedure for entering or modifying maximum operative storage data is identical to that of alert and minimum volumes discussed above.

5.8 Flood control storage

In this screen, the user specifies the maximum reservoir storage that avoids downstream flooding in each stage. The model will use minimum value between the value informed in the field [maximum reservoir storage](#) and the informed values in this table to decrease the maximum reservoir storage, that is, as if the reservoir was physically smaller. The procedure for entering or modifying flood control storage data is identical to that of alert and minimum volumes discussed above.

5.9 Maximum turbinning outflow

Allows the definition of chronological maximum turbinning outflow limits. This data replaces the maximum turbinning outflow defined on the “Basic data > Hydro plants > Hydro plant configuration” screen, i.e., it is a hard constraint (the upper bound of the turbinning outflow) to the optimization model.

5.10 Minimum spillage

Allows the definition of chronological minimum spillage constraints for a hydro plant. The penalty cost for not meeting these constraints can be defined by the user ("Fixed value") or automatically calculated by the program ("Automatic calculation") as $1.1 \times (\text{deficit cost of the system}) \times (\text{plant's mean production coefficient})$. In other words, for the automatic calculation of the penalty, the program will only violate this constraint if it is physically impossible to meet it.

5.11 Maximum spillage

Allows the definition of chronological maximum spillage constraints for a hydro plant. The penalty cost for not meeting these constraints can be defined by the user ("Fixed value") or automatically calculated by the program ("Automatic calculation") as $1.1 \times (\text{deficit cost of the system}) \times (\text{plant's mean production coefficient})$. In other words, for the automatic calculation of the penalty, the program will only violate this constraint if it is physically impossible to meet it.

5.12 Maximum total outflow

Allows the definition of chronological maximum outflow limits (sum of turbined and spilled flows) for each plant. This type of constraint is used to model safety constraints for bridges and population living downstream, among others.

5.13 Minimum total outflow

Allows the definition of chronological minimum outflow limits (sum of turbined and spilled flows) for each plant. As mentioned previously, this type of constraint is used to model environmental or navigation constraints, among others. A penalty must be associated to be utilized if the restriction is violated.

5.14 Alert energy

Allows the definition of chronological alert energy storage constraints for a set of reservoirs. The penalty cost for not meeting these constraints can be defined by the user ("Fixed value") or automatically calculated by the program ("Automatic calculation") as 1.1 times the operative cost of the most expensive thermal plant. In other words, for the automatic calculation of the penalty, the program will only violate this constraint to avoid rationing.

5.15 Security energy

Allows the definition of chronological minimum energy storage constraints for a set of reservoirs. The penalty cost for not meeting these constraints can be defined by the user ("Fixed value") or automatically calculated by the program ("Automatic calculation") as 1.1 times the

deficit cost of the system. In other words, for the automatic calculation of the penalty, the program will only violate this constraint if it is physically impossible to meet it.

5.16 Flood control energy

Allows the definition of chronological flood control energy storage constraints for a set of reservoirs. When the flood control energy storage is reached, the set of reservoirs associated to this constraint have to spill to keep the stored energy below the user-defined target.

5.17 Stored volume x head polynomial function

Allows the definition of a stored volume x head polynomial function (SHP) coefficients for each hydro plant. This information, when specified, is used in the evaluation of hydro plants' stored energy which is presented in an output worksheet file produced by the program. If the user does not specify a polynomial function for each plant, then the program will assume a standard calculation for the stored energy.

In the head x stored volume polynomial function data screen, the user must inform the function coefficients, the hydraulic losses and the specific productivity of the plants.

5.18 Parameters for stored energy calculation

This screen allows parameters definition for calculating the system's stored energy, maximum storable energy capacity and inflow energy, according to one of the following options:

1. *By reservoir*: (default option). Suppose that hydro plant i belongs to system s . The energy produced by i , plus the sum of the energies produced by all hydro plants downstream of i , as a result of the depletion of the water stored in reservoir i , is assigned to system s .
2. *By generator*: In this case, the energy produced by hydro plant i as a result of turbinning its own stored volume plus the stored volumes of all upstream plants is assigned to system s .

These allocation methodologies give the same results if all hydro plants in each cascade belong to same system.

The participation factor of each plant in each system indicates the contribution of the reservoir volume of that plant in the calculation of energies. The screen below indicates that Serra da Mesa contributes with 55 % of its useful storage to the calculation of the stored energy, maximum stored energy and energy inflow to the North system. It is important to mention that in spite of the allocation of part of the stored energy, maximum stored energy and energy inflow in another system, the generation of the plant is always fully accounted for in its original system ("Sudeste" in this case). The same screen shows that the hydro plants Três Marias, Irape and Queimado contribute with 100% of their useful storage to the Northeast system.

[illegible]

5.19 Operating constraints of hydro plants

One of the main motivations for performing hourly executions is to capture chronological effects which are not seen in executions with block representation. For more info, please read the [Hourly representation](#) chapter.

On this screen, the users may define the following hydro operational chronological constraints:

- Water travel time related to the turbinning path (hours)
- Water travel time related to the spilling path (hours)
- Outflow ramp-up ($\text{m}^3/\text{s}/\text{min}$)
- Outflow ramp-down ($\text{m}^3/\text{s}/\text{min}$)
- Ramp-up (MW/min)
- Ramp-down (MW/min)

5.20 Constant water flow constraints

It is possible to force the turbinage and/or the spilling and/or the total outflow for each hydro plant to be constant throughout the stage on the “Complementary data > Hydro plants > Constant water flow constraints” screen, i.e., if, for example, the user changes the “No” field to “Yes”, the turbinage outflow in the stage will remain a decision variable for the model, but it will have to be constant all the time at every stage.

6 FUELS

6.1 Fuel selection

The selection, addition and elimination of fuels are made from the [list of elements](#) located on the upper part of the screen.

6.2 Basic fuel data

The basic fuel data comprises:

- Identifier number
- Name
- Unit (ton, m3, gallon, etc.)
- Price (\$/unit)
- Emission factor (ton CO2/unit)
- System
- Type of price variation – “Chronological” or “Chronological by scenario”. Through this option, the user can select if the fuel prices (i) will just be chronologically updated or (ii) besides being chronologically updated, they will change by scenario. If for a given fuel option (ii) is chosen, the number of scenarios and the fuel prices per scenario can be introduced in the “Complementary data > Fuel > Fuel price > Chronological by scenario” screen.

6.3 Fuel price

There are two types of price forecast:

- **Chronological** (\$/unit) – it is allowed to inform variable fuel prices in time, that is, to represent different fuel prices at each stage.
- **Chronological by scenario** (\$/unit) – SDDP can handle multiple user-defined fuel price scenarios. This means that the decisions will consider fuel price forecast variability in addition to the other sources of uncertainty already considered such as hydro inflows and renewable generation.

These constraints are informed for each stage and the data is handled by means of a [chronological data table](#).

6.4 Fuel availability

There are two types of fuel availability constraints:

- **Total Consumption** (in thousands of units of fuel per stage)
- **Consumption Rate** (in units of fuels per hour)

These constraints are informed for each stage and the data is handled by means of a [chronological data table](#).

6.5 Carbon credits cost

The costs of purchasing carbon credits associated with the emissions of each fuel are defined in a [chronological data table](#) and the data must be informed for each system.

7 THERMAL PLANTS

7.1 Plant selection

The selection, addition and elimination of thermal plants are made from the [list of elements](#) located on the upper part of the screen.

The plant data is organized in two groups:

- Generating group (basic operating data)
- Fuel (fuel consumption and multiple fuel data)

7.1.1 Basic operating data

a) minimum generation (MW)

If unit *commitment* is allowed – see option (g) below – this value represents the minimum plant generation if it is dispatched; the scheduling decision is made by SDDP as a result of the least-cost operation, using integer programming techniques. This is usually applied to represent oil or coal plants. If commitment is not allowed, this value represents the minimum plant generation regardless of system operating costs. This is usually the case of nuclear plants or gas-fired plants with take or pay contracts.

b) maximum generation (MW)

Maximum generation capacity of the plant

c) number of units

This information is used for maintenance purposes and generator outage sampling. Note that the minimum and maximum generation limits (previous fields) refer to the entire plant, not to each unit.

d) forced outage rate – FOR (%)

Represents the effect of random equipment outages on the plant production capacity. If a maintenance schedule is provided for the plant (see Maintenance section), the plant maximum capacity after maintenance is multiplied by $(1 - \text{FOR}/100)$ at each stage. Otherwise, the composite outage rate index – COR – is used, as described next.

e) composite outage rate – COR (%)

Represents the *joint* effect of equipment maintenance and equipment outage on the plant production capacity. If no maintenance schedule is provided for the plant, its maximum capacity is multiplied by $(1 - \text{COR}/100)$ at each stage.

f) number of alternative fuels

Indicates the number of fuels that can be used in a multiple-fuel plant. The fuel description and corresponding efficiency data are informed in separate fields described in section 7.1.3.

g) commitment

There are two commitment options:

1. the same commitment decision applies to the whole stage. In this case, a plant which is dispatched to supply load in the peak hours may have to remain dispatched (at the minimum level) in the valley hours.
2. a separate commitment decision applies to each load block. In this case, the plant can dispatch in the peak load block but be off-line in valley load block.

As mentioned previously, integer programming techniques are used to solve the unit commitment problem. In case (a), one integer variable, with an associated start-up cost (k\$), is used for each stage commitment decision; in case (b), the number of integer variables – and start-up costs - is equal to the number of load blocks in the stage.

h) plant type

There are three types of thermal plant:

- standard: this is the “normal” thermal plant
- must-run: the plant is always base loaded, regardless of system operating costs. This is the typical case of geothermal plants. Note: if minimum generation data is supplied to a must-run plant, this is interpreted as a fixed external generation, that is, the minimum generation data will be seen as a compulsory generation schedule for the plant.
- benefit: represents an interruptible energy purchase. The plant “operating cost” and “capacity” in this case represent respectively the energy purchase price and the maximum load. It is easy to see that the interruptible load will be supplied whenever the system spot price is smaller than the energy purchase price.

i) construction status

An **existing** plant is already in operation in the beginning of the study.

A **future** plant is not operating in the beginning of the study. Its activation date is defined in the modification screen. Note that the configuration data should include *all* existing and future plants that will be used in the study.

j) generator outage sampling

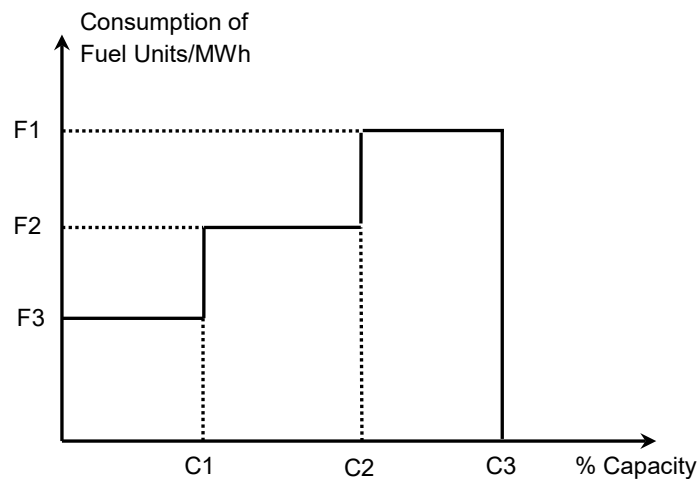
If this switch is selected, the model will carry out a Monte-Carlo sampling of generation availability. For each hydrological scenario and stage in the final simulation, a random number between 0 and 1 will be sampled from a uniform distribution. If the sampled value is smaller than the plant forced outage rate FOR – see item (d) – the plant will be represented as failed (capacity = 0); otherwise, the plant will be working. Note that the Monte-Carlo sampling is not used in the hydrothermal policy calculation, only in the final production simulation.

k) combined cycle

Thermal plants taking part of a combined cycle must be associated to the combined cycle group in the thermal configuration screen. Once the group has been defined, it is only necessary associated the thermal plant to it.

7.1.2 Fuel consumption

The fuel consumption curve is piecewise linear curve with up to three segments, as shown below. Consumption information can be entered by load block.



The information is composed of:

- fuel code - fuel used by the thermal plant; it is selected from a menu of previously defined fuel data.
- variable O&M cost (\$/MWh) – added to the plant operating cost.
- fuel transportation cost (\$/unit) – represents the cost of transporting the fuel from the wells to the plant site. Added to the unit fuel cost.
- CO2 emission coefficient (p.u.) – is the thermal plant's coefficient applied to obtain the costs of purchasing of carbon credits. A coefficient equals to 1 means that all the CO2 from fuel burning on the thermal plant will be emitted. Values between 0 and 1, indicate that there is a carbon filter that captures part of CO2 emissions. For example, 0.8 indicates that the thermal plant emits 80% of CO2 from the fuel burned.

The plant operating cost (\$/MWh) is calculated as:

$$\begin{array}{ccccccc}
 \text{fuel unit} & & \text{fuel transp.} & & \text{consumption} & & \\
 \text{cost} & + & \text{cost} &) \times & \text{factor} & + & \text{O\&M} \\
 \uparrow & & \uparrow & & \uparrow & & \uparrow \\
 \$/\text{units of fuel} & & \$/\text{units of fuel} & & \text{units of fuel/MWh} & & \$/\text{MWh}
 \end{array}$$

The following terms are added to the objective function in order to represent the purchasing cost of carbon credits:

$$\begin{array}{ccccccc}
 \text{CO}_2 \text{ credit} & & & & & & \text{CO}_2 \text{ emission} \\
 \text{costs} & \times & \text{emission factor} & \times & \text{emission} & \times & \text{consumption} & = & \text{costs} \\
 \uparrow & & \uparrow & & \uparrow & & \uparrow & & \uparrow \\
 \$/\text{ton CO}_2 & & \text{ton CO}_2/\text{units of} & & \text{coef.t} & & \text{units of fuel/MWh} & & \$/\text{MWh} \\
 & & \text{fuel} & & \text{p.u.} & & & &
 \end{array}$$

7.1.3 Multiple fuels

In order to use multiple fuels the user must activate the “Alternative fuel?” option and select the associated fuels. Then the user must inform the specific data associated to each alternative fuel in the “Fuel” group.

The basic operating data such as minimum generation, FOR(%), COR(%) must be the same as the main thermal plant, and therefore the interface does not allow the modification of these values. The user must inform the maximum generation, the efficiency curve, the O&M cost, the transportation cost and the CO₂ emission coefficient.

If the study represents the transmission network, the user should connect the new dummy thermal plant to the same bus where the main thermal plant is located.

7.2 Maintenance

Thermal plant maintenance data is handled in the same way as [hydro plant maintenance](#). Note that it is not necessary to provide maintenance schedules for the dummy plants used to represent multiple fuels.

7.3 Expansion/Modification

Thermal plant modification data is handled in the same way as [hydro plant modification](#).

The fields that can be altered are:

- number of units
- minimum generation (MW)
- maximum generation (MW)
- forced outage rate - FOR (%)
- composite outage rate – COR (%)
- variable O&M cost (\$/MWh).
- consumption factor (unit/MWh) for the main and alternative fuels
- fuel transportation cost (\$/unit)
- CO₂ emission coefficient (p.u.)

7.4 Minimum Generation

This data set has been superseded by the [generation constraints](#), which offers more flexibility. It remains in the current version to allow users with data sets prepared for this format to migrate to the new format; however, it will no longer be available in the future

7.5 Startup Cost

It is possible to specify variable startup cost for commitment plant. This startup cost is indicated by stage and load block.

7.6 Operating constraints of thermal plants

One of the main motivations for performing hourly executions is to capture chronological effects which are not seen in executions with block representation. For more info, please read the [Hourly representation](#) chapter.


On this screen, the users may define the following thermal operational chronological constraints:

- Ramp-up (MW/min)
- Ramp-down (MW/min)
- Minimum uptime (hours)
- Minimum downtime (hours)
- Maximum number of start-ups (per stage)
- Maximum number of shutdowns (per stage)
- Shutdown cost (k\$) – it is worth noting that the startup cost (in k\$) will continue to be defined in the “Basic data > Thermal plant configuration” screen

7.7 Operative Status of Combined Cycle Thermal Plant

It is possible to specified variable operative status for combined cycle thermal plant. It indicates the thermal plant participating in the combined cycle group which will be in operation in each stage.





The list of plants that compose the cycle is shown below the [list of combined cycle groups](#) as well as the [chronological data table](#), as illustrated in the following figure:

System All 

Code	Name	System
1	CC-1	Sistema 1

} combined cycle list

Code	Name	System	Capacity (MW)
1	Termica 1	Sistema 1	10
2	Termica 2	Sistema 1	5
3	Termica 3	Sistema 1	20

Operative state    

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	1	1	1	1	1	1	1	1	1	1	1	1
2007	2	2	2	2	2	2	3	3	3	3	3	3

Suppose for example a combined cycle group called CC-1, whose possible configurations are defined by three thermal plants: Termica1, Termica2 and Termica3. Then the user must select the corresponding combined cycle and define the operative state for each study stage. It is possible to inform in the table the code associated to the plant which will be in operation in a certain stage or, simply, drag the corresponding plant from the list to the correspondent position in the chronological data table.

According to the spreadsheet in this screen, the plant Termica1 will be available to be dispatched during all 2006, the plant Termica2 will be available to be dispatched from January to June of 2007 and the plant Termica3 will be available to be dispatched from July 2007 until the end of the study. It is important to observe that only the selected plant will be considered available to be dispatched at each period; the remaining plants from the same combined cycle group will be considered as totally unavailable.

7.8 Specific consumption per block

On this screen, the user can add time changes related to the values of each segment of the thermal plant specific consumption.

8 EMISSIONS

SDDP can represent generic pollutants and their corresponding thermal emission coefficients. Besides presenting outputs of the emissions, each pollutant can have (i) associated emission costs, which will increase the thermal operating costs and/or (ii) multistage emission budget constraints. All related data is defined in the “Complementary data > Emissions” section.

9 FUEL CONTRACTS

The operative cost of a thermal plant is calculated using the following parameters: (i) transportation cost; (ii) O&M cost; (iii) specific consumption; (iv) fuel cost; (v) emission cost. Until version 12 of SDDP, the representation of thermal plants with different operative costs for a same fuel (different contracts), was only possible through the duplication of the fuel so that each plant had its own fuel with a cost defined specifically to it. For those cases, this representation did not allow the consideration of availability constraints for the fuel used by a group of thermal plants. From version 12 of the model, these limitations do not exist anymore, being allowed the definition of “fuel contracts”, which makes possible the association of different costs for different plants using the same fuel.

Additionally, it is possible to define fuel contracts of “Integral” type (which have a maximum amount of fuel that can be purchased during the lifespan of the contract) and that can have Take-or-Pay clauses (which impose a minimum payment for a pre-defined amount of the contract). SDDP will determine the optimal use of the available fuel in each contract.

The main data related to fuel contracts is defined on the “Basic data > Fuel > Fuel contract configuration > Basic clauses” screen.

9.1 Contract selection

The selection, addition and removal of fuel contracts is based on the [list of elements](#), located in the upper part of the screen.

9.2 Basic parameters

The basic fuel contract parameters are:

- number
- name
- fuel
- system

9.3 Fuel contract types

SDDP allows the representation of two types of fuel contracts: “Free” or “Integral” contract.

A Free contract is the one for which the thermal plants can purchase any amount of fuel (respecting, of course, the fuel availability constraints and the maximum offtake limit defined by the contract) by paying the fuel cost defined for this contract, which can be fixed or variable over time.

An Integral contract, in its turn, is the one in which the generator has available a total (maximum) amount of fuel that can be purchased and consumed during the lifespan of the contract. Optionally, the Integral contract can have a Take-or-Pay (ToP) amount, which corresponds to the minimum amount of fuel that the generator must pay for at the beginning of the contract, regardless of consuming or not that fuel. In other words, the ToP amount corresponds to the

minimum quantity of fuel that the generator pre-pays and that can be used at any time during the lifespan of the contract. In each stage, the generator decides which amount of fuel will be withdrawn from its “account”. This fuel can either be used to supply fuel to the thermal plants associated and/or be stored in associated physicals fuel reservoirs for future use, in case they exist. At the end of the contract, any amount of fuel remaining in the “account” is usually lost. In some special ToP contracts, a fraction of the remaining fuel can be transferred to the following contract (contract renewal). The contract can present different prices for the consumed fuel until reaching the ToP amount and for the one that exceeds the ToP amount (extra ToP fuel).

9.4 Data for Free contracts of fuel

The following data defines a Free contract of fuel:

- maximum offtake rate (units of fuel/h): define the maximum fuel consumption allowed per hour
- fuel cost (\$/unit of fuel): is the price paid for the consumed fuel
- set of thermal plants associated to the fuel contract (optional)
- set of physical fuel reservoirs associated to the contract (optional)

9.5 Data for Integral contracts of fuel

The following data defines an Integral contract of fuel:

- maximum offtake rate (units of fuel/h): define the maximum fuel consumption allowed per hour
- contracted amount (thousands of units of fuel): is the total (maximum) amount of fuel that can be purchased and consumed during the lifespan of the contract
- Take-or-Pay amount (thousands of units of fuel): is the minimum amount of fuel that the generator must pay for by the ending date of the contract, regardless of consuming or not that fuel
- consumed amount (p.u. or thousands of units of fuel): is the fuel amount that has been consumed from the current contract before the beginning of the study horizon. In the extremes, 0 means that no fuel from the current contract has been consumed before the starting date of the horizon and 1 means that all contracted fuel has already been consumed, making the contract unavailable until its next renewal. The value defined in the field “consumed amount” does not apply for fuel contracts whose starting date is later than the beginning of the study or whose ending date, including all possible renewals, took place before the beginning of the study.
- Take-or-Pay fuel cost (\$/unit of fuel): is the cost of the consumed fuel up to the ToP amount
- extra Take-or-Pay fuel cost (\$/unit of fuel): is the cost of the consumed fuel in excess of the ToP amount. This cost can be equal to the cost of the ToP fuel; in many contracts this cost is higher than the ToP cost
- initial and final stages: define the lifespan of the contract

- number of renewals: indicate how many times the validity of the contract is extended. The renewals are continuous and of the same duration as the initial contract
- Maximum transfer on renewal (thousands of units of fuel): amount of ToP that was paid but not used and that can be transferred for the next renewal
- set of thermal plants associated with the fuel contract (optional)
- set of physical fuel reservoirs associated with the contract (optional)

9.5.1 Make-up and carry forward

Additional Take-or-Pay clauses may be introduced on the “Basic data > Fuel > Fuel contract configuration > Special clauses” screen:

- **Carry forward right** provides the option to anticipate ToP quantities from future contract periods to avoid extra payments associated with fuel consumption over the current ToP quantity. This debt is carried forward to the future periods as a reduction of the ToP quantity
- **Make-up right** provides the option to recover ToP payments associated with unused fuel of previous periods, granting the buyer the right of getting fuel over the ToP quantity without or with a reduced payment (depending on the make-up credits). In previous versions, SDDP represented unlimited make-up credits via transfers between contract renewals. Now, SDDP represents an associated “expiration” time and the consequent obligation of using the current make-up credits inside this period

9.6 Time variable contract cost

Optionally, the contract cost (\$/unit of fuel) can be defined through a [chronological data table](#), variable per stage.

9.7 Time variable maximum offtake

Optionally, the maximum withdrawal (units of fuel/h) can be defined through a [chronological data table](#), variable per stage and load block.

10 PHYSICAL FUEL RESERVOIR

Besides the new option to define fuel contracts, it has been introduced in version 12 of SDDP a new agent to represent physical reservoirs of fuel. This type of reservoir allows the storage of fuel from fuel contracts, in order to use it in the future by one or more thermal plants supplied by this reservoir. The representation of a physical fuel reservoir requires, therefore, its association to a fuel contract.

10.1 Reservoir selection

The selection, addition and removal of physical fuel reservoirs is based on the [list of elements](#), located in the upper part of the screen.

10.2 Basic parameters

The basic physical fuel reservoir parameters are:

- number
- name
- fuel
- initial condition (p.u.)
- maximum limit (thousands of units)
- maximum injection limit (units/h)
- maximum withdrawal limit (units/h)
- set of contracts associated with the physical reservoir
- system

10.3 Expansion/Modification

The expansion screen allows the editing of parameters which can vary with time.

The field that can be modified is:

- maximum capacity (thousands of units)

10.4 Reservoir constraints

Optionally, the reservoir constraint screen allows the representation of two types of stage-varying constraints:

- **Injection limit** (units/h)
- **Withdrawal limit** (units/h)

These constraints are defined through the [chronological data table](#), variable per stage and load block.

11 HYDROLOGY

The hydrology data is divided into three groups:

- Inflows – gauging station configuration and the historical inflow records.
- Reduced uncertainty - define different stochastic inflow parameter files for different periods.
- Parameters estimation - calculate the stochastic inflow model parameters.

11.1 Inflow records

11.1.1 Adding a new gauging station

The selection, addition and elimination of gauging stations are made from the [list of elements](#) located on the upper part of the screen.

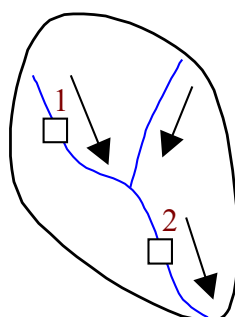
For each gauging station, besides informing a code and a name, it is also possible to inform the downstream plant code. This field should only be filled in case the downstream plant inflows have been defined as total inflows, not incremental.

11.1.2 Selecting a gauging station

The first step is to select a gauging station from the menu. The corresponding inflow data is then read into the Excel-like data file. Each row provides inflow data for a year, in either monthly (12 columns) or weekly (52 columns) stages. Weekly data is not automatically transformed into monthly data; the user should provide separate data files if both monthly and weekly studies are made.

11.1.3 Total or incremental inflows?

The figure below shows a river basin with two river branches. There are two inflow stations represented by the white boxes. The first one is located in one of the tributaries and the other is located in the main river, after the confluence.



There are two ways of providing inflow information: (a) the total inflow arriving at each station; or (b) the incremental (lateral) inflow. Some countries, such as Brazil, use the first option; others, such as Colombia and Panama, use option (b). Although both arrangements are allowed by the program, the downstream information for the hydro stations will be different, as illustrated by the following examples.

- Total inflows

Suppose that the measured inflows at gauging stations 1 and 2 in January are, respectively, 10 m³/s and 15 m³/s. These values can be entered directly into the inflow data, as long as we specify that station 2 is downstream of hydro station 1.

- Lateral (incremental) inflows

The inflow value for gauging station 1 is the same, because there are no upstream hydro stations. However, the "Downstream site" is left blank.

For gauging station 2, we now provide the lateral inflow (difference between the total inflows of hydro stations 1 and 2).

11.1.4 Inflow statistics

The *Statistics* option located on the menu bar runs a program for statistical analysis of the inflow record for the selected hydro station. These statistics can be visualized selecting the *Report* option from the menu bar. The results are presented in the "Notepad". The traditional edition functions are available: find, copy to clipboard, etc.

Plant code: 103 Plant name: LIBBY Historical : 1937/1994						
Month	Mean (m3/s)	Maximum (m3/s)	Minimum (m3/s)	Standard Deviat. (m3/s)	Skewness Coefficient	Coef. Variat (%)
01	88.2	175.	47.8	25.7	1.468	29.1
02	89.3	172.	46.9	23.8	1.012	26.7
03	96.3	177.	59.9	23.8	1.445	24.7
04	241.	783.	85.6	121.	1.889	50.2
05	799.	1268.	369.	236.	0.384	29.5
06	1087.	1933.	518.	332.	0.462	30.5

The following statistics are estimated: weekly or monthly average inflow and standard deviation, autoregressive and partial autoregressive functions for each week (month). In addition, statistical tests for stationary are performed, including Smirnov and Mann-Kendal tests.

11.2 Estimation of the Stochastic Inflow Model parameters

The hydrologic parameters screen has a list with all gauging stations. Use the buttons (>>) and (<<) to select one or more gauging stations. The following fields are related to the parameters estimation:

- Minimum and maximum years

In the estimation of the parameters of the linear regressions for the stochastic inflow models, it will be considered as samples all historical observations that fall between the interval defined by the minimum and maximum years defined by the user. However, as the autoregressive models relates the observation of one stage (called the dependent variable) with the observations of the previous stages (called explanatory or independent

variables) and as SDDP considers a maximum order of 6, in the monthly cases, for example, for the months from July to December of the initial year, the 6 previous observations will correspond to historical observations of this same year (values from January to June of the initial year) and, therefore, will be available (if the user has defined them in the screen of historical inflow data). However, for the months from January to June of the initial year, the 6 previous observations will correspond to historical observations of the year before this initial year (from July to December of the year before this initial year) and, consequently, will be outside of the period defined by the minimum and maximum years defined by the users for the consideration of samples and must not be used. In the case where the minimum year is equal to the first year of the historical inflow record, data for the previous year will not even exist. In this way, SDDP will not consider as dependent variables the observations of the minimum year, only will consider them as explanatory variables. In other words, it will only use, in monthly cases, the historical inflows from July to December of the minimum year as explanatory variables in the estimation of the hydrological models for the months from January to July, when the observation of January of the year after the minimum year can depend on the observations from July to December of the minimum year, when the observation of February of the year after the minimum year can depend on the observations from August to December of the minimum year and so on. In addition to that, the absence of any historical inflow observation will be considered as failure in the samples that has this observation as explanatory or dependent variable. Individual samples with failure will be removed from the complete sample. The recommendation is that the historical inflow record be entirely filled for all the period between the minimum and maximum years. It is worth noting that negative values for the historical incremental inflows are not considered as failures.

- Type and order selection

There are two possible choices for the type and order selection. If the selected option is *maximum order equal to M*, the model will be adjusted to all orders $m = 1...M$ and the chosen order will be the one that satisfies the defined criterion (which can be Residuals variance change or Akaike). If the indicated option is *fixed order equal to M*, a model for this order will be adjusted, and the program might reduce the order in case the adjusted model does not pass the stationarity test for the indicated order.

- Criterion: Residuals variance change or Akaike

The criterion *Residuals variance change* was the one used by SDDP in versions previous to version 12.

The *Akaike* criterion has introduced in SDDP in version 12 and is now the recommended option. The Akaike information criterion (AIC) is a measure of the relative quality of a statistical fitting. In general terms, this criterion weights the tradeoff between quality of the fitting and number of parameters. Therefore, the principle is the same as the Residuals variance change criterion. The difference is in the way the comparison is performed.

The AIC is based on the Information Theory. Its logic is the following: suppose that the data have been generated by an unknown process f and that exist candidate models. The model chosen would be the one that minimizes the loss of information in this representation of f . Nevertheless, it is not possible to make this choice with certainty since f itself is unknown. Akaike shown in 1974 that it is possible to compare the relative loss of information between candidate models through a simple formula (AIC), given by:

$$AIC = 2k - 2 \ln(L)$$

Where k is the number of parameters of the statistical model being considered and L is the maximized value of the likelihood function for the estimated model.

Note by the AIC equation that the criterion rewards the improvement in the fitting (the greater the likelihood L of the estimated model, the smaller the AIC value), at the same time that penalizes the number of parameters being used (the more parameters used in the model, measured by k , the higher is the AIC value), in a way to avoid over fitting. In practice, for different models, when the one with the smaller AIC is chosen, the probability of choosing the model with less loss of information is maximized.

- Enable outlier filter

In the pre-processing phase of the inflow models, the outliers in the historical data are eliminated, in order to avoid distortions in the fitting process of the inflow models caused by these outliers.

- Climatic variable representation

When this option is enabled, the estimation model may incorporate exogenous climatic information. It is necessary to choose the weighting factor associated with the effect that the exogenous climatic variable will cause in inflows and fill up the tables described in section 11.4. For more information on the functionality, please refer to the methodology manual.

Once all options are defined, the estimation of parameters is started by clicking on the Run button.

After choosing the option “Run”, the statistic results can be visualized in a text editor by selecting the option “Log” on the top menu bar.

11.3 Reduced uncertainty

This option allows the use of different stochastic inflow model parameters for different stages of study period. This is used whenever there are differences in macro-climatic conditions for a limited period. For example, suppose that the first year of a study period corresponds to an “El Niño” condition, in which it is possible to predict that inflows will be lower than usual. One possibility is to adjust a specific stochastic streamflow model to those conditions, using a subset of the inflow record associated to past “El Niño” events.

The El Niño-based parameters would then be applied to the first year of the study period, being replaced by the “normal” parameters in the second year. The Figure below illustrates the use of a specific parameter file, called hparam2.dat, to the period jan/2001-dec/2002.

11.4 Climatic variable

The chronological records of climatic variables are filled in: Complementary data > Hydrology > Climatic Variable.

The fields “Climatic variable name” and “Unit” are merely informative to the user.

The chronological tables should be filled with values that correspond to a climatic index. The table “Historical data” should be filled in the same time horizon as inflow historical data table.

The “Scenario” table should be filled at the time horizon for which the user wants to consider climatic variables. The parameter estimation model will not consider climatic variables for time horizons not filled in this table.

For more information on the functionality, please refer to the methodology manual.

12 SYSTEM

12.1 Currency configuration

The currency configuration is described by the following parameters:

- reference currency
- currency
- exchange rate of each currency \Rightarrow reference currency

The costs and penalties data must be informed in the system's currency or the interconnection currency. The exchange rate is applied in order to produce all results accordingly to the reference exchange rate.

12.2 System configuration

The system data is described by the following parameters:

- code
- name
- identifier
- currency

12.3 Generation Reserve

The selection, addition and elimination of generation reserve constraints for a set of hydro and thermal plants are made from the [list of elements](#) located on the upper part of the screen.

In addition, the constraint type must be selected within three available options:

1. Factor of the demand: the generation reserve is represented in MW or as a function of a factor (in p.u.) of the system load;

This type of constraint allows the definition of values which may vary along the study period. By selecting the "Chronological data" tab, the user can inform in the data table the generation reserve amounts for each year and load block. The model will only use this information if the option "Configuration > Dynamic" is activated in the "Execution options > System configuration" screen.

For each reserve constraint, the user must indicate the system, the constraint type and the unit (p.u., MW or %).

2. Compensation of not-reserve generators outages: generation reserve can compensate the outage of any generation unit that does not belong to the reserve subset;
3. Compensation of reserve generators outages: generation reserve can compensate the outage of any generation unit that belongs to the reserve subset;

It is important to observe that the selection of one type of constraint does not exclude the selection of another, for example, the user can select one constraint to be type 1 and type 2 at the same time.

Selecting the *Violation penalty* option, the user may specify the value in k\$/MWh for the penalty due to generation reserve constraint violation.

The set of hydro and/or thermal plants defining the reserve constraint must be selected as follows:



12.4 Hydro spinning reserve

Define the spinning reserve constraint for each hydro plant. These limits are given in MW, % or % of the available capacity, for each stage (weekly or monthly) and load block.

The spinning reserve is an operative margin that allows the adjustment of the programmed operation with respect to the real time operation. The reserve is represented as a value that is subtracted from the maximum plant capacity.

The SDDP program checks the spinning reserve feasibility. These constraints will be relaxed when the resulting value of the spinning reserve subtracted from maximum capacity is lower than the minimum capacity.

12.5 Thermal Spinning Reserve

Thermal spinning reserve data is handled in the same way as the [hydro spinning reserve](#) data.

12.6 Generation constraints

This screen allows the user to introduce additional generation constraints for a single agent or for a set of agents. On the left-hand side of the constraint, the following agents can be introduced: hydro plants, thermal plants, renewable plants or batteries.

There are two possibilities for generation constraints:

- the sum of the generation of a group of agents should be greater than or equal to (\geq) a user-supplied value (MW); or
- the sum of the generation of a group of agents should be smaller than or equal to (\leq) user-supplied value (MW).

The procedure for adding or modifying data is:

1. add a constraint;
2. assign a number and a name to this constraint;
3. select the *Violation penalty* option if the user wishes to specify the value in k\$/MWh for the penalty due to generation constraint violation;
4. select the constraint type (\geq or \leq); and
5. select the group of agents from the list.

12.7 General constraints

A generic user-defined constraint can be created in the “Complementary data > System > General constraints” screen. The procedure for adding or modifying data is:

1. add a constraint;
2. assign a number and a name to this constraint;
3. select the agent² (hydro, thermal, renewable, load or battery);
4. select the corresponding decision variable of the agent (for example, the turbinning out-flow for a given hydro plant);
5. set the coefficient (and its unit) that will multiply the selected decision variable in step 4;
6. set the *Violation penalty* (in k\$/unit);
7. select the requirement type (fixed or variable); and
8. introduce the requirement. If the requirement is fixed, it must be entered in the field “Value” below the requirement type. If it is variable, the values must be entered in the “Chronological requirement” tab.

12.8 Risk aversion curve (RAC)

The risk aversion curve (RAC) definition screen is available at the complementary data section.

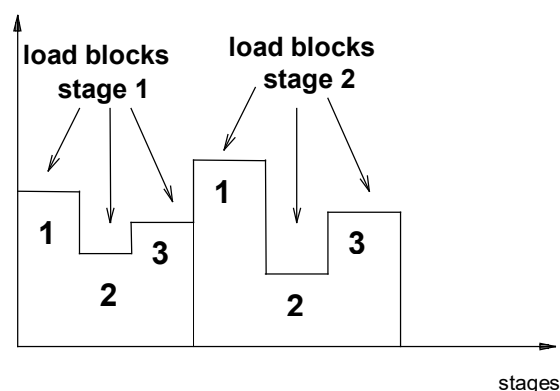
These data are informed by system and for each stage of the study in a [chronological data table](#). The minimum storage limit which has to be met is represented as a percentage of the

² Our goal is to extend this functionality to cover all agents. Tell us your favorite ones and help us to prioritize the next developments!

maximum storable energy of the system. The penalty for violating these minimum storage limits can be defined by the user ("Fixed Value") or calculated by the program ("Automatic calculation").

13 LOAD

The load in each stage is represented in SDDP by blocks, as shown below. Each block is in turn defined by a pair {duration (hours); load (GWh or MW)}.



13.1 Mid/long term load

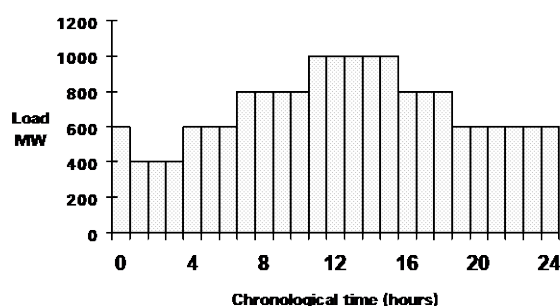
Select the system from the screen and the number of blocks represented in the load data set. Note that the load block menu to the left shows all load data sets in the directory. It is possible to represent up to 21 load blocks per stage. The number of load blocks is defined in the [directory selection](#) initial screen.

A [chronological data table](#) presents the load (in GWh or MW) for each block and stage. The duration of each load block is given as a % of the stage duration. The sum of the durations must necessarily be 100%.

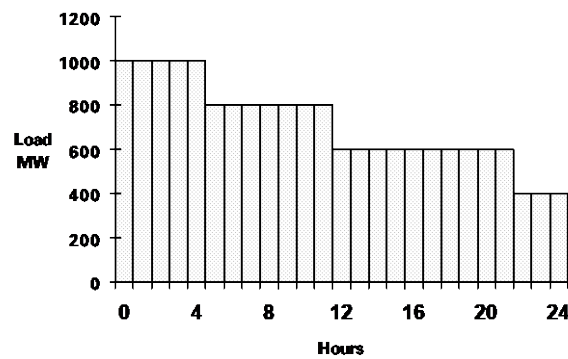
13.1.1 Approximating the load by block from an hourly load

The following procedure illustrates the transformation of an hourly chronological load into a set of load blocks.

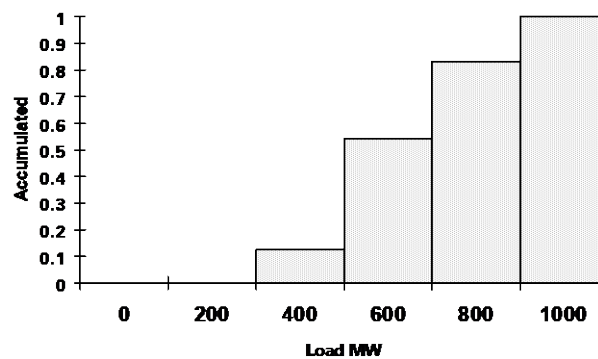
1. Hourly load



2. The load duration curve is obtained by sorting the loads from highest to lowest



3. Re-scale the hours to unity and invert the axis. We now have cumulative probability function of load, i.e., $f(x) = P(X \leq x)$:



The load blocks informed to SDDP are:

Block	Duration	Value (GWh)
1	10%	$0.10 \times d(t) \times 400$
2	40%	$0.40 \times d(t) \times 600$
3	30%	$0.30 \times d(t) \times 800$
4	20%	$0.20 \times d(t) \times 1000$

Note: $d(t)$ is the number of hours of the stage (month, week, etc.).

13.1.2 Variable duration of the load blocks

The duration of the load block, fixed by the load input data, can be selected to be variable through all the stages of the study. Select, from the screen, the number of blocks represented in the load data set. The number of load blocks is defined in the [directory selection](#) initial screen.

A [chronological data table](#) presents the duration of the load block (in hours) for each block and stage. The total duration (in hours) of each stage is given as the sum of all the duration (in hours) of each load block in this stage.

Note: the duration of the load blocks for additional years will be assumed equal to the duration of the last year of the study.

13.1.3 Hour-block mapping

The primary purpose of the [hour-block mapping](#) data is to establish the relationship between the hours and blocks in each stage. Thus, these data are optional in the case of studies with block representation and mandatory in case studies with hourly representation.

Although studies with block resolution do not represent hours individually in the optimization problem formulation, the hour-block mapping data can be used to [obtain the duration of the blocks](#) (instead of using the *fixed duration* or the *variable duration of the blocks*).

On the other side, in studies with hourly resolution, the mapping data is used to [reconstruct the hourly chronology](#) of the data that are informed by block. For more details, please read the [Hourly representation](#) chapter.

13.1.4 Chronological blocks

SDDP represents the process of operational decision-making (generation of each plant, inter-connections between regions, circuit flows, etc.) in two levels of detail. The first level accurately captures the dynamics of the large storage devices over time for mid and long-term planning with the representation of weekly or monthly stages considering the relevant uncertainties for this time scale and translated into Future Cost Functions for each stage. The second level captures the complex operational decisions within each stage in the optimization problem that seeks to balance immediate and expected future costs. So far, the intra-stage problem has been defined either by explicitly representing the hours chronologically or by aggregating variables/constraints in blocks of hours with similar data (also known as the load duration curve model). This latter representation turns the solution process faster and is very useful for obtaining the optimal solution of the first level but disregards the chronology, which might be necessary for the second level.

In SDDP, there is an intermediate option for the representation of chronology between blocks of hours. With this feature, the optimization problem at each stage will consider aspects such as the final storage variables for each block, the balance constraints between blocks for reservoirs, batteries, etc., thermal unit commitment, and start-up costs at each block and others. This modeling is also automatically used as part of a strategy to improve the solution time and accuracy of the problems with hourly resolution.

Building the chronological optimization problem requires a higher number of blocks and the input data must be defined in a chronological way per block. Additionally, a new automated tool in the interface creates an hour-block “remapping” table by applying clustering techniques enabling the direct use of this feature without changing the input data already introduced (for more details, please check section [Integrated clustering tools](#)). In this case, the model will use the hourly demand to build the new chronological blocks and will convert all data defined per block to the new (chronological) hour-block mapping. As can be seen, the

remapping data allows SDDP to build 21 chronological blocks based on an input data defined in 5 non-chronological blocks, for example.

Finally, it is worth mentioning that this feature is only available for weekly cases.

13.2 Multiple demands per system

The model allows the representation of different types of demand for each system. Each system can have more than one demand associated to it, which can be composed of a combination of elastics and inelastic components.

The combination of more than one demand per system allows the separate representation of residential, industrial and commercial demands. The total demand of the system will correspond to the sum of all its individual demands. The distribution of the demand over the electrical network is detailed in section 14.1.1.3

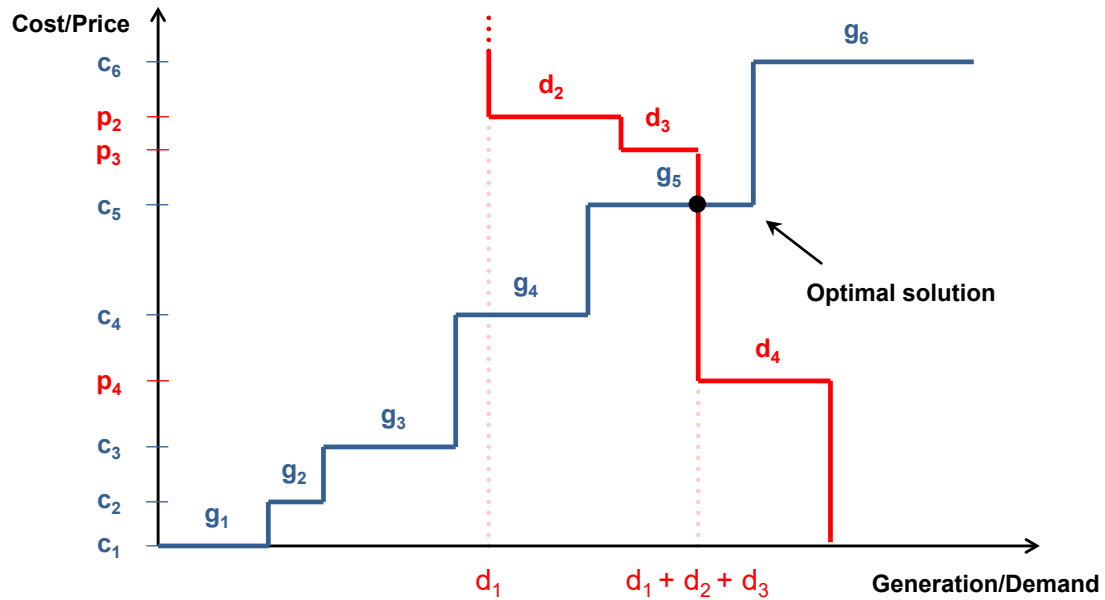
13.3 Elastic, inelastic and mixed demands

Each demand in SDDP can be defined as a curve that indicates its willingness to purchase energy for different price levels of the system. There are three types of possible demands:

- **Totally inelastic (or fixed) demand:** corresponds to a demand that must necessarily be met. Its supply interruption is only associated to a physical unavailability of the system to meet it. For this type of demand, the curve that represents it has only one level. Its definition is done by specifying the energy to be consumed by the demand.
- **Totally elastic demand:** corresponds to a demand with willingness to purchase energy that is sensitive to price levels. For the first price level defined by the user, it must specify which is the total energy amount (defined in GWh or in its equivalent in MW) that this demand is willing to purchase up to this system price, i.e., how much energy will be purchased if the system price (load marginal cost) is lower than the first price level of the elastic demand. Analogously, the other levels for the elastic demand are defined, respecting the following conditions: (i) the price of a given level must be necessarily lower than the price of the previous level and (ii) the energy amount of a given level must be necessarily greater than the energy amount of the previous level. The user can define as many levels for the elastic demand as needed.
- **Mixed demand:** corresponds to a demand that has one inelastic component and other elastic components. This type of demand is, therefore, a combination of the two types described above, being its first level obligatorily its inelastic component and its other levels its elastic components defined in decreasing order of price and following the same conditions that applies to totally elastic demands.

In the following example, it is presented the result of a dispatch for a mixed demand with first inelastic level associated to an energy consumption d_1 and three other elastic levels defined by the pairs (energy amount, price) equal to $(d_1 + d_2, p_2)$, $(d_1 + d_2 + d_3, p_3)$, and $(d_1 + d_2 + d_3 + d_4, p_4)$. The system has five generators with capacities g_1 to g_5 and costs given by c_1 to c_5 , respectively.

The optimal solution corresponds to meeting the inelastic component d_1 of the demand with the generators g_1 to g_4 , through their dispatch in ascending order of cost, and meeting the elastic components d_2 and d_3 while the load marginal cost is lower than their prices. In this way, the elastic components d_2 and d_3 will be supplied by generators g_4 and g_5 whose operative costs c_4 and c_5 are lower than the prices p_2 and p_3 of these elastic components. As not providing any economic benefit to the system, in other words, there are no generators with inferior operative costs than the price of load d_4 , this elastic component is not met. The total demand of the system that is supplied corresponds to the sum of the inelastic components d_1 and of the elastic components d_2 and d_3 .



In SDDP, the definition of each demand for each system must be done through the creation of its levels, following the rules above:

- The first level can be defined as inelastic or elastic
- The other levels, when exist, must be only elastic

The way to represent the demand data in all versions of SDDP previous to version 12 remains available to be used for the systems where there is no interest in using this new functionality that allows combining elastic and inelastic components of the demand.

The demand configuration data are defined via the interface through a [list of elements](#) containing the following information:

- Type of the first level: inelastic or elastic
- Energy to be consumed by the demand for each price level of the system, being the demand elastic or inelastic
- Price for each level of the elastic demand

The energy and price data for each level of the demand are defined through a [chronological data table](#), variable per stage and load block.

13.4 Flexible demand

In addition to the three types of demand presented on the last section, it is possible to define flexible demands. Flexible demands allow the representation of energy consumption within a stage to be delayed/anticipated, to minimize the consumer's energy cost. The load shifting is subjected to a minimum and a maximum consumption in each timestep (block, hour, minutes, etc) and an integrality constraint: the sum of shifted loads along the timesteps must be equal to the original total consumption. The reference load is specified for each timestep, which defines the amount of energy to be supplied in case there is no shifting. The minimum and maximum consumption are specified as maximum load decrease and maximum load increase factors (in p.u. of the reference load), defining the shifting limits for each timestep. Another characteristic of this type of demand is the consumer's tolerance for load curtailment, which is subjected to a maximum value (in p.u. of the reference load) and an associated premium (in \$/MWh). It is also possible to specify a shifting window (in hours), determining the timespan in which the load is allowed to be shifted.

13.5 Demand uncertainty

From version 12 of SDDP it is allowed to represent the uncertainty in the demand data, with variability following a normal distribution. For this representation, the user must inform the average of the normal distribution that describes the random variable of the demand and its variation coefficient (ratio between the standard deviation and the average). With the variation coefficient and the average, the model calculates the standard deviation of the distribution (the average and the standard deviation are the sufficient parameter to define a normal distribution). In this version, the model considers that the demand uncertainty is independent over time, i.e., it does not consider any time dependency in the demand sampling process.

14 TRANSMISSION

There are two mutually exclusive alternatives for representing transmission aspects:

- linearized power flow model;
- interconnection model

14.1 Linearized power flow model

The elements associated to the linearized power flow model representation are:

- bus
- circuit
- DC links
- import/export between areas constraints
- sum of circuit flows

14.1.1 Bus data

14.1.1.1 Bus configuration

The selection, addition and elimination of buses are made from the [list of elements](#) located on the upper part of the screen. When adding a bus, it is necessary to specify a code (number) and name, as well as the system where it is located.

14.1.1.2 Generation and area data

The generation data associated to each bus includes:

- area – used to define power import/export constraints
- hydro plants connected to the bus
- thermal plants connected to the bus

The connected hydro and thermal plants are selected using the buttons (>>) and (<<) in each plant list.

14.1.1.3 Load data per bus

The loads per bus correspond to the distribution of the demands among the electrical network. The disaggregation of the demands among the buses is done accordingly to their participation factors, calculated from the loads per bus as indicated below. These participation factors will be the same for all levels of the demand (elastic and inelastic) associated to a given bus.

The addition, modification and elimination of loads per bus are done through a [list of elements](#), containing:

- bus – identification of the bus to which the bus load is associated
- demand – demand to which the bus load is associated
- system – system to which the bus load belongs
- data – configuration or modification date of the bus load
- reference load – reference value of the bus load in MW

In a given stage t , for each bus m and load block k , the bus load component is defined as follows (to simplify the notation, the indexes referring to stage and load block have been omitted):

$$db(m) = \sum_{j \in \Gamma(m)} fd(m,j) \times d(j)$$

$$fd(m,j) = \frac{FR(m,j)}{\sum_{n \in B(j)} FR(n,j)}$$

where:

j	demand index	
$\Gamma(m)$	set of demands to which the bus m is associated	
$fd(m,j)$	participation factor of bus m in demand j	p.u.
$d(j)$	load j	MWh
$FR(m,j)$	reference load associated to the demand j on bus m	MWh
$B(j)$	set of buses associated to demand j	

14.1.1.4 Example of load by bus data

For a better understanding, consider the following system having two different demands, **Residential** and **Industrial**, one load block and two stages of 744 hours (July and August).

Dem Id.:	Description	Level (Inelastic) Stage 1	Level (Inelastic) Stage 2
1	Residential load	300 MW = 223.2 GWh	300 MW = 223.2 GWh
2	Industrial load	150 MW = 111.6 GWh	200 MW = 148.8 GWh

The system has the following initial configuration of buses:

Bus Id.:	Residential Load	Industrial Load
100	100 MW	50 MW
101	50 MW	100 MW
102	150 MW	-

In the second stage, new factories start to operate in bus 100, increasing the Industrial load of the system in 50MW, which turns to be as indicated in the following table:

Bus Id.:	Residential Load	Industrial Load
100	100 MW	100 MW
101	50 MW	100 MW
102	150 MW	-

For the first stage:

The sum of the reference loads associated to the **Residential Load** ($j=1$) is given by:

$$\sum_{n \in B(j)} FR(n, j) = 100 + 50 + 150 = 300 \text{ MW}$$

Therefore, the participation factors associated to the Residential Load will be:

$$fd(100,1) = \frac{100}{300} = 1/3$$

$$fd(101,1) = \frac{50}{300} = 1/6$$

$$fd(102,1) = \frac{150}{300} = 1/2$$

The sum of the reference loads associated to the **Industrial Load** ($j=2$) is given by:

$$\sum_{n \in B(j)} FR(n, j) = 50 + 100 = 150 \text{ MW}$$

Therefore, the participation factors associated to the Industrial Load will be:

$$fd(100,2) = \frac{50}{150} = 1/3$$

$$fd(101,2) = \frac{100}{150} = 2/3$$

For the second stage:

There is no modification in any of the bus loads associated to the Residential load, which implies that the participation factors keep constant. For the Industrial load, however, we have:

$$\sum_{n \in B(j)} FR(n, j) = 100 + 100 = 200 \text{ MW}$$

And the participating factors associated to the Industrial load Industrial turn to be:

$$fd(100,2) = \frac{100}{200} = 1/2$$

$$fd(101,2) = \frac{100}{200} = 1/2$$

14.1.2 Circuit data

14.1.2.1 Circuit configuration

The selection, addition and elimination of circuits are made from the [list of elements](#) located on the upper part of the screen.

The basic circuit data comprises:

- resistance (%) and reactance (%)

The power base used in the calculation of the resistance and reactance in % is 100 MVA.

The following example illustrates the calculation of the reactance in %:

The reactance base is defined as:

$$\text{Reactance base [ohm]} = \frac{(\text{Phase}_{\text{phase}} \text{ voltage base [kV]})^2}{\text{Power base [MVA]}}$$

If the phase-phase voltage base is 230 kV and the transmission line has 100 km and reactance equal to 0.5 ohm/km, we have:

Reactance base = $230^2 / 100 = 529$ ohm

Reactance [ohm] = $0.5 \text{ [ohm/km]} * 100 \text{ [km]} = 50$ ohm

Reactance [p.u.] = $50 \text{ [ohm]} / 529 \text{ [ohm]} = 0.0945$ p.u.

Reactance [%] = $0.0945 \text{ [p.u.]} * 100 \text{ [%]} = 9.45 \%$

- nominal flow limit (MW)
- emergency flow limit (MW)
- circuit type (existing or future)
- circuit operative condition (connected or disconnected)
- selected for monitoring

The option *Selected for monitoring* is associated to the *Selected circuits* activation of the *Monitoring of circuit limits* option located in the “Execution Options > System Configuration” screen. In this specific case, the selected circuits will have their limits monitored.

- security constraints

If selected, the circuit will be included in the contingency list for a security-constrained dispatch. In this case, the user must inform which circuits will be monitored in the post-contingency situation (see lower part of the screen), meaning that their flows must be less or equal to their respective emergency limits.

SDDP allows that up to 5 circuits be monitored in case of contingency of a given circuit. Then it is possible to include in the dispatch security constraints similar to the N(N-1) criterion, but less constrained.

- consider circuit outage

Note: this option is very specific, and was developed to allow the simulation of El Salvador's transmission pricing regulation (VECF). If selected, the field called outage probability (%) will be enabled; then the user informs the failure probability of the selected circuit. If one or more circuits are selected in this way, the model will carry out *two* separate dispatches for each stage and hydrological sequence in the final simulation: (i) a *base case dispatch*, where all circuits are assumed to be available; and (ii) a *contingency dispatch*, where the outage of *one* circuit is randomly sampled. The outage frequency of each line in the random sampling is proportional to the ratio between its failure probability and the sum of all circuit failure probabilities.

14.1.2.2 Expansion/Modification of circuit data

Circuit data modifications are handled in the same way as [hydro plant modifications](#). The fields that can be altered are:

- resistance (%)
- reactance (%)
- nominal flow limit (MW)
- outage probability (%)
- circuit operative status (connected or disconnected)

14.1.2.3 Circuit outage

For a circuit outage representation, the user can define the circuit as disconnected or as a future circuit with no associated expansion date.

14.1.3 DC link data

14.1.3.1 DC link configuration

The selection, addition and elimination of DC links are made from the [list of elements](#) located on the upper part of the screen.

DC links are characterized by the following parameters:

- number
- name
- FROM bus
- TO bus
- DC link type (existing or future)
- nominal flow limit (MW) in the FROM \Rightarrow TO direction
- emergency flow limit (MW) in the FROM \Rightarrow TO direction
- loss factor (p.u.) in the FROM \Rightarrow TO direction

- nominal flow limit (MW) in the TO \Rightarrow FROM direction
- emergency flow limit (MW) in the TO \Rightarrow FROM direction
- loss factor (p.u.) in the TO \Rightarrow FROM direction

14.1.3.2 Expansion/Modification of DC link data

DC link data modifications are handled in the same way as [hydro plant modifications](#). The fields that can be altered are the flow limits and loss factors.

14.1.4 Area import/export constraints

The area net import/export is given by the difference between generation and demand:

$$-\bar{I}_t(a,k) \leq G(a,t,k) - D(a,t,k) \leq \bar{E}_t(a,k)$$

where:

$G(a,t,k)$	total generation in area a , stage t and load block k
$D(a,t,k)$	total load in area a , stage t and load block k
$\bar{I}_t(a,k)$ and $\bar{E}_t(a,k)$	export and import limits in area a , stage t , and load block k

The total generation in area a is the sum of the generations at all buses in that area. The bus area is informed in the bus configuration screen. Different export/import limits can be given for each load block.

14.1.4.1 Modification of area import/export limits

Area import/export limits data modifications are handled in the same way as [hydro plant modifications](#). The only field that can be modified is the export / import limit per load block.

14.1.5 Sum of circuit flow constraint data

14.1.5.1 Circuit flow sum constraint configuration

The selection, addition and elimination of circuit flow sum constraints are made from the [list of elements](#) located on the upper part of the screen. When adding a new constraint, it is necessary to specify a code (number) and name.

For each constraint, the user must specify the operative lower and upper bounds as well as the circuits that belong to the constraint.

The *multiplication factor* allows specifying the direction and the multiplicative factor associated to each circuit that belongs to the constraint. Values equal to 1 indicate that the circuit is considered as it was defined, as “from” -> “to” definition, whereas values equal to -1 invert the direction of the flow.

14.1.5.2 Expansion/Modification of circuit flow sum constraint

Circuit flow sum constraint modifications are handled in the same way as hydro plant modifications. The fields that can be modified are the lower and/or upper bounds.

14.1.6 International circuit cost

The costs associated to this kind of circuit must be specified in both directions (From->To and To->From) and in \$/MWh, for each year and load block, in a [chronological data table](#), also indicating the associated currency.

14.2 Interconnection model

14.2.1 Interconnection

14.2.1.1 Configuration

The selection, addition and elimination of interconnections are made from the [list of elements](#) located on the upper part of the screen.

System interconnections are characterized by the following parameters:

- number
- name
- type (existing or future)
- FROM system
- TO system
- power exchange capacity (MW) in the FROM \Rightarrow TO direction per load block
- loss factor (p.u.) in the FROM \Rightarrow TO direction
- power exchange capacity (MW) in the TO \Rightarrow FROM direction per load block
- loss factor (p.u.) in the TO \Rightarrow FROM direction
- transmission cost (\$/MWh) in the FROM \Rightarrow TO direction per load block
- transmission cost (\$/MWh) in the TO \Rightarrow FROM direction per load block
- currency

14.2.1.2 Modification of the Interconnection data

Interconnection modifications are handled in the same way as hydro plant modifications. The fields that can be modified are the exchange capacity (in both directions) and the loss factor.

14.2.2 Interconnection sum constraint

14.2.2.1 Configuration of interconnection sum constraint

The selection, addition and elimination of interconnection sum constraints are made from the elements list located on the upper part of the screen. When adding a constraint, it is necessary to specify a code (number) and a name.

For each constraint the user must specify the operative lower and upper bounds as well as the interconnections that belong to the constraint.

14.2.2.2 Expansion/Modification of interconnection sum constraint

Interconnection sum constraint modifications are handled in the same way as [hydro plant modifications](#). The fields that can be modified are the lower and/or upper bounds.

14.2.3 Variable Interconnection Cost

The interconnection costs must be specified in both directions (From->To and To->From) and in \$/MWh, for each year and load block in a [chronological data table](#).

15 POWER INJECTION

The user can define generic power injections on the “Basic data > Power injection > Power injection configuration” screen. Input data required is the injection capacity and price (optional), both of which can be defined per block or in hourly resolution. After introducing the data, the user must select the data resolution on the “Execution options > Economic dispatch > Data resolution” screen for both: capacity – “Power injection (Capacity)” and price – “Power injection (Price)”.

Both power injection capacity and price can be positive or negative.

If no price is defined and the injection is positive, it can be seen as a thermal plant with operating cost equal to zero. If the injection is negative, it can be seen as an elastic load with a ceiling price equal to zero (it will only be met when there is a surplus of energy in the system and meeting this demand reduces costs in the objective function of the problem, for example to avoid paying a penalty for spilling renewable energy).

If prices are defined and the injection is positive, it can be seen as a thermal plant with operating cost equal to the user-defined price. If the injection is negative, it can be seen as an elastic load with a ceiling price equal to the user-defined price.

Additionally, it is worth mentioning that the power injections may be contemplated in runs with or without the electrical network.

16 GAS SYSTEM

The gas system network configuration is represented by the gas systems or nodes, the gas pipelines and the non-thermoelectrical demand data.

The following sections describe in detail each element of the gas system network configuration.

16.1 Gas node data

16.1.1 Gas node configuration

The selection, addition and elimination of gas nodes are made from the [list of elements](#) located on the upper part of the screen. When adding a node, it is necessary to specify a code (number) and a name, as well as the system where it is located.

For each node, the minimum and maximum local production and its production cost must be specified.

The gas system units are in Millions of Units of Volume (MUV), where the volume unit is defined for the fuel which is used by all thermal plants that belong to the gas system. Note that all of these thermal plants must obligatory use the same fuel or different fuels that have the same volume unit (defined in the fuel configuration screen).

In the same window, the thermal plants, associated to the gas node, by system, are selected.

16.1.2 Expansion/Modification of the gas nodes

Gas node modifications are handled in the same way as [hydro plant modifications](#). The fields that can be modified are the minimum and maximum local production and the production cost.

The program will only consider this information if the option “Dynamic Configuration” in Execution/System Configuration screen was selected.

16.2 Gas Pipeline

16.2.1 Gas pipeline configuration

The selection, addition and elimination of gas pipelines are made from the [list of elements](#) located on the upper part of the screen.

Gas pipelines are characterized by the following parameters.

- number
- name
- FROM node
- TO node

- gas pipeline capacity (MUV/day) in FROM \Rightarrow TO direction
- loss factor (p.u.) in FROM \Rightarrow TO direction
- gas pipeline capacity (MUV/day) in TO \Rightarrow FROM direction
- loss factor (p.u.) in TO \Rightarrow FROM direction
- transportation cost (\$/m3)
- currency

16.2.2 Expansion/Modification of gas pipelines

Gas node modifications are handled in the same way as [hydro plant modifications](#). The fields that can be modified are the pipeline capacity and the loss factor.

The program will only consider this information if the option “Dynamic Configuration” in Execution/System Configuration screen was selected.

16.3 Non-thermoelectrical gas demand

For each non-thermoelectrical demand the user must specify a number, a name, the gas node associated and a penalization for un-served gas demand.

Data for non-thermoelectrical demand are given by stage and load block.

16.4 Gas production cost

The gas production costs are specified for each year and load block.

17 RENEWABLE SOURCES

The renewable source agent allows the representation of wind power plants, small hydro plants, biomass plants etc.

The renewable sources are not under the scheduling control. First, the renewable generation is discounted from the system load and then the scheduling problem is solved. This process is described in detail in the SDDP's Methodology Manual.

In order to represent a renewable source, the user must inform its configuration data, its modifications (if exist) and its generation scenarios. Each of these data is described next.

17.1 Renewable source configuration

The selection, addition and elimination of renewable source are made from the [list of elements](#) located on the upper part of the screen. When adding a new renewable source, the user must specify a code and a name for it.

For each renewable source, the user must specify the number of units, the installed capacity, the operation factor and its type (existing or future). The operating factor must be used in order to represent constraints in the plant's maximum power output due to possible constraints in any support equipment. The outage probability and the outage sampling options are reserved for a future version of the model.

17.2 Expansion/Modification of renewable sources

Renewable sources modifications are handled in the same way as hydro plant modifications. The fields that can be modified are the number of units, the installed capacity, the operation factor and the outage probability.

The program will only use the modification data if the option "Dynamic" is selected for the "Configuration" field on the "Execution options > Economic dispatch > Horizon & resolution" screen.

17.3 Renewable source scenarios

The generation scenarios are specified for each renewable source, as a factor (p.u.) of its installed capacity, varying by stage and load block in a [chronological data table](#). These scenarios represent seasonal changes in the renewable source plant's generation profile, for instance, variations in the wind pattern in case of wind farms. In addition to having the possibility to introduce the scenarios of renewable generation directly in SDDP, the user can also use the Time Series Lab (TSL) to generate them. For more details on TSL, please refer to the [Time Series Lab \(TSL\)](#) chapter of this manual.

Finally, it is important to remember that the scenarios used by SDDP (forward and backward) are composed of a combination of hydrological scenarios and renewable generation.

The scenarios drawn by SDDP are thus composed by the combination of hydrological scenarios and those from the renewable source plants.

17.4 Concentrated Solar Power (CSP)

The general idea is that the sun is reflected by mirrors (panels) that focus sunlight on a receiver in which a fluid is heated. In the most usual configuration of CSP plants, parabolic mirrors concentrate the heat at the focus, through which the fluid passes. All CSP configurations aim to use sunlight to heat this fluid, which when hot is stored in thermally insulated tanks. When the plant is started, the fluid leaves the tank and generates water vapor, which drives a turbine to produce electricity.

For more details on CSP, please consult the Time Series Lab (TSL) methodology and user manuals.

17.4.1 Configuration

To represent a CSP plant, it is necessary to inform its configuration data, its modifications (if they exist) and its generation scenarios, similarly to renewable sources. Each of these data is described below.

17.4.2 Selection of a CSP

The selection, addition and removal of CSP plants are performed on the “Basic data > Renewable source > CSP Configuration” screen from the [list of elements](#), located at the top of the screen. When adding a new plant, it is necessary to specify a code and a name for it, along with the identifier of the system where it is located. The addition of generation scenarios is done in the same way as the renewable ones, on the “Basic data > Renewable source > Renewable station scenarios” screen.

17.4.3 Operating data of CSP plants

- Code
- Name
- System
- Type (existing or future)
- Associated renewable station
- Number of units
- Installed capacity (MWe)
- Solar Multiple: the Solar Multiple (SM) describes the relationship between the capacity of the solar panels and the steam turbine capacity. Therefore, an oversized CSP ($SM > 1$) can,

at certain times, produce more energy than the motor can handle. In those cases, the CSP can use storage tanks to prevent the generated energy from being spilled

- Efficiency (MWe/MWt): efficiency of the physical process of converting heat into energy from the steam turbine
- Maximum Storage (MWht)

17.4.4 Expansion/Modification

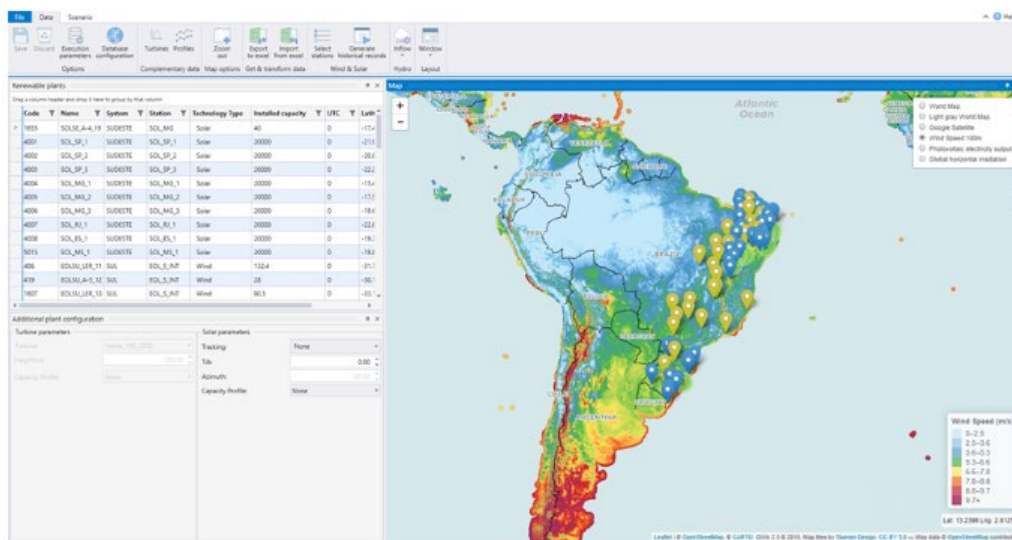
On the expansion screen, it is allowed to change some of the original data which may vary over time.

The fields that can be modified are:

- Number of units
- Installed capacity (MWe)
- Solar multiple (SM)
- Efficiency (MWe/MWt)
- Maximum storage (MWht)

18 TIME SERIES LAB (TSL)

In the SDDP model, scenarios of renewable generation can be expressed in two resolutions: (i) by blocks; or (ii) hourly, defined as an annual profile or detailed profile for the entire study horizon. The worldwide increasing penetration of Variable Renewable Energy sources (VREs) continuously requires an increase in the quality of the input scenarios for operation planning studies. Because of that, PSR develops tool called Time Series Lab (TSL), which can generate these scenarios. TSL is completely integrated with SDDP and offered free of charges for all SDDP licensed users.



TSL has two main modules: (i) TSL-Data and (ii) TSL-Scenarios:

- **TSL-Data** creates a synthetic hourly renewable generation historical record by processing the information available at the MERRA-2 global reanalysis database. The idea behind **TSL-Data** is to download historical reanalysis data of wind and/or solar irradiance (available since 1980) and transform these natural resources into power production based on: (i) the characteristics of the wind turbine model and height of the hub, and (ii) solar panels (with different tracking systems). By creating a synthetic hourly historical record, this methodology allows the assessment of new sites for renewable candidates located anywhere in the world, besides the improvement in the representation of existing renewable plants;
- **TSL-Scenarios** is a statistical model that uses historical data to estimate parameters and generate future scenarios for the SDDP model. In the case of VREs, these scenarios may be (i) the real input data (based on generation measurements) or (ii) the synthetic historical record created by **TSL-Data**, always generated maintaining the spatial and temporal correlations between all renewable stations. Additionally, it is possible to choose whether to contemplate (or not) the effects of spatial and temporal correlations with hydro inflows that will be later used by SDDP.

For more details about TSL, please visit <https://www.psr-inc.com/software-en/?current=p13874>.

19 BATTERY

19.1 Battery configuration

19.1.1 Battery selection

The selection, addition and elimination of batteries are made from the [list of elements](#) located on the upper part of the screen.

19.1.2 Battery operating data

- 1) Minimum storage (MWh)
- 2) Maximum storage (MWh)
- 3) Initial storage(p.u.)

Initial condition of the battery storage at each step. This value must be set according to the useful storage.

- 4) Maximum capacity (MW)
- 5) Maximum regulation time (h)
- 6) Charge efficiency (p.u.)
- 7) Discharge efficiency (p.u.)
- 8) Charge ramp (MW/min)
- 9) Discharge ramp (MW/min)

19.2 Expansion/Modification

In the expansion screen, it is possible change some of the original data that may vary over time (see [hydro plant modifications](#) section).

The fields that can be modified are:

- Maximum storage (MWh)
- Maximum capacity (MW)
- Charge efficiency (p.u.)
- Discharge efficiency (p.u.)

20 HYDROGEN AND ELECTRIFICATION

There is a worldwide drive for a global transformation in energy production and consumption patterns to achieve net-zero GHG emissions in the coming decades. This requires rethinking key energy-dependent sectors such as industry, transportation, construction, and heating. Electricity will play a crucial role in this transformation by providing clean and sustainable energy, leveraged by the decreasing costs of renewable generation resources.

Hydrogen attracted attention because it can be produced from clean electricity via electrolysis (splitting water into hydrogen and oxygen). The hydrogen is then used in fuel cells for transportation and as an energy source in industrial processes.

SDDP can explicitly model the hydrogen supply chain and its integration into the power system: hydrogen production factories consuming electricity from the power grid, hydrogen distribution nodes, transportation, storage, and price-responsive hydrogen demand can be combined to design and simulate in detail a hydrogen system.

In addition to the hydrogen chain, SDDP makes it possible to create electrification processes. The following sections describe each element of the hydrogen/electrification configuration.

20.1 Process and unit configuration

For electrification, the user must define the process. The process is a generic element in SDDP that includes node, producer, transport, storage and demand. For hydrogen, the user only needs to enter the unit and the deficit cost. In this case, on the “Basic data > Hydrogen > Unit configuration” and “Basic data > Electrification > Process configuration” screens, the users may define the following data:

- Code (for electrification only)
- Name (for electrification only)
- Unit
- Deficit cost (\$/Unit)

20.2 Node configuration

Represents the connection between producer, transport, storage and demand. It's important to highlight that each node is associated to only one process.

On this screen, the users may define the following data:

- Code
- Name
- System
- Associated process

20.3 Transport

20.3.1 Transport configuration

Represents the transport of some node to another, in units/day. The selection, addition and elimination of hydrogen/electrification transport are made from the [list of elements](#) located on the upper part of the screen.

On this screen, the users may define the following data:

- Code
- Name
- Associated process
- FROM node
- TO node
- Type: existing or future
- Capacity FROM \Rightarrow TO (Unit/day)
- Capacity TO \Rightarrow FROM (Unit/day)
- Cost FROM \Rightarrow TO (\$/Unit)
- Cost TO \Rightarrow FROM (\$/Unit)
- Loss factor FROM \Rightarrow TO (p.u.)
- Loss factor TO \Rightarrow FROM (p.u.)

As can be seen, a transport element of a hydrogen/electrification process is modeled analogously to an interconnection between systems in the SDDP model.

20.3.2 Expansion/Modification

The modifications of this element are handled in the same way as [other modifications \(in the Complementary Data\)](#). The fields that can be modified are:

- Capacity FROM \Rightarrow TO (Unit/day)
- Capacity TO \Rightarrow FROM (Unit/day)
- Cost FROM \Rightarrow TO (\$/Unit)
- Cost TO \Rightarrow FROM (\$/Unit)
- Loss factor FROM \Rightarrow TO (p.u.)
- Loss factor TO \Rightarrow FROM (p.u.)

20.4 Producer

20.4.1 Producer configuration

Represents the production of some product (for example, Hydrogen or another product from a defined electrification process). If the SDDP case has the representation of the electric network, the producer must be connected to a bus (because it consumes electricity from the power grid) and to a node of the hydrogen/electrification process.

On this screen, the users may define the following data:

- Code
- Name
- System
- Associated process
- Associated node
- Specific consumption (MWh/Unit)
- Maximum production (Unit/day)
- O&M Cost (\$/Unit)
- The associated bus must be defined on the “Basic data > Electric network > Bus configuration” screen

20.4.2 Expansion/Modification

The modifications of this element are handled in the same way as [other modifications \(in the Complementary Data\)](#). The fields that can be modified are:

- Specific consumption (MWh/Unit)
- Maximum production (Unit/day)
- O&M Cost (\$/Unit)

20.5 Storage

20.5.1 Storage configuration

Represents a storage facility connected to a given node, and it works like a “fast response storage” (mathematically it is modeled analogously to a battery in the SDDP model). The selection, addition and elimination of hydrogen/electrification storage are made from the [list of elements](#) located on the upper part of the screen.

On this screen, the users may define the following data:

- Name
- Number

- System
- Associated process
- Associated node
- Minimum storage (Unit)
- Maximum storage (Unit)
- Initial storage (p.u.): initial storage condition at each stage. This value should be set according to the useful storage
- Maximum charge rate (Unit/hour)
- Maximum discharge rate (Unit/hour)
- Charge efficiency (p.u.)
- Discharge efficiency (p.u.)
- Maximum regulation time (hour)
- Charge ramp (Unit/min)
- Discharge ramp (Unit/min)

20.5.2 Expansion/Modification

The modifications of this element are handled in the same way as [other modifications \(in the Complementary Data\)](#). The fields that can be modified are:

- Minimum storage (Unit)
- Maximum storage (Unit)
- Maximum charge rate (Unit/hour)
- Maximum discharge rate (Unit/hour)
- Charge efficiency (p.u.)
- Discharge efficiency (p.u.)

20.6 Demand

Represents the demand of a given node and it can be elastic or inelastic; if inelastic, there will be a deficit cost associated previously defined on the “Basic data > Hydrogen/Electrification > Process configuration” screen. The selection, addition and elimination of hydrogen/electrification demand are made from the [list of elements](#) located on the upper part of the screen.

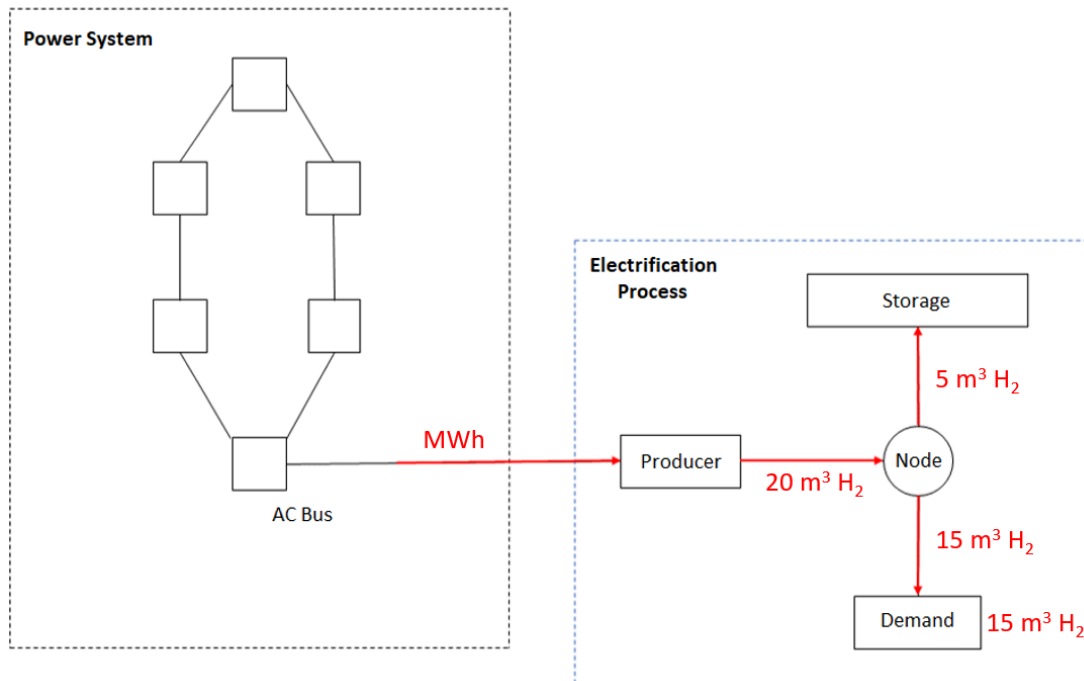
On this screen, the users may define the following data:

- Name
- Number

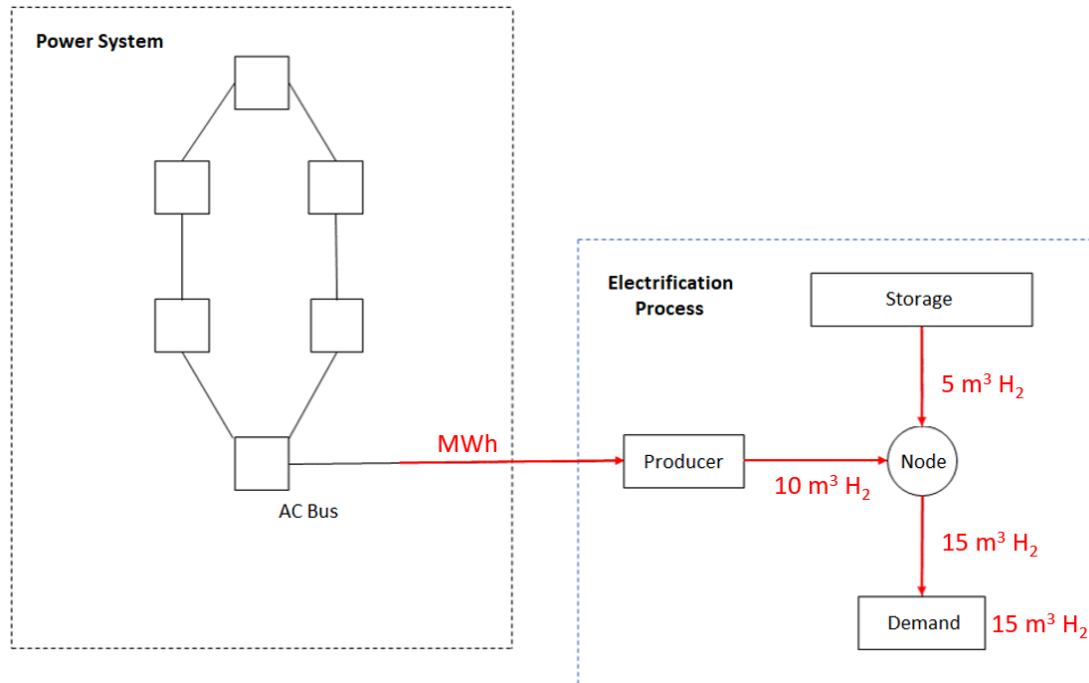
- System
- Associated process
- Associated node
- Levels
- Demand per block (Unit)
- Price per block (\$/Unit)

20.7 Application examples

The schematic diagram of a hydrogen/electrification process is illustrated in the figures presented below. For the SDDP modeling, mathematically speaking, both hydrogen and electrification processes are modeled in the same way. Then, based on the input data (aforementioned basic data), it is expected that the system will behave as follows: energy will flow from the power system to the producer of the hydrogen/electrification process, which will have a specific consumption for the production (in addition to a maximum production in units/day); if the energy in the power system in a given moment is cheap, there will be a greater production so that there is a surplus to be stored (Case 1):



If the energy in another given moment is expensive, part of the storage will be used to lower the cost, if there is any stored product (Case 2):



Finally, if there is no storage and the energy is more expensive the hydrogen/electrification deficit cost, a deficit will be seen; look that the user-defined deficit cost of the hydrogen/electrification process plays an important role here.

21 EXECUTION OPTIONS

The execution options are composed by the following modules:

- study options
- system configuration
- economic parameters
- system and operating modes
- output in worksheets
- solution strategy
- sensitivity
- risk aversion curve
- chronological data

21.1 Study options

21.1.1 Study title

The study title allows the identification of the study through a descriptive title.

21.1.2 Activities

Operating Policy	Determines the optimal stochastic hydrothermal operating policy by using a stochastic dual dynamic programming algorithm - SDDP.
Simulation	Simulates the system operation along the planning period for several streamflow sequences. <i>Note: This activity requires the future cost functions produced by the Operating Policy activity</i>
Simulation with reduced FCF	This execution option allows the user to run a final simulation selecting the FCF that has been “built” until a given iteration from a previous policy calculation to be used (indicated in the field <i>No. of iterations</i> in the <i>Parameters</i> section).
Gas network simulation	This option allows the user to run a separated gas network simulation for given thermal generation scenarios.

21.1.3 Inflows

Autoreg. model	Uses a periodic auto-regressive model - PAR(p) to generate stochastic inflow sequences used in the forward phase and conditioned inflow scenarios in the backward phase of SDDP.
Initial Hydrological Year	Indicates the historic year <i>Y</i> that will be used as the initial condition for hydrology. If historic inflows are used, then inflow scenario #1 starts in

	<p>the week (or month) of the beginning of the study and will continue until the last stage of the study. Scenario#2 starts with year Y+1, and so on.</p> <p>Example 1</p> <p>Study: from Jan. 2000 to Dec.2001 (2 years in monthly steps)</p> <p>Inflows: Historic, initial hydrological year: 1950</p> <p>Number of forward scenarios: 30 (stochastic)</p> <p>Let Q_t represent the inflow of stage t. The hydro inflows sequences (scenarios) used by SDDP in the simulation are:</p> <p>Scenario #01 : $Q_{jan1950}, Q_{feb1950}, \dots, Q_{dec1951}$</p> <p>Scenario #02 : $Q_{jan1951}, Q_{feb1951}, \dots, Q_{dec1952}$</p> <p>Scenario #30 : $Q_{jan1979}, Q_{feb1979}, \dots, Q_{dec1980}$</p> <p><i>Note: if initial hydrological year + number of forward scenarios > last year of recorded hydrologic year, SDDP will "loop back" to the first year of complete hydrological data to complete the remaining data for the sequences.</i></p> <p>Example 2 - Same as example 1, except for the inflows. Instead of historic, now produced by the PAR(p) model. In this case, SDDP will use the initial hydrological year as a "seed" to the PAR(p) model. This model forecasts inflows in month t conditioned to previous inflows $t-1, t-2, \dots, t-p$, where p is the lag memory. So supposing $p=2$ in January, SDDP will produce 30 inflows scenarios for Jan.2000, given the inflows conditions (the seed) of Nov 1949 and Dec. 1949. For this reason, the first year of the historic streamflow records cannot be used as the initial hydrological year when using the autoregressive model. Also, if SDDP is being used to produce the system dispatch for the current week/month, it is recommended that the selection of initial hydrological year reflects a hydrology similar to the current (at the beginning of the study).</p>
Historic	Uses historic inflow sequences in the forward phase of the algorithm and a stochastic model AR(p) to generate the conditioned inflow scenarios used in the backward phase.
External	<p>It is possible to use an external model to produce hydrological inflow scenarios that can be used by SDDP.</p> <p>Forward: reads "forward" scenarios produced by external model</p>

	Forward/Backward: reads scenarios produced by external model to be used in both "forward" and backward phases of the algorithm.
Filter outliers from the generated series	SDDP will apply a set of statistical tests to identify and eliminate outliers from the synthetically generated inflow series.

21.1.4 Study definition

Deterministic	there is only one scenario of future inflows. A deterministic policy is calculated for this given scenario supposing there is perfect knowledge regarding the future inflows. SDDP's system operation will be "tailor-made" for this specific inflow scenario in order to minimize thermal operating costs.
Stochastic	Future inflows are unknown; in this case, the number of forward and backward inflow scenarios must be informed (see the methodology manual for a description of the algorithm).

21.1.5 Forward series for simulation

All	System operation is simulated using all forward scenarios.
Selected	The user selects a subgroup from all possible hydrological forward scenarios in the simulation phase of the algorithm.

21.1.6 Report level

Normal	The program produces a summary printed report with average generation, operation cost etc. for each stage. This is the recommended option.
Detailed	<p>The program produces a detailed printed report with the water and power balance per month.</p> <p><u>Note:</u> this option should only be used for debugging purposes since it may considerably affect the execution time.</p>

21.1.7 Parameters

No. of forward series	Number of hydrological scenarios used in the forward phase of the SDDP algorithm.
No. of backward series	Number of conditioned inflow scenarios used in the backward phase of the SDDP algorithm, or in the simulation.
Tolerance/ No. of standard deviations	Convergence criterion for the SDDP algorithm. If the study is deterministic, it represents the difference between the upper bound and the lower bounds on the operating cost, expressed as a percentage (%) of the initial

	difference. If the study is stochastic, it represents the number of standard deviations for the confidence interval on the upper bound of the operating costs.
No. of Iterations	Limits of the forward and backward phases of the algorithm of the stochastic dynamic dual program (SDDP).

21.2 System Configuration

Weekly or monthly stages can be specified.

21.2.1 Parameters

Initial Stage	Initial month (or week) of the planning study.
Initial Year	Initial year of the planning study.
Final Stage	Final month (or week) of the planning study.
Final Year	Final year of the planning study.
No. of Steps	Number of months (or weeks) of the planning study.
No. of Load blocks	Number of load levels represented in each step. This value is calculated automatically by the model.
Aggregate in the operating policy	SDDP program aggregates load blocks in operating policy. They are represented in details only in the final simulation. The user can select a detailed representation of load blocks in the operating policy. However, the use of this detailed representation in the operation policy calculation increases the execution time and, in most of systems, this may not improve the results.
No. of Additional Years	The additional years are used as a "buffer" to avoid an unrealistic end-of-period reservoir depletion in hydro-thermal operating policy calculation. For example, a two-year study (52 weekly stages) with two additional years is represented as four-year study (208 weekly stages) in which the load for the years # 3 and 4 are the same as the load for the last "official" year - #2 in this case.
Repeat chronological data of the last year. In case of maintenance, use COR	SDDP will repeat the chronological data of the last year of the study for the additional years. For the maintenances, the model will use the unavailability historic factor COR for the additional years.

Use chronological data of the additional years for all chronological constraints	SDDP will consider the chronological data explicitly defined by the user for the additional years. The user is then obliged to define all chronological data for the additional years.
Include additional years in the final simulation	Additional years are not included in the final simulation. The user can extend the final simulation for the additional years.

21.2.2 Stage

Weekly	The study stages have weekly interval.
Monthly	The study stages have monthly interval.

21.2.3 Configuration

Static	There are no data modifications along the planning period.
Dynamic	Data modification along the planning period.

21.2.4 Maintenance

Average	Uses COR (%), from the hydro/thermal configuration file.
Schedule	Uses the maintenance schedule.

21.2.5 Demand uncertainty

Fixed demand	Does not consider demand uncertainty.
Variable demand with normal distribution in the final simulation	Considers (only) in the final simulation the demand uncertainty with a drawing process from a normal distribution with average and variation coefficient (ratio between the standard deviation and the average) defined by the user). The demand drawing is independent over time. During the operative policy, the model will not consider any uncertainty in the demand.
Variable demand with normal distribution in the policy and final simulation phases	Considers in the operative policy and final simulation phases the demand uncertainty with a drawing process from a normal distribution with average and variation coefficient (ratio between the standard deviation and the average) defined by the user). The demand drawing is independent over time.

21.3 Transmission model

21.3.1 Transmission Network

No network/only interconnections	Represents a simplified “pipeline” model with limits on power exchange among systems.
DC load flow model without losses	Represents the complete transmission network (linearized power flow model), but does not consider circuit losses, which should be summed in the demand.
DC load flow model with losses	Represents the complete transmission network (linearized power flow model) and also estimates the quadratic circuit losses.
Represent Losses	If selected, quadratic circuit losses will be represented.
Load Shedding in Buses	Indicates if all buses will be candidates to load cut or only the subset of buses that had been selected in the bus configuration screen.
Circuit Limit Monitoring	Indicates if all system circuits will have their limits monitored or only the subset of circuits that had been selected in the circuit configuration screen.
Option for Circuit Losses	<p>The circuit losses are explicitly represented in the final simulation. However, SDDP allows having an approximate representation for the losses in the policy phase, which consists in starting the policy without losses, calculate the losses associated to the flows in the circuits in the third iteration of the policy and continue with the calculation of the policy with these losses added to the demand.</p> <p>There are two associated parameters:</p> <ul style="list-style-type: none"> • Iteration for the calculation of fixed losses in the policy (recommended value: 3) • Maximum number of micro-iterations for losses calculation in the final simulation (recommended value: 6)

21.3.1.1 Details of the transmission losses model in the final simulation

In SDDP, the model used to represent the transmission network is based on a compact formulation (see methodology manual), where the flows are not explicitly represented in the problem, and a relaxation scheme to include the violated circuits via constraints that use the rows of the β matrix (which represents the sensitivity of the flows with respect to the power injections – generation or demand). In order to represent the losses, this model is not adequate and, therefore, a formulation where the losses are explicitly represented has been adopted.

$$\text{Min } c'g$$

sujeito a:

$$\begin{aligned}
B\theta + g - 1/2|S|p &= d \\
-\bar{f} &\leq \gamma S'\theta \leq \bar{f} \\
p_j &\geq \hat{p}_j^k + 2r_j\hat{f}_j^k(\gamma_j\Delta\theta_j - \hat{f}_j^k) \quad \forall j = 1, \dots, M; \forall k = 1, \dots, K
\end{aligned}$$

Where $B = S\gamma S'$. This model has more variables than the compact model, since represents explicitly the nodal angles and the circuit losses as variables of the problem. On the other hand, the constraints have a sparse structure.

21.3.1.2 Solution strategies

In order to solve this problem, the relaxation strategy described below has been adopted:

Initially the problem is solved without neither considering the constraints of flow limits nor the losses linearizations. After solved the problem, the flows are calculated as $f = \gamma S'\theta$ and the model verifies if there are circuits whose flows are greater than the respective capacities. In such cases, these constraints are added to the problem and it is solved again, and this checking is repeated until all circuits are operating within their capacities.

In the sequence, the circuit losses are calculated for the dispatch solution obtained in the previous problem. In the first losses iteration, losses linearizations are added for all circuits whose quadratic losses are greater than a given tolerance (criterion 1 = 10^{-2} MW). With these constraints added, the problem is solved again, having now one loss variable per circuit that must meet the constraint given by the loss linearization. Starting from the second iteration, the circuits that meet each of the following criteria are verified: (a) the quadratic loss is greater than a given tolerance (criterion 1 = 10^{-2} MW), (b) the absolute difference between the quadratic loss and the approximated linear loss is greater than a given tolerance (criterion 2 = 10^{-1} MW), (c) the difference in percentage between the quadratic loss and the approximated linear loss is greater than a given tolerance (criterion 3 = 2.5%). For these circuits, two linearizations are added: one associated to the flow f_j another one to the flow $-f_j$.

The suggested maximum number of iterations for the inclusion of linearizations is 6, but it can be modified by the user. The idea to add two linearizations from the second iteration is due to the fact that it has been observed that in a few cases the flow changes its sense, given by the fact that in the relaxed formulation the loss is seen as zero in the other direction. It is observed that the number of added linearizations from the second iteration is a lot reduced in comparison to the total number of circuits and also that in the peak load blocks a single linearization is enough, due to the fact that the dispatch does not have many degrees of freedom.

A strategy for the cases where, due to negative marginal cost, the losses in some circuits were artificially increased, “detaching” from the linearizations, has been introduced. When a case like that is detected, a loss penalty of \$1/MWh is defined. This penalty can be iteratively increased until the losses are not used to artificially increase the demand. Once a solution is obtained, the losses are fixed in the obtained values, the penalties are removed and a primal

restart is performed (from the feasible primal base) in order to have the correct calculation of the marginal costs.

Additionally, it has been implemented a scheme for treating the reservoirs with non-controllable spillage, when modeled with penalties. These penalties are considered in the problem in the first micro-iterations (without losses, addition of FCF cuts and addition of flow limits constraints for the violated circuits). Before starting the first micro-iteration of losses (addition of linearizations), the penalties are removed and the final storage and spillage variables are fixed with the following criterion: if the reservoir is spilling, the storage is fixed to the maximum storage; if the reservoir is not spilling, the spillage is fixed to zero.

Finally, a similar strategy is used for all constraints modeled with integer variables; i.e., they are considered in the model in the first micro-iterations and fixed in the first micro-iteration of losses.

21.3.2 Gas network representation

This option allows the selection of:

- Gas network is not considered;
- Gas network is considered, and the production costs of all gas fired thermal plants connected to the gas network are evaluated by the thermal operating costs;
- Gas network is considered, and the production costs of all gas fired thermal plants connected to the gas network are evaluated using the production cost data of gas nodes.

21.4 Economic parameters

21.4.1 Currency

Currency in which the total outflow penalty, spilling penalty and unserved energy costs are specified.

21.4.2 Discount Rate

Annual discount rate, transformed by the model into weekly or monthly rates. Note that the value is p.u., that is, 12% per year is entered as 0.12.

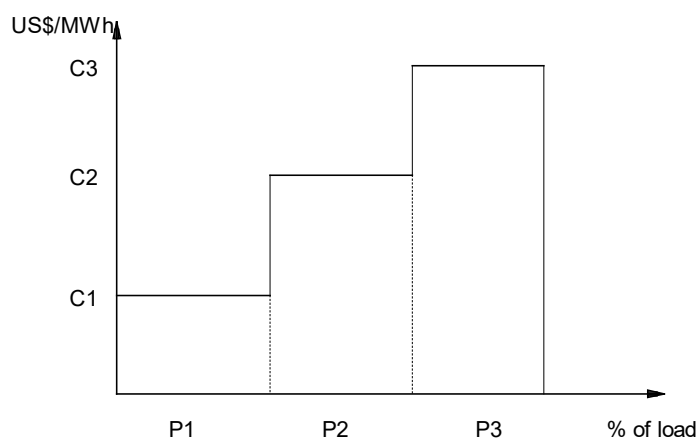
21.4.3 Penalty factors

The penalties for violating operational constraints include:

- **Minimum outflow violation (\$/hm³)**
- **Spillage (k\$/hm³)** – the objective of this penalty is to avoid unnecessary spillage when the future cost is zero, i.e. on high inflow/high storage situations. It should normally be set to zero or a low value. This spillage penalty applies equally to all hydro plants; note that it is also possible to specify a different spillage penalty per plant (see item (r) of the hydro configuration screen in section 5.1.3. The informed specific values always override the general parameter.

21.4.4 Unserved energy costs

Unserved energy costs are represented by a piecewise linear function, as shown below:



Note: $P1 + P2 + P3 = 100\%$

The segments are represented in % of each system load. The incremental cost of each segment is in US\$/MWh. The incremental costs should be non-decreasing.

21.5 System and operation modes

Defines the power exchange policy among subsystems. There are three possibilities:

Autonomous	There is no power exchange among interconnected subsystems.
Coordinated	The operating policy is separately calculated for each system. Economic interchanges based on short-run marginal costs for each system are represented in the simulation.
Integrated	System operation is jointly optimized for all subsystems.

21.6 Output files in worksheets

Defines the output files generated in the final simulation. Select the desired worksheets by checking the first column of the table in the graphical interface.

21.7 Solution strategy

21.7.1 Future cost functions (FCFs) and restart options

This section deals with the initialization of the SDDP algorithm using externally generated information such as future cost functions - FCFs - and initial states. These options are:

- read and write a Terminal FCF
- restart

21.7.2 Read and write a Terminal FCF

As it is well known, the FCF provides a link between the immediate consequences of an operating decision (e.g. reduction of thermal operating costs at the stage due to an increase in hydro generation) and its future consequences (e.g. increase of thermal operation costs in the future due to lower reservoir storage at the end of the stage).

In particular, the end-of-period FCF provides a link between shorter and longer-term operation studies. For example, suppose that the operating policy was initially calculated for a three-year period, in monthly steps. Suppose now that we want to study the first year in more detail, using weekly steps. The FCF associated to month 12 of the longer-term study can be used as the end-of-period FCF of the shorter-term study (i.e. associated to the end of week 52).

In this case, the longer-term monthly study would be executed first, and the option to write a file containing the FCF associated to stage # 12 - end of the first year - would be activated.

Next, the shorter-term study would be executed, with the option of reading that *same* file as the end-of-period FCF, that is, associated to the weekly stage #52.

21.7.3 Restart

As described in the methodology manual, the SDDP algorithm is based on the iterative construction of a piecewise linear approximation to the future cost function (FCF) around the selected system states (reservoir storage levels).

The piecewise linear FCFs are generated in the backward step of the algorithm, and are automatically written to a file. As a consequence, one can start (or restart) the algorithm reading a FCF file generated in a previous study. This option is used to control the computational effort of the SDDP algorithm. For example, it would be possible to start with a small number of iterations to get an initial appraisal of the system operation, and afterwards restart the algorithm.

During the iterative process, the program uses internal temporary FCF and volume files (.WRK). The files with .PSR extension store the FCF and stored volumes for the last complete iteration, composed of a backward recursion followed by a forward simulation. This allows the program to be restarted if, for some external reason (e.g. lack of energy or lack of space in the hard drives) its execution was interrupted.

The COSTYYXX.PSR file, where YY indicates the stage duration (ME for monthly steps and SE for weekly) and XX is the system identifier, contains the cuts, or support hyperplanes, of the future cost function for each stage of the study. Each cut is composed of an independent term plus coefficients for the final storage of the reservoirs and for the p past inflows (order of the autoregressive streamflow model) to the hydro plants. Note that a previous FCF file can only be used if it contains the same set of hydro plants of the current study. However, the *order* of the plants in the data can now be different from that of the FCF file (in the previous versions of the program, the plant order had to be the same). This is the reason for including the indices of the hydro plants in the FCF file, described previously.

The VINPOL.PSR file contains the initial volumes for each reservoir, for each hydrological scenario and for each stage of the study. As mentioned, this is produced by the last forward simulation of the iterative process of the policy calculation.

As in the case of using the restart option the user must certify that no new hydro plant has been added to the study configuration.

21.7.4 Commercial Dispatch

By this option the SDDP performs a separated simulation reading initial volumes, by stage and hydro scenario, from an external file (VINSIM.PSR). This file must be available and can be generated by a previous study.

21.7.5 Non-controllable spillage

The non-controllable spillage can be represented as follows:

- Through penalties. Using this option, spillage in non-controllable hydro plants are deeply penalized on the objective function in order to avoid spills when the storage volume is less than the maximum volume.
- Using integer variables. Using this option all non-controllable hydro plans can spill only if the stored volume is equal to the maximum volume.

21.7.6 Initial storage for the first stage

This option allows the user to choose the data source for the hydro reservoir initial storage for the first stage of the study. Two possibilities are available:

- From hydro configuration data
- From external data file containing the initial storage of each plant and each hydro series.

If the user chooses the second option, then SDDP will require the existence of the initial storage external file, called VOLINI.DAT (see SDDP file's description manual). This file is obtained using the interface button for importation of a CSV formatted file. The existence or inexistence of the initial storage external file is indicated by a message shown on the interface. Besides, this file can be edited by Excel application using the interface button which opens this file. The user, however, must be careful when saving the file in order to keep its name and data format.

21.7.7 Initial storage for the first backward

This option allows the user to choose, as a solution strategy, the initial storage data source for all stages on the first backward recursion. Two possibilities are available:

- From the discretization of the reservoir's storage.
- From external data file containing the initial storage of each plant in each stage and each hydro series.

The external file reading option allows the construction of segments of the future cost function around more interesting and/or probable operation points (reservoir storage level),

which may accelerate the convergence process. The user can use in a new study the initial storage condition obtained in a previous run. This can be done by selecting the file VOLINI.CSV as the importation data file, where VOLINI.CSV is an output file generated by SDDP.

21.7.8 Initial inflows (initial condition of hydrology)

This option allows the user to choose the data source for the hydro initial inflows for the six stages before the beginning of the study. Two possibilities are available:

- From inflow historical data
- From external data file containing the initial inflows of each plant and each hydro series.

If the user chooses the second option, then SDDP will require the existence of the initial inflows external file, called INFLOW.DAT (see SDDP file's description manual). This file is obtained using the interface button for importation of a CSV formatted file. The existence or inexistence of the initial inflows external file is indicated by a message shown on the interface. Besides, this file can be edited by Excel application using the interface button which opens this file. The user, however, must be careful when saving the file in order to keep its name and data format.

21.7.9 Non-convexity representation in the policy phase

In the forward simulation step of the SDDP algorithm, it is possible to represent in detail non-convex functions (e.g., hydro plant variable production factors) and binary operating decisions (e.g., unit commitment of thermal plants) using mathematical programming techniques such as Mixed Linear Integer Programming (MIP). However, the modeling flexibility is more limited in the backward recursion step – which calculates the future cost function (FCF) - because it is necessary to ensure the FCF's convexity.

If the user activates the option “Non-convexity representation in policy” on the “Execution options > Economic dispatch > Solution strategy” screen, he will have to define the iteration from which the forward phases will contemplate non-convexities. The idea is to apply linear relaxation in all forward and backward phases before this user-defined iteration, and from there, represent the non-convexities in the forward phase and continue with the linear relaxation during the backward phases.

The objective of this option is to make the interesting storage points found in the forward phases of the policy adhere to those that will be visited during the final simulation. As these interesting points are used for the addition of cuts, i.e., to approximate the FCF in the backward recursion of the policy, the objective is that the FCF is well approximated around these points, which, as previously mentioned, are adherent to those that will be visited in the final simulation.

21.8 Sensitivity Analysis

The sensitivity screen allows the multiplication of the following data by user-given factors:

- System load
- Forced outage rate - FOR (%) of selected thermal plants
- Lateral water inflows to hydrological stations
- Fuel Cost for selected systems

There are two options: implicit sensitivity factors – which are applied to all the data - and explicit sensitivity factors – which are applied only to selected data. Both can be entered simultaneously. The explicit sensitivity factor, when given, overrides the implicit sensitivity factor.

21.9 Risk Aversion Curve (RAC)

This screen allows the selection of the execution parameter for the representation of the RAC. More specifically:

Risk aversion	<p>Do not consider: the risk aversion curve data, if exist, will be ignored.</p> <p>Operating policy and final simulation: represent the RAC in the operating policy and in the final simulation.</p> <p>In the final simulation only: represent the RAC only in the final simulation.</p>
Penalty type	<p>Fixed: consider a fixed penalty, informed by the user.</p> <p>Reduced (1st backward series): determine the reduced penalty for each backward series (in the Forward phase) and for the first backward opening of each forward series (in the Backward recursion). For the remaining openings, consider that the reduced penalty calculated for the first opening is a good approximation and use it in order to reduce the computational time.</p> <p>Reduced (all series): determine the reduced penalty for each forward series and opening of the backward recursion.</p>
Production factor	<p>Production factor x storage table: define that the production factor resulting from the interpolation of the Production factor x storage table is used for the stored energy calculation for the RAC.</p> <p>Forward: function of the HSP / Backward: average: define that the production factor resulting from the integration of the Head-Storage Polynomial (HSP) will be used for the stored energy calculation of the RAC in the Forward phase and that the average production factor (configuration data) will be used in the Backward recursion.</p> <p>Function of the HSP: define that the production factor resulting from the integration of the Head-Storage Polynomial (HSP) will be used for the stored energy calculation of the RAC both in the Forward phase and in the Backward recursion.</p>

21.10 Chronological data

This option allows the user to disable a set of chronological data without needing to remove the associated input data, as presented below:

Check the chronological data that will be considered

<input type="checkbox"/>	<input checked="" type="checkbox"/> Hydro plants	<input checked="" type="checkbox"/> Maintenance
		<input checked="" type="checkbox"/> Alert storage
		<input checked="" type="checkbox"/> Flood control storage
		<input checked="" type="checkbox"/> Maximum total outflow
		<input checked="" type="checkbox"/> Minimum total outflow
		<input checked="" type="checkbox"/> Irrigation
		<input checked="" type="checkbox"/> Minimum storage
<input type="checkbox"/>	<input checked="" type="checkbox"/> Fuels	<input checked="" type="checkbox"/> Fuel consumption
		<input checked="" type="checkbox"/> Fuel consumption rate
		<input checked="" type="checkbox"/> Carbon credit costs
		<input checked="" type="checkbox"/> Chronological fuel data
<input type="checkbox"/>	<input checked="" type="checkbox"/> Thermal plant	<input checked="" type="checkbox"/> Maintenance
		<input checked="" type="checkbox"/> Startup cost
		<input checked="" type="checkbox"/> Minimum Generation
<input type="checkbox"/>	<input checked="" type="checkbox"/> System	<input checked="" type="checkbox"/> Generation constraint
		<input checked="" type="checkbox"/> Generation reserve
		<input checked="" type="checkbox"/> Variable duration of the demand blocks
		<input checked="" type="checkbox"/> Spinning reserve

22 HOURLY REPRESENTATION

22.1 Introduction

SDDP represents the process of operational decision making (generation of each plant, inter-connections between regions, circuit flows, etc.) in two levels of detail. At the first level, operational decisions are periodically updated with the purpose of incorporating values observed in previous periods, such as storage levels. The new operational decisions taken in the second level are calculated as a solution of a stochastic optimization problem that seeks to balance the benefit of: (i) using more intensely the resources available in the storage devices (typically hydro plants, pump-storages, fuel storages, batteries, emission limits and some types of contracts) at that stage and thereby reducing the so-called *immediate cost*; and (ii) keeping them fuller and thereby reducing the so-called *expected value of the future cost* (the expected value comes from the uncertainty about future hydrology, wind, consumption, availability of equipment, etc.). This first level is intrinsically related to the storage devices that create a *time-coupling* between stages and today's operating decisions can impact the mid and long-term operation affecting thus the future operating costs.

In the current version of SDDP it is possible to choose between weekly or monthly decision periods (which is also called *stages*). This choice depends on several factors, such as the regulation capacity of the reservoirs; the availability of historical data to adjust stochastic water inflow models and even regulatory requirements³. In addition, computational effort is influenced by the study decision type (monthly or weekly), since it grows linearly with the number of stages.

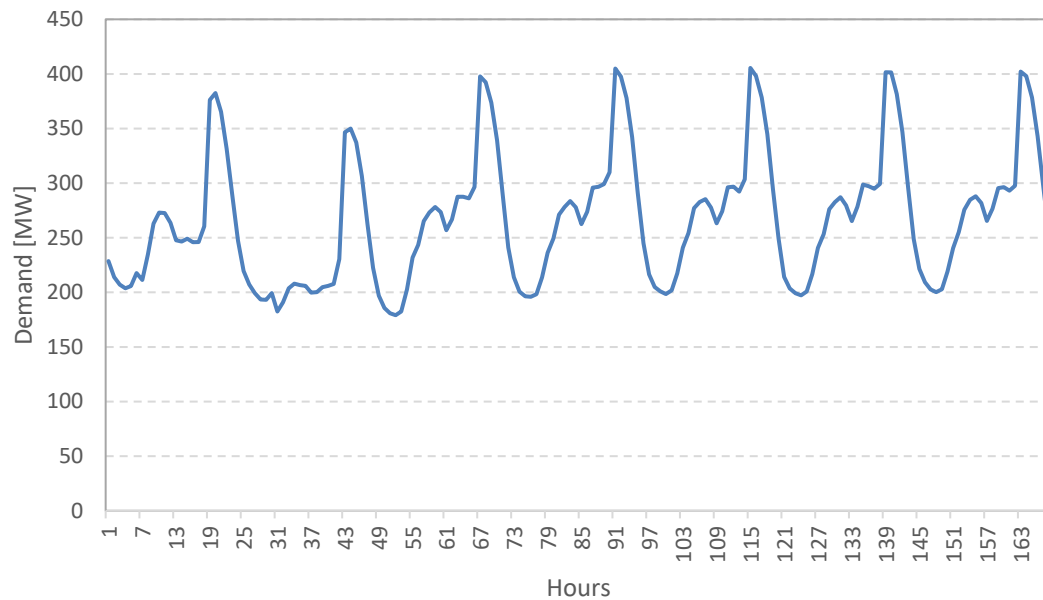
The second level of detail refers to the calculation of the immediate cost at each stage. The least detailed (and faster) representation type would be to calculate the immediate cost for the average input data (hourly demand, wind production, hydrology, etc.). On the other hand, the cost of thermal generation varies in a non-linear way with the demand to be met, since the plants are dispatched based on the increasing order of operating cost (for example, natural gas generation capacity - cheaper - is used before more expensive oil thermal plants). Because of this non-linearity, the thermal cost of supplying the average demand is lower than the resulting cost of, for example, supplying the demand in case it is represented by blocks of similar hours (such as peak consumption, off-peak load period and others).

Up to the current version of SDDP, the user could represent different operating conditions throughout each stage (weekly or monthly) by aggregating the hours in up to 21 “clusters”, or *blocks* of hours (which in weekly cases results in up to 3 blocks per day). These load blocks allowed to capture, in an approximated way, the effect of non-linearities inherent to the stages. This non-chronological aggregation of hours to represent different operating conditions are also known as the *Load Duration Curve* representation.

³ For example, monthly stages are adequate for Brazil due to the large regulation capacity of the reservoirs. However, the regulation determines that the prices for the wholesale market must be calculated every week.

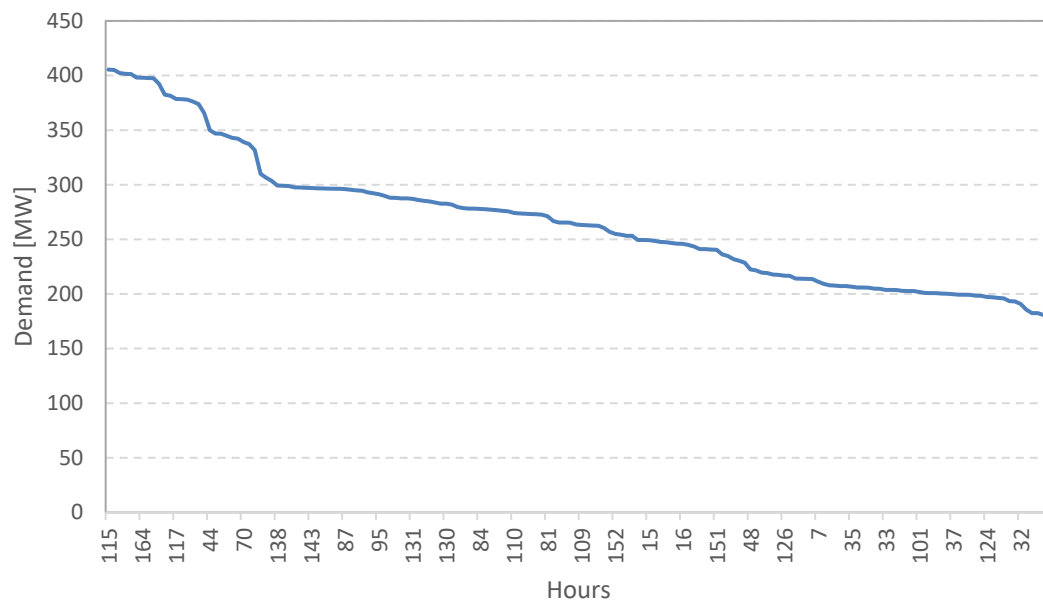
22.1.1 Block representation

The procedure for creating the blocks will be illustrated below for a representation in weekly stages. In this example, the goal is to represent the demand in blocks, although the same methodology can be applied to any data with hourly resolution. The procedure initially considers the chronological hourly demand data, illustrated in the following figure.

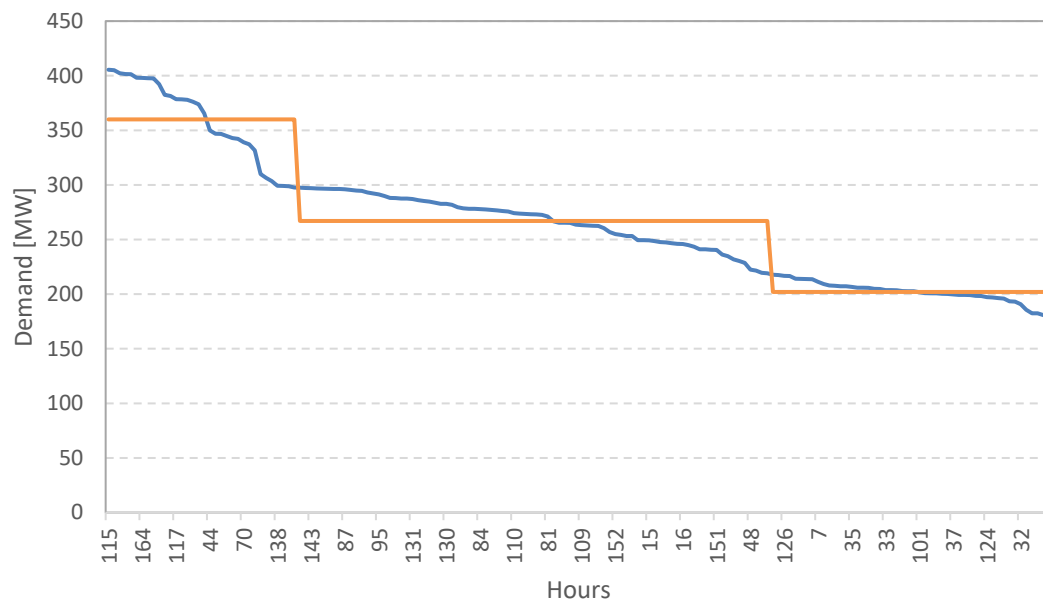


We can observe in the figure that the hourly data has seven cycles, which correspond to the days of the week. It is also observed that the first two cycles are different (and with lower demand) than the other five, since they correspond to Saturday and Sunday (if there was a holiday in the middle of the week, it would have a similar daily profile to Sunday).

The next step is to sort the 168 hours demand values in descending order as shown in the following figure.



The non-chronological demand curve in descending order is also known as the *Load Duration Curve*. This ordering facilitates the aggregation of similar consumption levels in blocks, as the following figure illustrates.



In general, the load block curve adjustment procedure aims to minimize the sum of the differences (absolute or quadratic) between the average demand of each block and hourly demands. Additionally, it is important to preserve the total energy amount in the stage. In the example presented above, this means that average demand (in MW) of each block times the respective duration (in hours) must be equal to the sum (in MWh) of the 168 hourly demands.

In more complex cases, the blocks are usually constructed based on multivariate cluster analysis algorithms such as the *k-means*. For instance, this approach might be important in cases with two countries with different demand patterns or systems with strong renewable penetration.

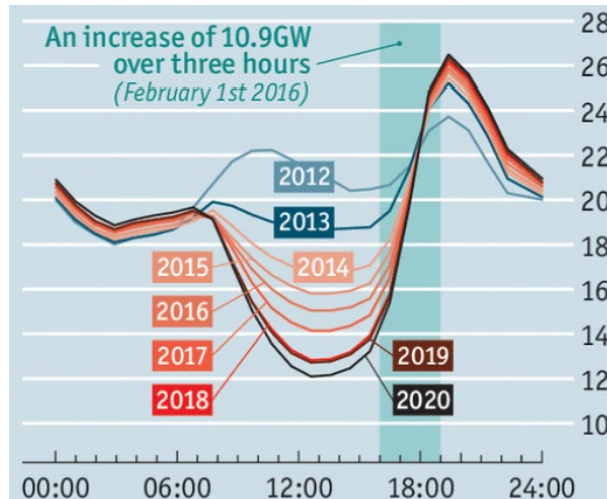
It is straightforward to observe that the larger the number of blocks, the better the load curve will be represented. The choice of the number of blocks to be used depends basically on the commitment relationship between precision and computational effort (which increases non-linearly with the number of blocks).

22.1.2 Motivation: representation of wind generation and other intermittent renewable sources

The increasing economic competitiveness of wind, biomass and solar generation sources has attracted worldwide a great deal of attention. These energy resources not only reduce greenhouse gas emissions, but also reduces countries' vulnerability to import fossil fuels (particularly, oil and natural gas).

However, the fast penetration of these new sources has also raised some concerns for both planners and operators for two main reasons: (i) most of these sources are non-dispatchable, i.e., their generation cannot be controlled by the system operator; and (ii) their energy production presents strong *volatility*, i.e., the production can change significantly from one hour to the next.

To exemplify the challenges of system operators with the high penetration of intermittent renewable sources, the following figure illustrates the curves of California's net demand (demand minus intermittent renewable generation) in the past and expected in the future:



As can be seen, the penetration of intermittent renewable sources ends up causing representative impacts on the net demand profile. In addition to the change in the profile, it is worth noting the raise of the decrease/increase net demand ramps and their respective inclinations with the greater renewable penetration. These impacts lead to new operational challenges, which stand out:

- **Over-supply situations:** periods when the renewable generation is higher than the demand to be met (this occurs especially in the middle of the night in regions with strong night winds);
- **Fast upward and downward ramps:** dispatchable plants must have the ability to fast respond to the increase and decrease of intermittent renewable generation to maintain supply reliability and system stability;
- **Increasing thermal cycling:** possible increase in the number of startups and shut-downs of thermal plants in the system due to renewable generation intermittency.

Due to the aforementioned reasons, interest arose in a more detailed representation of the operation throughout each stage. To meet this interest, the new version of SDDP allows the use of a chronological hourly representation of each stage operation.

22.1.3 Hourly representation

When the hourly representation is activated, the optimization problems solved will explicitly be defined with hourly resolution. This means that the number of variables and constraints are proportional to the number of hours at each stage. **This representation can significantly increase the computational effort required to solve the optimization problems with hourly granularity when compared to the block representation at each stage.** Additionally, the volume of output results is also significantly larger. Therefore, a careful analysis of the user's need of increasing granularity is suggested, which should mainly be based on the objectives of the executions and the effects that are desired to be captured.

Solving these hourly problems efficiently was a challenging task that required the development of new algorithms and procedures to ensure the solution quality while keeping the computational times acceptable. Even so, if any problems or high execution times associated to the hourly representation occur the user are recommended to contact PSR at sddp@psr-inc.com immediately.

22.2 First Steps

22.2.1 Data definition

In theory, it would be possible to allow all input data to be informed in hourly resolution for the entire study horizon. However, since SDDP is a mid and long-term dispatch tool, many of these data have a low frequency of variation and their representation on a weekly or monthly basis is suitable. Even in the case of a higher variation frequency it is possible to identify standardized variation profiles over a stage. Therefore, an hourly representation for all data, besides being unnecessary, would require a large volume of input data that might not be available.

In this way, a flexible approach was adopted so that only a few additional input data is required to obtain results with hourly representation. Through the hour-block mapping table described below, it is possible to re-create the chronology of each stage by associating the

values of the corresponding block to each hour. This approach is very flexible because it allows an existing

SDDP database to be easily used as a starting point for obtaining results with hourly detailing⁴. Besides, it's worth to highlight that it is possible to refine the model to the most relevant quantities by adding hourly input data (such as hourly demand, intermittent renewable generation scenarios, etc.), which will be used instead of data mapped from data defined by blocks.

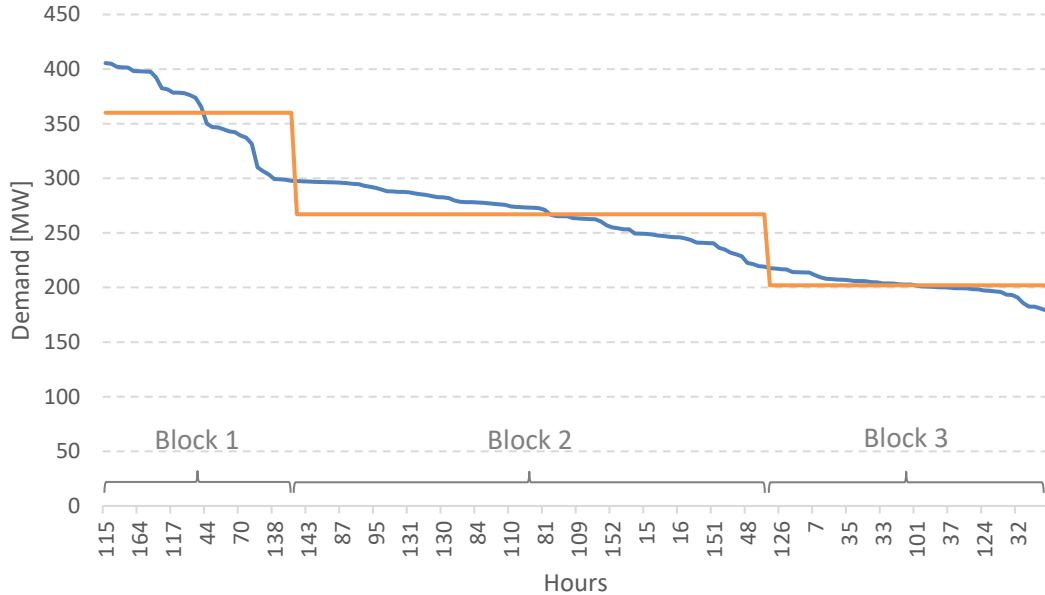
In this context, data per block are treated as different data configurations (or *clusters*) within each stage. In other words, up to 21 different data sets can be defined for each stage and this data will be used to automatically recreate the chronological hourly representation within each stage, once an hour-block mapping is defined.

22.2.2 Hour-block mapping

The [process of creating the load curve by blocks](#), also known as *clusterization*, generates two direct results:

- Average demand per block, and
- Duration of each block (in hours).

In addition, one byproduct of the clustering process is the association, or *mapping*, between the hours and the blocks, as shown in the following figure.



⁴ In addition to the advantage of enabling the usage of existing SDDP databases as a starting point for hourly runs, in general detailed data related to additional chronological constraints are not available for medium and long-term horizons, differently from the datasets that are available for the detailed short-term operating model (NCP).

Thus, it is also possible to extract from this process a table of correspondence, as exemplified below:

DAY	HOUR											
	00h	01h	02h	03h	04h	...	18h	19h	20h	21h	22h	23h
1	2	3	3	3	3	...	1	1	1	1	2	2
2	2	3	3	3	3	...	1	1	1	1	2	2
3	3	3	3	3	3	...	1	1	1	1	2	2
4	3	3	3	3	3	...	1	1	1	1	2	2
5	3	3	3	3	3	...	1	1	1	1	2	2
6	3	3	3	3	3	...	1	1	1	1	2	2
7	2	3	3	3	3	...	1	1	1	1	2	2

In this table, for each hour of the week it is indicated which is the corresponding block.

22.2.2.1 Calculation of the duration of the blocks from the hour-block mapping table

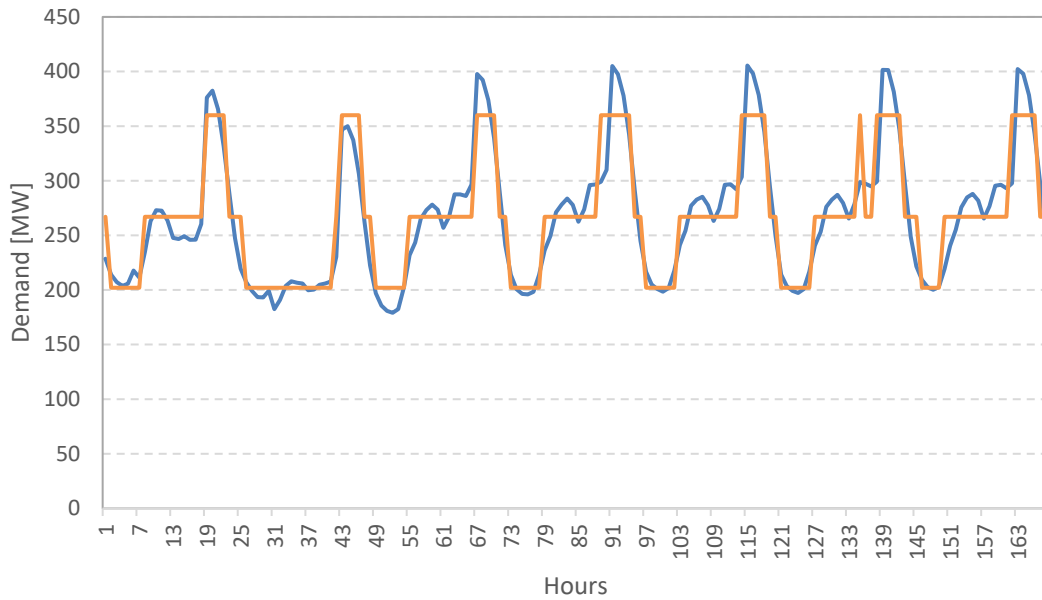
The hour-block mapping table also implicitly defines the duration of the blocks in each week/month. The duration of each block is calculated by counting the number of hours associated with each block. Therefore, when the hour-block mapping data is used, the original data of *fixed duration* and *variable duration of the blocks* will be disregarded.

22.2.3 Creating hourly data series from block data by using the hour-block mapping

Suppose that, initially, the hour-block mapping data is informed, as in the previous table, and the demand by block data, as shown in the table below:

Block	Duration (hours)	Demand (GWh)	Demand (MW)
1	34	12.2	360
2	84	22.4	267
3	50	10.1	202

Based on this information, SDDP will automatically transform the input data to recreate an hourly approximation of the input data, as shown in the figure below. Hereafter, the values of each hour obtained from this hourly data series will be used as input data for the optimization problem that will be solved at each stage.



As previous mentioned, the quality of the approximation is directly related to the definition of the blocks, as well as the computational effort involved in the solution process.

The procedure described above is applied to all input data that varies by blocks to obtain hourly data.

22.3 Input Data

The resolution of the input data defined is *independent* of the resolution selected for the study execution, by block or hourly. In other words, the user has the flexibility to define the data as desired and the model can transform the input data informed according to the resolution of the study:

- For studies that consider block representation:
 - **Data defined per block:** are directly used to build the optimization problem with block resolution;
 - **Hourly data:** are automatically aggregated into blocks using the user-defined hour-block mapping. Finally, the data aggregated in blocks are used to build the optimization problem with block resolution. For this reason, if the user wants to use hourly data, it is also necessary to inform the hour-block mapping data.
- For studies that consider hourly representation:
 - **Data defined per block:** are automatically mapped in the hours using the hour-block mapping to obtain hourly data from the block data. Finally, these hourly chronological data are used to build the optimization problem with hourly resolution;

- **Hourly data:** are directly used in the assembly of the optimization problem with hourly resolution;

Additionally, it is worth noting that data only need to be informed for the selected resolution. For example, if the user chooses to inform hourly demand data, the demand by block data definition is not needed. The same applies to the renewable generation scenarios.

As previously highlighted, some input data will still be informed with block resolution and, due to this fact, the hour-block mapping must be informed for all studies that consider hourly representation.

22.3.1 Input data resolution

Before executing the model, the user must select the desired resolution for each data type. This selection must be defined in the “Execution options > Economic dispatch > Data resolution” screen.

The following data and their respective available options are:

- Hour-block mapping:
 - Do not consider
 - Per hour: annual profile
 - Per hour: detailed
- Demand (Energy):
 - Per block: detailed
 - Per hour: detailed
- Demand (Price):
 - Per block: detailed
 - Per hour: detailed
- Renewable station:
 - Per block: annual profile
 - Per block: detailed
 - Per hour: annual profile
 - Per hour: detailed
- Power injection (Capacity):
 - Per block: detailed
 - Per hour: detailed
- Power injection (Price):
 - Per block: detailed
 - Per hour: detailed

Two types of hourly data definition are available:

- **Annual profile:** must be informed for all hours of all stages (months or weeks) of a typical year. This pattern allows the representation of seasonality over a year and is periodically repeated throughout the study horizon;

- **Detailed data:** must be informed for all hours of all stages of the study horizon.

All other input data which may vary within each stage, shall be informed per block.

22.3.2 Hour-block mapping data

The primary purpose of the [hour-block mapping](#) data is to establish the relationship between the hours and blocks in each stage. Thus, these data are optional in the case of studies with block representation and mandatory in case studies with hourly representation.

Although studies with block resolution do not represent hours individually in the optimization problem formulation, the hour-block mapping data can be used to [obtain the duration of the blocks](#) (instead of using the *fixed duration* or the *variable duration of the blocks*).

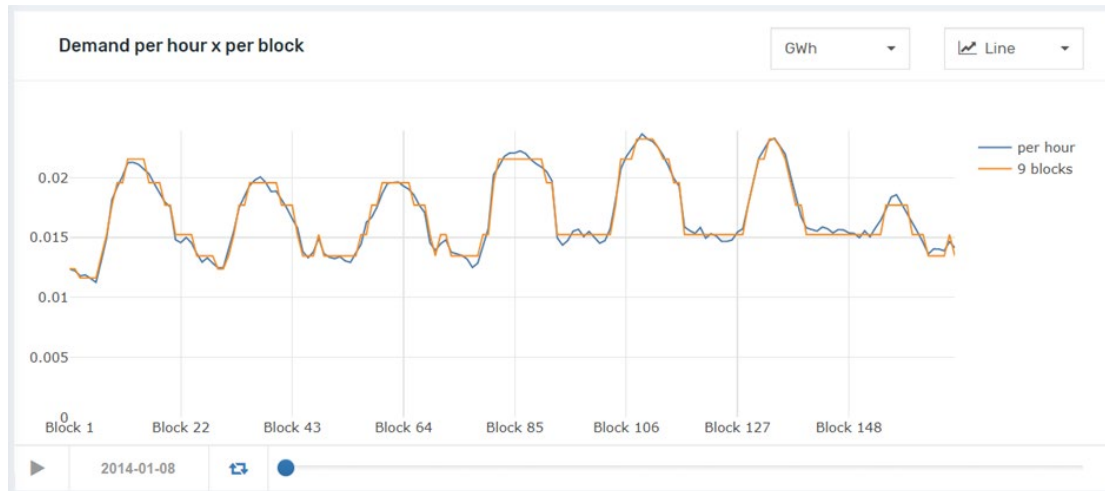
On the other side, in studies with hourly resolution, the mapping data is used to [reconstruct the hourly chronology](#) of the data that are informed by block.

22.3.3 Integrated clustering tools

There are two tools integrated into SDDP related to the hour-block mapping:

- Block representation:** this feature helps from scratch or replaces the hour-block mapping for the selected number of blocks, if there already exists an hour-block mapping defined in the database. It is accessed on “Execution options > Clustering > Block representation.”
- Hour-block remap:** this feature helps create a new hour-block mapping for a different (desired) number of blocks. For example, it is possible to have data defined for 5 blocks and run the model for 15 blocks, which can be chronological or not. It is enabled by simply activating the option “Stage resolution > Use a different number of blocks > Hour-block remap” option in the “Economic dispatch > Horizon & resolution” screen. SDDP will run the case with the desired (different) number of blocks without any additional information. The remapping tool is accessed on “Execution options > Clustering > Hour-block remap.”

Both options take the hourly demand data already defined in the SDDP database as input data and use a multivariate cluster analysis algorithm called *k-means* to create the blocks. The objective is to minimize approximation errors for the user-defined number of blocks while assigning (“clustering”) the hours into the blocks, as in the example shown below:



It is worth remembering that the hour-block mapping must be unique for the entire database. Now, imagine that you have two systems defined in the database and system 1 has a demand much bigger than the other one. If the user does not activate the "Normalize data" option, the demand of system 1 will be much more representative while calculating the hour-block mapping than the demand of system 2. In other words, the size of each demand will reflect its representativeness on the "total" demand that will be used to assess the hour-block mapping. On the other hand, if you activate the "Normalize data" option, the demands of systems 1 and 2 will be first normalized in a separate way and after that they will be used to calculate the hour-block mapping. As a consequence, both demands will have the same representativeness on the hour-block mapping assessment.

Additionally, if the user does not activate the "Peak" and/or "Off-peak" options, all blocks will be automatically calculated by the algorithm. On the other hand, if the user activates the "Peak" option and sets the "Number of blocks" equal to 1, for example, the "Peak" block won't be calculated, it will be arbitrarily defined by the user. In this case, all values above the threshold will be in block 1. So, if the Threshold is equal to 0.02 p.u., the model will take the 2% highest demand values and assign them to the peak load block. If the user sets the "Number of blocks" equal to 2, then, the first two blocks will be arbitrarily defined by the user based on the threshold value.

The same behavior is valid for the "Off-peak" option, i.e., if the user activates the "Off-peak" option, sets the "Number of blocks" equal to 1 and the "Threshold" equal to 0.02 p.u., the model will take the 2% lowest demand values and assign them to the off-peak load block.

22.3.4 Hourly demand data

Optionally, the demand data can be informed in hourly resolution. These data are provided through the graphical interface in "Basic data > Load > Demand configuration", option "Resolution: Hourly". Data can also be imported/exported to Excel via CSV (comma-separated) files.

22.3.5 Hourly scenarios for the generation of renewable sources

Optionally, scenarios for the generation of renewable sources can be informed on an hourly basis. These data should be informed through the graphical interface in “Basic Data > Renewable source > Renewable station scenarios”, option “Resolution: Hourly”. Data can also be imported/exported to Excel via CSV (comma-separated) files.

22.3.6 Operating constraints of thermal plants

One of the main motivations for performing hourly executions is to capture chronological effects not seen in executions with block representation. In this case, users will have the option of representing thermal operational chronological constraints, such as: ramp-up/down, minimum up/downtime, maximum number of start-ups/shutdowns and so on. These data can be informed through the graphical interface in “Complementary data > Thermal plants > Operating constraints”. Data can also be imported/exported to Excel via CSV (comma-separated) files.

22.3.7 Operating constraints of hydro plants

Users will also have the option of representing hydro operational chronological constraints, such as: water travel time for turbinizing/spilling, outflow ramp-up/down and ramp-up/down (in MW/min). These data can be informed through the graphical interface in “Complementary data > Hydro plants > Operating constraints”. Data can also be imported/exported to Excel via CSV (comma-separated) files.

22.3.8 Study options

The default option for the economic dispatch is the aggregated representation by blocks, where the operational decisions within each stage (week or month) are made taking into consideration a representation of up to 21 blocks of hours.

To activate the chronological hourly representation, after defining the hour-block mapping and choosing the data resolution to be used as previously explained, the option “Hourly representation” must be activated in the “Execution options > Economic dispatch > Horizon & resolution” screen.

After the completion of each hourly execution, it is very important to check the heatmap called “[Execution status per stage and scenario](#)” that is available in the SDDP Dashboard.

22.4 Execution parameters for the hourly run

The execution parameters for the hourly run are defined on the “Execution options > Economic dispatch > Hourly parameters” screen.

22.4.1 System representation

22.4.1.1 Operative constraints

- Terminal function:
 - FCF + Target Storage: at each stage (monthly/weekly), before the hourly run, SDDP solves the problem with block resolution and determines target storage values for the end of each stage that will be used as a guide curve during the hourly simulation. The future cost function (FCF) calculated in the policy phase is also considered at the end of each stage for the regularization reservoirs so that the model can evaluate the best trajectory throughout the month/week based on economic criteria (future value of water) together with the target storage values. The target storage values are applied to hydroelectric reservoirs, fuel contracts, fuel reservoirs and gas emission volumes.
 - FCF: only the FCF is considered.
 - Target storage: only target storage values are considered.
- Non-controllable spillage representation [Yes/No]: the non-controllable spillage constraints for hydroelectric plants will be created or not, through the considered option. This is a constraint that strongly impacts the convergence of optimization problems, and therefore we recommend that it is used sparingly.
- Operative state of combined cycle [Optimized/User-defined]: the hourly representation can optimize the operative state of the combined cycle, i.e., which configuration should dispatch in each hour. In the "User-defined" option, the model will use the configuration selected at each stage in the "Complementary data > Thermal plants > Operative state of combined cycle" screen.
- Initial storage type [Optimized/User-defined]: the hourly representation can optimize which is the initial storage value for each battery in the case, since these components represent constraints of the type "Initial volume = final volume" within each regulation time window. Therefore, the definition of the initial condition is a very important issue for the optimization of the intra-stage operating cycles of the batteries. All of the above is also valid for hydrogen and electrification storage devices. By default, the "optimized" option is selected, since the initial storage of the cycle (which will be equal to the final at the end of the regulation time) will be defined by the optimization itself. This is interesting because we are not "limiting" or introducing a constraint that "forces" a given initial storage value, leaving the model free to define this storage value according to the optimization process and the system conditions, since in the long term there is no way to know precisely what level of storage the battery will have to start the day. As can be seen, the definition of the initial storage of the battery by the user can lead to suboptimal operation during the regulation cycle, however, we leave this option available to the user if he wishes to use it (either due to knowledge of the system or for any other reason, such as a regulatory issue).

22.4.1.2 Secondary reserve

- Joint reserve type [Upward/Downward/Upward and Downward]: the assignment of the secondary reserve to the power plants can be defined in these three ways in the hourly representation. The standard case is the allocation of secondary reserve only for production increase, but this can be changed according to this option. By selecting the “Upward and Downward” option, the model imposes symmetric reserve allocations in both directions.

22.4.1.3 Electric network

- Circuit loading limit for monitoring: this option is used only in the representation of the electrical network with the compact model (section 8.2.4 of the methodology manual). Only the circuits that reached, in the previous simulation (with block resolution), the threshold defined by the user in this field, are represented in the optimization problem with hourly granularity. This is an option that aims to reduce the size of the hourly optimization problem to avoid creating numerous hourly constraints for circuits whose loading has not reached the user-defined threshold value in the execution with block resolution.
- Sum of circuit flow constraints [Only active constraints/All]: starting from the same explanation as in the previous item, the sum of circuit flow constraints that did not reach the maximum limits in the previous simulation (with blocks) are not taken to the hourly model. When selecting "All", the hourly model will create all flow sum constraints for all hours of the stage, regardless of whether they are active or not in the previous simulation (with blocks).

22.4.2 Solution strategy

22.4.2.1 Initial status

- Chronology representation of operating constraints between stages (reading the initial conditions): the chronology between stages (month/week) of the operative constraints (travel times, ramps, minimum uptimes) can be considered or not in planning studies. By activating this option, the model will automatically generate the final conditions (water in transit, generation, unit commitment decisions) in each stage that will be used as initial conditions of the next stage, so that the constraints maintain the chronological link during the whole horizon.
- Represent water travel time initial condition in the first stage [Yes/No]: since it is not possible to define the initial condition of the water in transit for the first stage of the horizon, the model can create specific constraints that emulate this behavior in each scenario of the first stage of the horizon. If this option is active, SDDP will calculate the water travel time in the first hours of the study considering that the turbined outflows of each hydroelectric plant in the hours prior to the start of the study are equal to the values in the last hours of the first stage.
- Preserve storage chronology in the transition between stages: if this option is activated, the initial storage values (of water reservoirs, fuel contracts, fuel reservoirs and gas emission volumes) of each stage (month/week) will be equal to the final storage values of the

previous stage calculated by the SDDP with hourly resolution, thus ensuring the chronology between stages. Otherwise, the previous simulation of the model with block resolution will determine the initial condition of each stage of the study horizon during the hourly simulation. The chronology in this second case is preserved through the previously mentioned target storage constraints.

22.4.2.2 *Intra-stage representation*

- Decompose stages in slices [Yes/No]: the monthly stages are automatically divided into weekly sub-stages (168 hours), so that the optimization problem with hourly granularity is not so complex from the point of view related to the number of variables/constraints involved in each problem. Instead of solving a single problem with more than 700 hours, this option breaks down the problem into sub-stages that are easier to be solved. Associated with this topic is the definition of the duration of the sub-stages, where for some large systems, the decomposition into daily sub-stages (24 hours) is necessary to obtain more reasonable execution times.
- Preserve ramp constraints in the transition between slices [Yes/No]: ramp constraints can become a problem in the decomposition of stages into sub-stages, since they are hard constraints (without a slack variable) and can be a factor of infeasibility during transitions between sub-stages. This can occur in significant changes in the renewable generation and demand scenarios along the horizon together with very restrictive ramp values.

22.4.2.3 *Optimization parameters*

- Represent binary variables [Yes/No]: the dispatch with unit commitment of thermal power plants, as well as the operating constraints of minimum uptimes, require this option to be enabled. Otherwise, these constraints will not be created by the model with hourly representation.
- MIP relative tolerance (p.u.): the model converges when the difference between the best solution found and an upper bound is less than the defined relative tolerance. The standard value is 0.005 p.u. (0.5%).
- MIP maximum execution time (seconds): if a solution with a convergence gap smaller than the relative tolerance of the MIP is not found in the maximum time defined, the model presents the best solution found so far. The maximum execution time of the MIP is a value defined by the user that will be applied for each stage (month/week) of the planning horizon and will be considered proportionally to the duration of the sub-stages, if this option is enabled.

22.5 Results

22.5.1 Heatmap of the execution status per stage and scenario

Some of the underlying MIP optimization problems solved by SDDP may require substantial computational effort, especially those related to the hourly representation. To get a better overview of the trade-off between solution quality x computational effort, there is a heatmap called “Execution Status per stage and scenario” in the SDDP Dashboard. In this graphic, the

status of the problem solved in each stage and scenario is illustrated in a heatmap, according to the following color scheme:

- **Green (success):** optimization problem successfully solved.
- **Yellow (warning):** the maximum CPU time has been reached and the feasible solution found exceeds the MIP convergence tolerance.
- **Red (error):** no feasible solution found the within maximum CPU time.

It is very important to review this heatmap after the hourly runs. In warning and error situations, the initial recommendation is to increase the maximum execution time of each MIP to see if the model, with more time, manages to find the optimal solution for these optimization problems (or at least a feasible solution for problems of certain stages/scenarios that are colored in red).

22.5.2 The GRAPH module

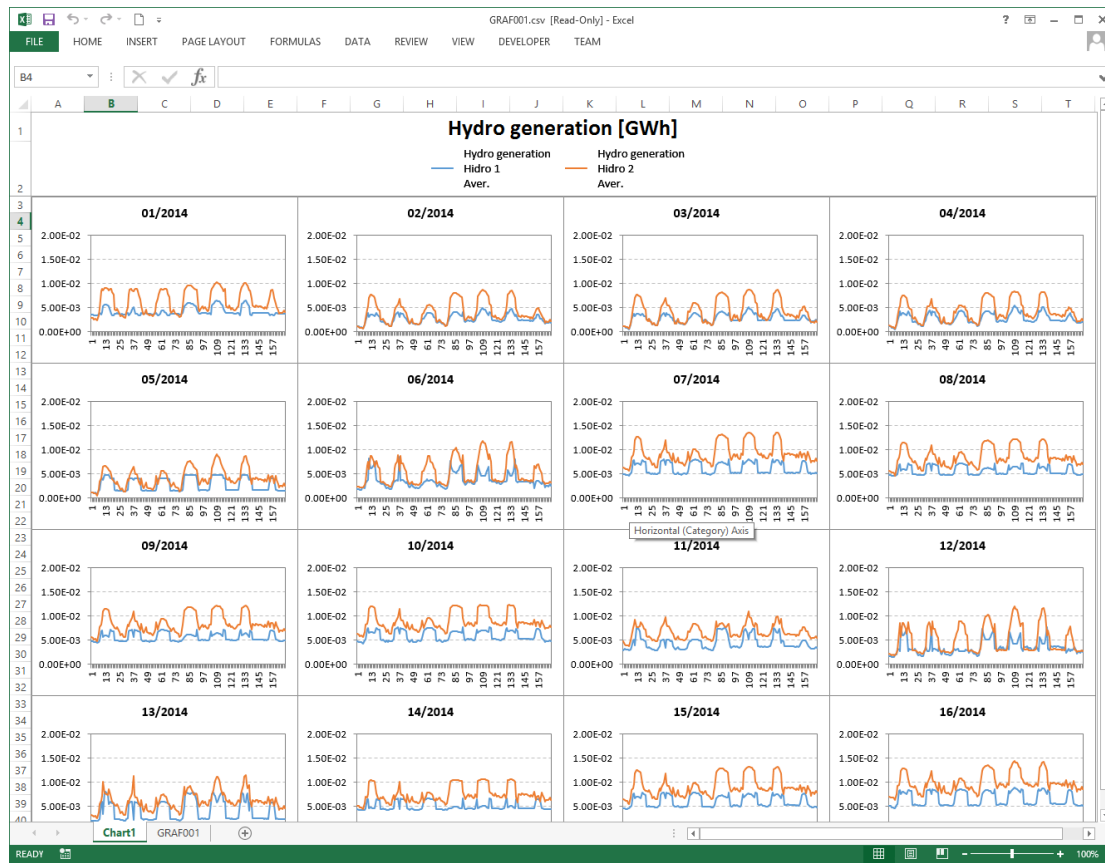
With the hourly representation, all SDDP results that vary by stage will be available for all hours of each stage of the study horizon. The GRAPH module has been extended to handle hourly results. Instead of the traditional selection of blocks, the results will be printed on an hourly basis.

For more details about the GRAPH, please check the following chapter: [The GRAPH module](#).

22.5.2.1 New graphic options

The chart options have been redesigned and a new chart option has been added to make it easier to view the results on an hourly basis. The generated worksheet will be the same, however, for each new prepared graph, one of the three options may be selected:

- Do not generate chart, only table: the worksheet with consolidated results will be generated in CSV format, opened in Excel and no graph will be created for visualization;
- Default: the worksheet with consolidated results will be generated in CSV format, opened in Excel and a single graph will be created that consolidates the visualization of all generated results.
- By stage: the worksheet with consolidated results will be generated in CSV format, opened in Excel and a spreadsheet with a graphic matrix will be created, one for each selected stage. The purpose of this chart is to allow the overview of the hourly results for the whole horizon of interest by organizing the results by stage, as exemplified in the following figure.



23 OUTPUT FILES FOR HOURLY REPRESENTATION

23.1 Overview

Solving stochastic dispatch model in hour granularity is a challenging task due to the increase of the problem complexity, which requires new algorithms to keep the resolution time acceptable. Moreover, the large volume of output results can create I/O bottlenecks and, in some cases, dramatically affect the performance of the execution.

PSR performed several internal tests that pointed out that execution time of cases with large volume of output files, such as cases with hourly representation and some cases with large number of blocks, might have the final simulation⁵ times up to 10x faster when using BINARY instead of standard CSV output format.

Apart from this potential execution time reduction, the hard disk size required to save the results in the binary format is approximately 3x smaller when compared to the CSV output format. This becomes relevant since the volume of the hourly representation results is much larger when compared to the block representation.

The GRAPH module has been extended since version 14 and it works flawlessly, regardless of the selected format for the output files.

Due to the aforementioned reasons, the CSV output format has been discontinued for cases with hourly representation and then binary output format must be used instead.

Nevertheless, it will still be possible to obtain CSV output files from the binary results, as described in the next section.

23.2 Generating CSV files from binary output formatted files

There are two alternatives to convert binary into the standard CSV formatted files:

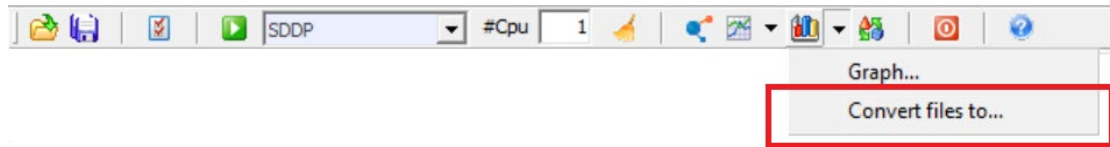
- via graphical interface;
- via command line tool.

In both process mentioned above, it is possible to convert only the files of interest and keep the rest of the output files in the original binary format. The conversion process creates extra CSV files in the data directory. The GRAPH module will always use the original (binary or CSV) files generated in the SDDP execution, regardless if the converted files are also present in the data directory.

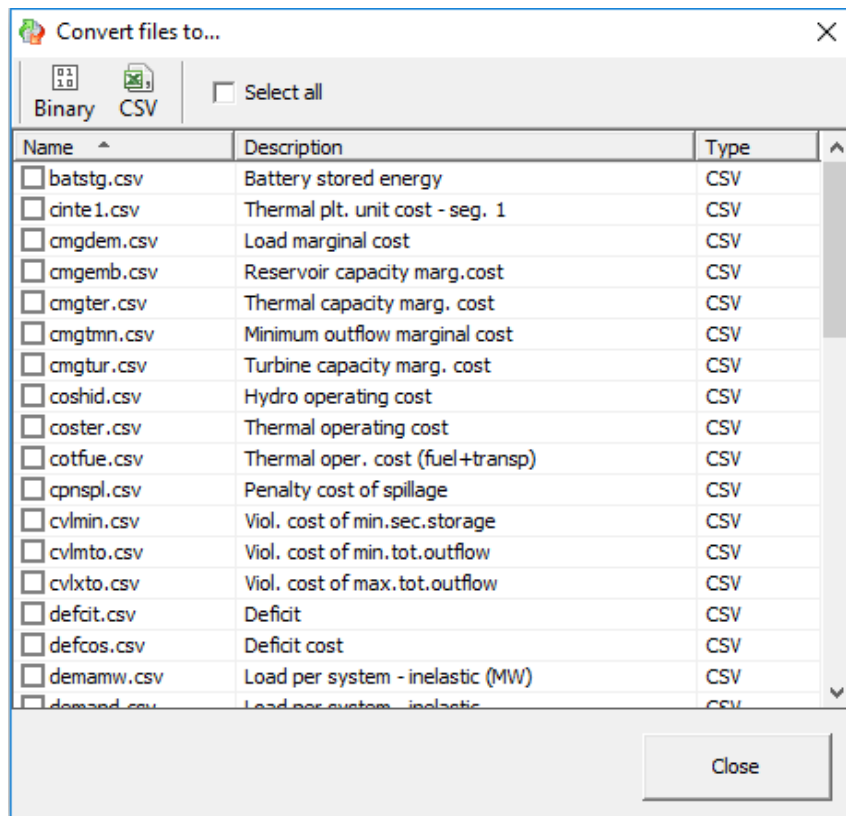
⁵ The final simulation is performed after the operation policy and it is the solution phase in which SDDP writes all the statistics to the output files.

23.2.1 Conversion process via graphical interface

There is a new “Convert files to...” button in SDDP interface screen that can be accessed from the toolbar, as shown below:



This tool allows the conversion of the selected output files from binary to csv format (for cases that generated outputs in binary format) or from CSV to binary (for cases that generated outputs in binary).



This process must be done after the execution of each case.

23.2.2 Conversion process via command line

The converter is a command line tool called `BIN2CSV.EXE` that is located at the `Oper` folder in SDDP installation directory. This tool provides the functionality of converting a single file of all output files at once from binary to CSV format and vice-versa.

If the tool is called from command line without arguments, it will show the available options:

```

C:\WINDOWS\system32\cmd.exe
Microsoft Windows [Version 10.0.15063]
(c) 2017 Microsoft Corporation. All rights reserved.

C:\>cd C:\PSR\Sddp15Beta\Oper

C:\PSR\Sddp15Beta\Oper>bin2csv.exe
BIN2CSV - version 1.5 (90f6e21-win32-intel15-release)

Converts SDDP output files in binary format (hdr/bin)
to csv format

Usage:

bin2csv [OPTIONS] -file <full filename without extension>
bin2csv [OPTIONS] -path <path containing indice.grf file>

Options
  -bin          convert CSV to HDR/BIN format
  -path_out <PATH> Optional path for output files
                  If not informed, output will be created in the input path
  -csv-as-dat   use DAT extension when converting from HDR/BIN to CSV
  -v            increase verbosity to print debug information
  -help         shows this help

Remarks:
  Use simple quotes at the beginning and ending of filenames/paths with spaces

Report bugs to <sddp@psr-inc.com>

C:\PSR\Sddp15Beta\Oper>

```

23.2.2.1 Converting a single file

For example, to convert the “Load marginal cost” output of the “Example” case from binary to CSV format the converter must be executed from command line with the following syntax:

```
bin2csv.exe -file C:\PSR\Sddp15.0\Example\cmgdem
```

and the output of the tool shows:

```

BIN2CSV - version 1.5 (90f6e21-win32-intel15-release)

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15.0\Example\cmgdem.hdr
  Input : C:\PSR\Sddp15.0\Example\cmgdem.bin
  Output: C:\PSR\Sddp15.0\Example\cmgdem.csv

Done!

```

23.2.2.2 Converting all output files

To convert all output generated in the “Example” case from binary to CSV format the converter must be executed from command line with the following syntax:

```
bin2csv.exe -path C:\PSR\Sddp15.0\Example
```

and the output of the tool shows:

```

BIN2CSV - version 1.5 (90f6e21-win32-intel15-release)

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15.0\Example\inflow.hdr
  Input : C:\PSR\Sddp15.0\Example\inflow.bin
  Output: C:\PSR\Sddp15.0\Example\inflow.csv

(...)

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15.0\Example\gerhid.hdr
  Input : C:\PSR\Sddp15.0\Example\gerhid.bin
  Output: C:\PSR\Sddp15.0\Example\gerhid.csv

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15.0\Example\gerter.hdr
  Input : C:\PSR\Sddp15.0\Example\gerter.bin
  Output: C:\PSR\Sddp15.0\Example\gerter.csv

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15.0\Example\cmgdem.hdr
  Input : C:\PSR\Sddp15.0\Example\cmgdem.bin
  Output: C:\PSR\Sddp15.0\Example\cmgdem.csv

Converting from HDR/BIN to CSV:
  Input : C:\PSR\Sddp15Beta\Example\duraci.hdr
  Input : C:\PSR\Sddp15Beta\Example\duraci.bin
  Output: C:\PSR\Sddp15Beta\Example\duraci.csv

(...)

Done!

```

23.2.3 Automated process via *post-run* hook

The post-run hook is a general scheme to trigger custom scripts after the successful execution of a case occurs. To enable the post-run hook script, it is necessary to put a file called `post-run.bat` in the `Oper` folder in SDDP installation directory. After a successful execution occurs, this script is called and the directory of the case is passed as argument to it.

There is a template script file called `post-run.sample` in the `Oper` folder in SDDP installation directory that can be copied and renamed to `post-run.bat` to enable the user-defined script.

```

:: An example hook script that is called after a successful
:: run is made.
::
:: To enable this hook, rename this file to "post-run.bat".

:: -----
:: Main parameters
:: -----
SET PATH_DATA=%~f1
SHIFT

:: -----
:: User-defined action
:: -----

:: example.exe %PATH_DATA%

```

post-run.sample script

This scheme can be used to automate the execution of any process after SDDP. For example, we will describe in the next sections how to automate the execution of the GRAPH module and the BIN2CSV conversion process.

23.2.3.1 Automating the execution of the GRAPH module

To automate the execution of the GRAPH module after the execution of SDDP, it is necessary to open the GRAPH module, define the graphics of interest and select them to be created. This definition will be saved to the `instruc.grf` file that will be input to the GRAPH module to generate the statistics files automatically.

Additionally, the following script must be defined in order to automate the execution of the GRAPH module:

```

:: An example hook script that is called after a successful
:: run is made.
::
:: To enable this hook, rename this file to "post-run.bat".

:: -----
:: Main parameters
:: -----
SET PATH_DATA=%~f1
SHIFT

:: -----
:: Running GRAPH module
:: -----
IF EXIST "%PATH_DATA%\instruc.grf" (
    ECHO -----
    ECHO Running Graph...
    ECHO -----
    CALL graf.exe
    ECHO.
)

```

post-run.bat script to automate the GRAPH module execution

23.2.3.2 Automating the execution of the conversion tool

To automate the execution of the BIN2CSV conversion tool after the execution of SDDP, it is necessary to define in the `post-run.bat` script many calls to the conversion tool as desired, accordingly to the files needed to be converted.

```

:: An example hook script that is called after a successful
:: run is made.
::
:: To enable this hook, rename this file to "post-run.bat".

:: -----
:: Main parameters
:: -----
SET PATH_DATA=%~f1
SHIFT

:: -----
:: Running BIN2CSV conversion tool
:: -----
ECHO -----
ECHO Converting files to CSV format
ECHO -----
bin2csv.exe -file %PATH_DATA%\cmgdem
bin2csv.exe -file %PATH_DATA%\gerter
bin2csv.exe -file %PATH_DATA%\gerhid

```

post-run.bat script to automate the conversion of binary files to CSV

In the example above, the “Load marginal cost”, “Thermal generation” and “Hydro generation” binary files are converted to CSV format automatically after the execution of SDDP.

24 ROLLING HORIZON STRATEGY

The trade-off between the immediate benefits of generating more hydro energy today by emptying the reservoirs; and the expected increase of future costs because less hydro energy is transferred to the following stages is at the core of the SDDP algorithm. One interesting question related to this trade-off is: how far into the future are operating costs affected by today's scheduling decision? It is intuitive to see that this "horizon of influence" depends on the system's storage capacity. Most systems have seasonal storage, which means that their scheduling decision does not impact next year's operation. Some systems have yearly storage, which translates into a horizon of influence of an additional year. And a few systems have multi-year storage, with corresponding horizons of influence around three years.

The "Rolling Horizon" (RH) strategy consists of partitioning the study horizon and calculating the system operation policy for each of the sub-horizons in a chained fashion. This means that an SDDP study for a long planning horizon, e.g., 15 years, can be carried out by an RH scheme: first run for years 1-5 (three "true" years, plus two for end-of-period buffer); then for years 4-8 (using as initial storage for January of year 4 the set of final storages at the end of December of year 3); for years 7-11; and so on.

What are the advantages of using this RH scheme? The most significant benefit is to ensure that the short-run marginal costs and other results for the later years are as accurate as those for the first years.

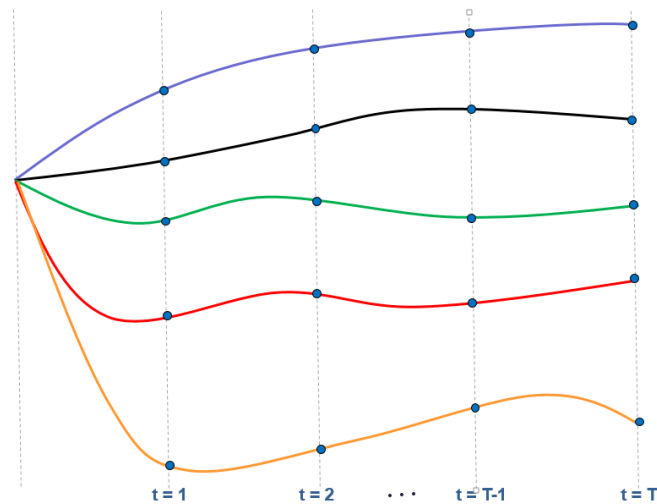
Given this benefit of the RH scheme, the next question is: will the total execution time increase? According to empirical tests involving many systems with different storage capacities and generation mixes, the answer is: the total execution time with the HR application is likely to be the same or even less.

25 PARALLEL EXECUTION

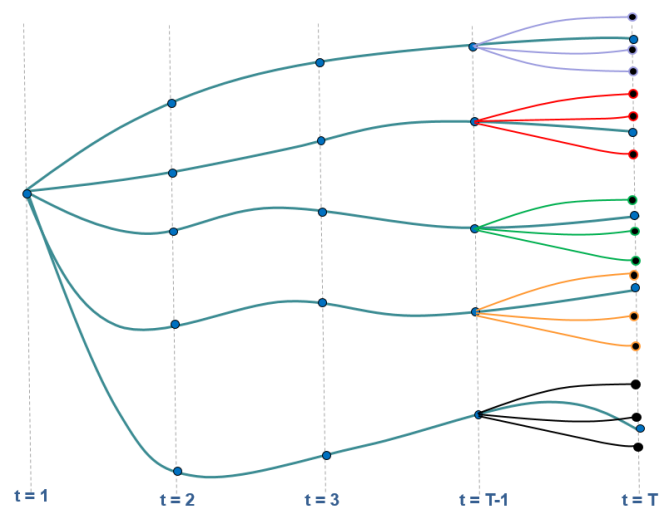
25.1 Parallel distribution

SDDP's parallel execution scheme is handled in the following way:

Forward phase: the scenarios are solved in parallel by the involved processes. After all scenarios have been solved, the algorithm moves forward to the next stage.



Backward phase: all backward scenarios associated to a given forward scenario in a given stage are solved by the same processor. After all backward scenarios of all forward scenarios are solved, the algorithm moves backward to the previous stage.



For more information on SDDP forward and backward algorithm, please refer to the SDDP Methodology Manual.

Results: during the simulation phase, the first process of the master node is dedicated to all output writing.

25.2 Choosing the number of nodes and processes

As each forward scenario will be solved by at most one processor, there is point on using more processors than the number of forward scenarios. In fact, if the number of processors exceeds the number of forward scenarios, the communication between them might result in significant performance degradation. To achieve a better performance, PSR recommends that the number of user-defined parallel processes does not exceed: (i) the number of physical cores of the processor and (ii) the number of forward scenarios.

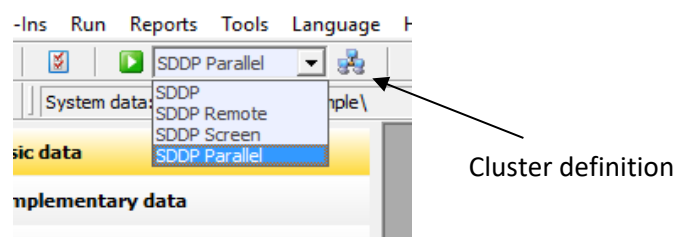
Internal tests have shown that, in many cases, the ideal number of processors to be used ranges from a third to a half of the number of forward scenarios of the study case. However, PSR encourages users to perform their own performance tests in order to define the most efficient configuration for their cases. If some help is needed, please contact the SDDP technical support by email.


25.3 Setting parallel execution

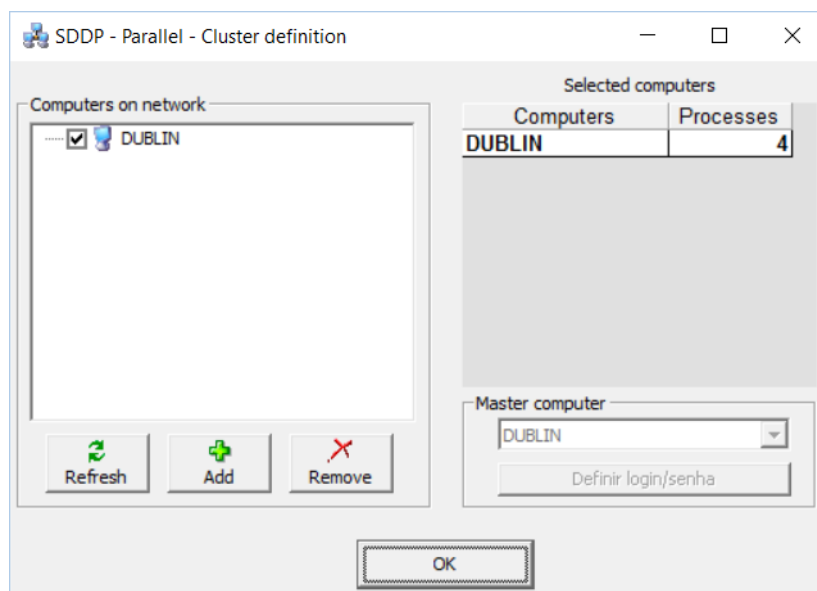
SDDP standard version license allows the parallel processing to use all processors available in your computer. You can set SDDP parallel execution by the following ways:

25.3.1 From graphical interface

It can be easily set via the interface, by selecting the option “SDDP Parallel” in the toolbar:



It is also necessary to define the information about the nodes that will be used in the parallel execution in “cluster definition” screen, accessed by the  button. In this window, you can select the machines that will be used in the run and the number of processes each machine will use:



25.3.2 From command line

If you do not wish to use the interface to run parallel cases, the following steps should be followed:

Step 1) Create the MPD.HOSTS file

Text file containing the name of all computers that will be used in the run and the number of processors in each computer. Each line of the file must be defined as follows:

```
<Computer Name>:<Number of Processes>
```

The first register defines the master computer. This file should be located in the same folder as the “sddpar.exe” application (the default folder is <SDDP installation directory>\OPER). An example of the file is shown below:

```
DUBLIN: 4
```

Step 2) Call the “sddpar.exe” application from the command line. The following arguments must be defined:

```
--path=<PATH>          <PATH>: path to the SDDP “Oper” subfolder
--mpipath=<PATH>       <PATH>: path to the MPI Installation folder
```

It is possible to check whether the execution is performed in parallel mode or not by looking at the execution log in the line that says “Processing type” (“SEQUENTIAL” or “PARALLEL”), which appears both in the output screen and in the sddp.out file. In case of “PARALLEL” execution, the total number of processes is also specified, as shown in the picture below.

```

C:\WINDOWS\system32\cmd.exe
c:\PSR\Sddp14\Oper>sddpar.exe --path="C:\PSR\Sddp14\Oper" --mpipath="C:\Program Files\MPICH2\bin"
SDDP Version 14.0.3 (Big Cut)
SignatureId: 2990413-win64-intel115-XPRESS-bigcut-release

Reading Execution Options and General Data file
Copy licensed to: PSR License authorization file
STUDY DATA - DIRECTORY: \\DUBLIN\sddpdat_c\PSR\SDDP14\EXAMPLE\
HYDRO DATA - DIRECTORY: \\DUBLIN\sddpdat_c\PSR\SDDP14\EXAMPLE\
Case: Caso ejemplo / Sample case

Reading additional parameters file
Solver: Xpress - Version: 28.01.04

Processing type: PARALLEL
Cluster configuration:
Node. #Proc. Computer name
-----
1      4 dublin.eedm.com
TOTAL:      1 node(s)
           4 processes

Reading system file

System: System 1 - Reading data...
Reading load configuration data
Warning: File not found - a unique load associated to this system will be considered
Reading load data file (load )
Reading Hydro Plant configuration file
Reading Fuel Configuration file
Reading Thermal Configuration file
Reading Minimum Total Outflow file

Generating Inflow file...
Cputime Creation of inflow file      =      0 s

Operation Policy Calculation: System 1
Convergence report
+-----+-----+-----+-----+-----+-----+
| Iter | Zinf | Zsup | Gap | Tol | CPURec | CPUFwr |
+-----+-----+-----+-----+-----+-----+
| 1 | 340.27 | 305.09 | -35.180 | 88.050 | 0 | 0 |
+-----+-----+-----+-----+-----+-----+
Cputime Operation Policy      =      0 s

Operating Simulation: System 1 ...
+-----+-----+-----+-----+-----+-----+
Average Cost      296.86
Cputime Operating Simulation      =      0 s
SDDP Success

SDDPTASK success

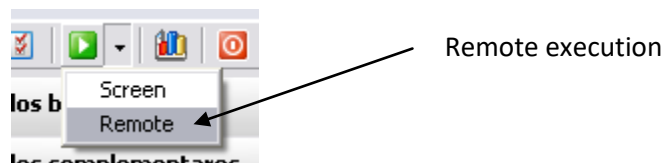
c:\PSR\Sddp14\Oper>_

```

Parallel execution example

26 REMOTE EXECUTION

In the main menu of SDDP, the user has access to the program's *Remote Execution* by pressing the execution button as shown below:

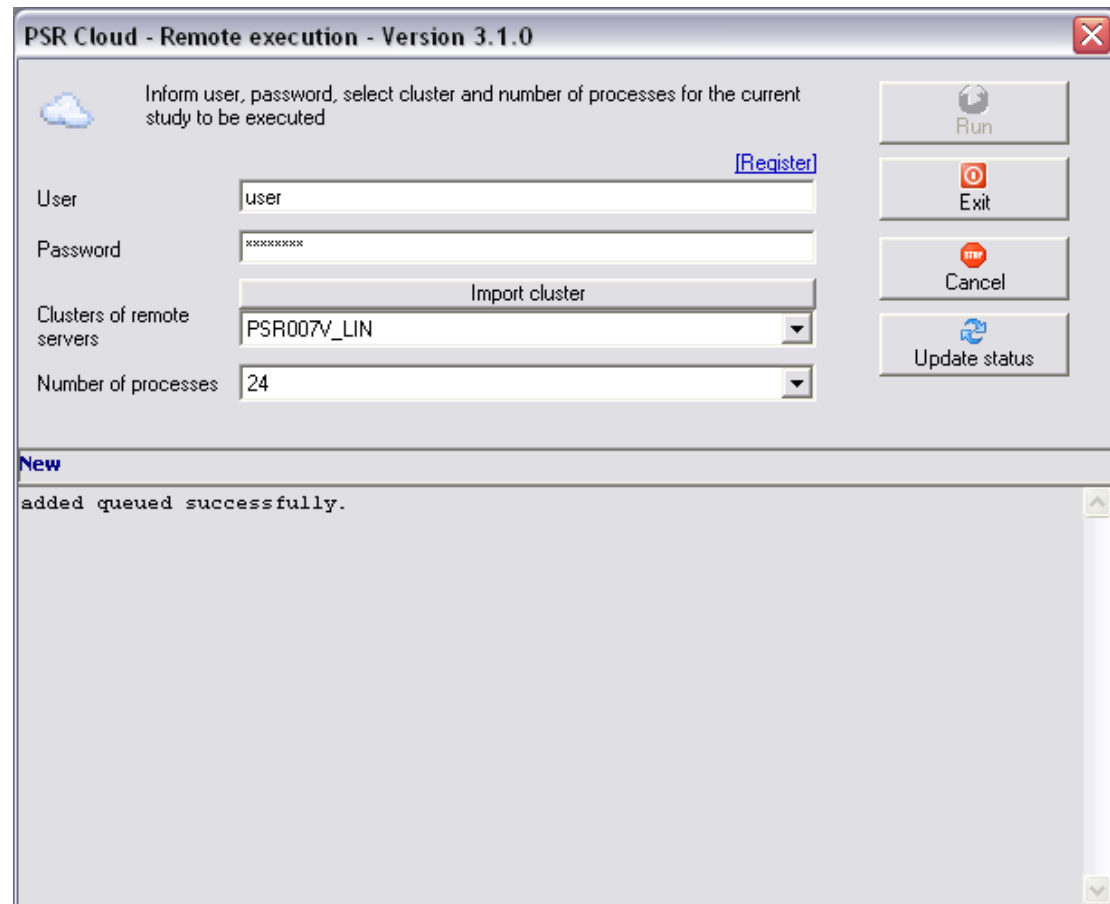


After accessing the Remote Execution screen, the user must inform the login and password that have been created during the registration in PSR Portal. In case the user is not yet registered in PSR Portal, press the button *[Register]* as shown in the following figure.

 A screenshot of the 'PSR Cloud - Remote execution - Version 3.1.0' dialog box. The dialog has a title bar with a close button. Inside, there's a cloud icon and the text 'Inform user, password, select cluster and number of processes for the current study to be executed'. Below this, there are four input fields: 'User' (containing 'user'), 'Password' (masked with 'XXXXXXXXXX'), 'Clusters of remote servers' (with an 'Import cluster' button and a dropdown arrow), and 'Number of processes' (containing '8'). To the right of these fields are five buttons: 'Run' (green play icon), 'Exit' (red stop icon), 'Cancel' (circular arrow icon), and 'Update status' (circular refresh icon). A blue '[Register]' link is located to the right of the 'User' field.

Next step is importing the list of available clusters. Select the desired cluster and the number of processes that will be used (this number must be a multiple of 8).

By pressing the button *Execute*, the local data set is uploaded to the remote server. The following screen shows that this execution step has been successfully completed.



The image shows a software window titled "PSR Cloud - Remote execution - Version 3.1.0". Inside the window, there is a cloud icon and a text instruction: "Inform user, password, select cluster and number of processes for the current study to be executed". Below this, there are four input fields: "User" with the value "user", "Password" with masked characters "xxxxxxxx", "Clusters of remote servers" with a dropdown menu showing "PSR007V_LIN", and "Number of processes" with a dropdown menu showing "24". To the right of these fields are four buttons: "Run" (with a play icon), "Exit" (with a red square icon), "Cancel" (with a red stop icon), and "Update status" (with a refresh icon). Above the "Exit" button is a link labeled "[Register]". Below the input fields is a button labeled "Import cluster". At the bottom of the window, there is a section titled "New" followed by a text area containing the message "added queued successfully.".

PSR Cloud - Remote execution - Version 3.1.0

Inform user, password, select cluster and number of processes for the current study to be executed

[Register]

User: user

Password: xxxxxxxx

Clusters of remote servers: PSR007V_LIN

Number of processes: 24

Run

Exit

Cancel

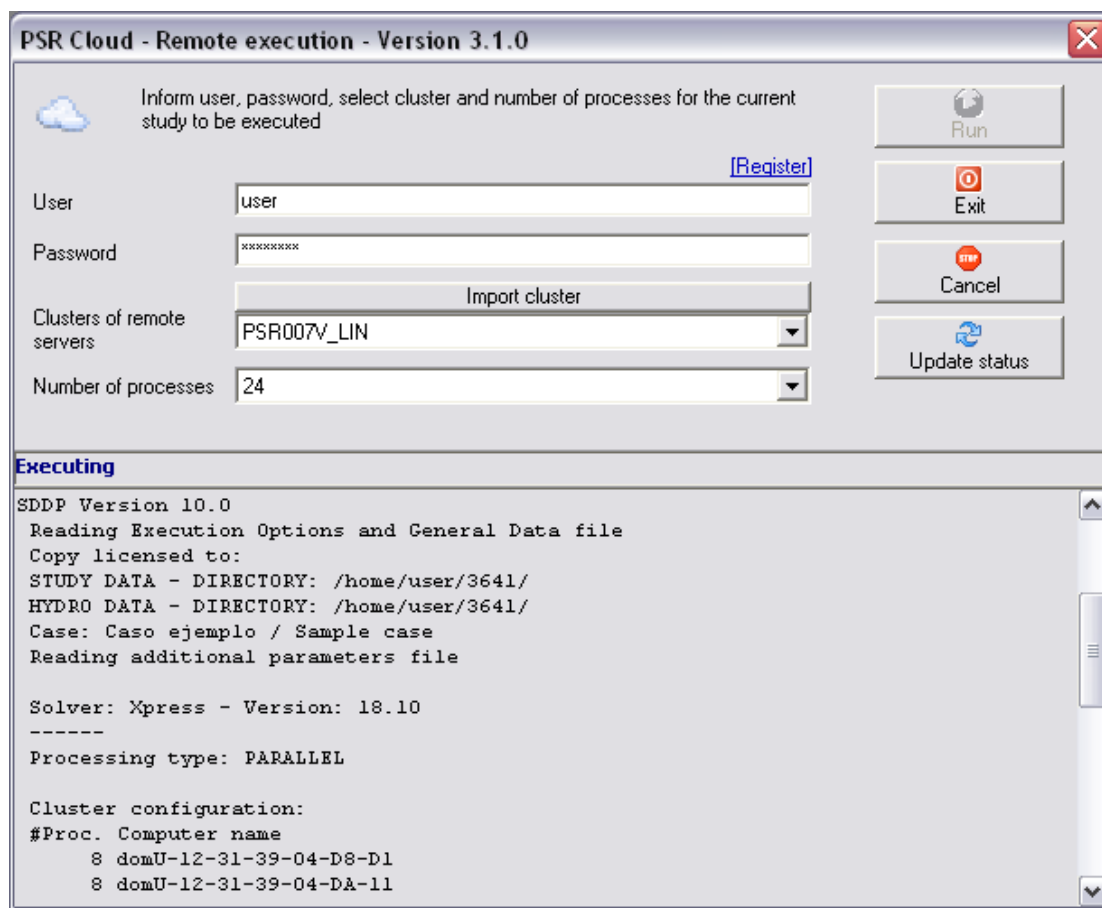
Update status

Import cluster

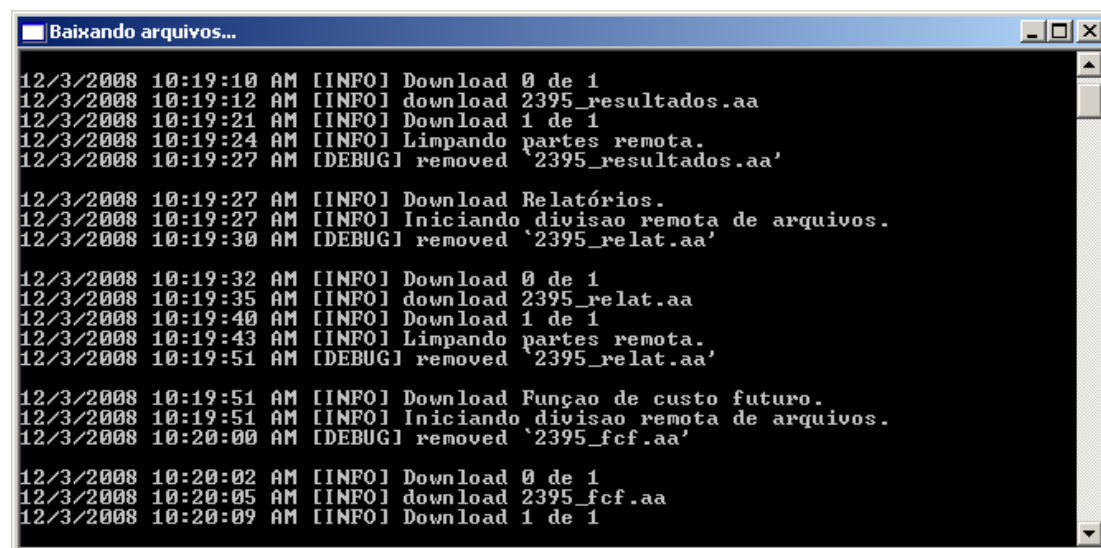
New

added queued successfully.

During the execution, periodic updates of the convergence process status are made and the resulting report is shown as illustrated in the next figure. The update of the convergence status can also be requested by the user by pressing the button *Update status* in the interface.



Once finalized the convergence process, the download of the results from the remote server to the local machine is started. This process is automatic as shown in the following figure.



Once the download of the results to the local data directory is concluded, it is possible to access the files produced by the program (report files, csv outputs for the Graph module, Future Cost Function, initial storage etc.) in the same way as if SDDP has been run locally.

In case of difficulties in remotely executing SDDP, please contact the SDDP support staff by e-mailing to sddp@psr-inc.com.

27 ADDITIONAL OUTPUT FILES

SDDP produces, in addition to the user-selected output spreadsheets, the following files:

Name	Type	Description
sddp.out	ASCII	Contains an echo of the input data, the convergence report and the total CPU time.
sddpcope.csv	Microsoft Excel	Contains a summary of the operation costs by series, as well as the standard deviation, minimum, maximum and average costs.
sddpgrxx.csv	Microsoft Excel	Contain the final generation, by plant, for system xx.
sddpctxx.csv	Microsoft Excel	Contain the final cost, by plant, for system xx
sddprisk.csv	Microsoft Excel	Contain the annual deficit risk by system.
sddpconv.csv	Microsoft Excel	Contains a summary of the convergence process
sddpcmga.csv	Microsoft Excel	Contains the mean annual load marginal cost

28 THE GRAPH MODULE

28.1 Introduction

SDDP has a module that allows graphing the results of a simulation. To access this module, click on its icon on the menu bar as illustrated below:



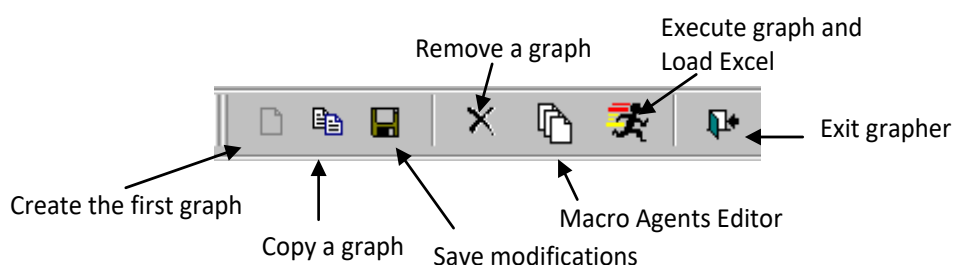
After clicking on the Graph module icon, the program displays the main screen of the module. Six activities are presented in the Graph module screen:

- General options
- Stage selection
- Block selection
- Series selection
- Axis title
- Variables, agents and macro agents selection

There is also the Edit Macro Agent option. Macro Agents are created as linear combinations of agents. For example, one can define a macro agent called HydroX which contains the sum of the generations of all hydro plants of enterprise X. There are two standard Macro Agents: TotalHydro (containing the total hydro production) and TotalThermal (total thermal production)

Once all options have been selected, press the Graph button to generate these Excel graphs.

28.2 General options



a) Creating the first graph

If no graphs have been defined, the only possibility is to Add a new graph. Click on the blank sheet icon to create a new graph. Enter the graph name and press Ok. Note that all options become enabled in the main screen.

b) Selecting a graph

SDDP allows the definition of several graphs. Choose a graph from the menu located on the upper part of the screen, which contains the list of all created graphs.

c) Modifying the graph name

- Choose a graph from the list.
- Enter the new name. Note that the modifications are automatically updated in the list.

d) Copying graphs (creating new graphs)

- Select a graph from the list.
- Press the Copy Graph button.
- Enter the name of the new graph and press Ok. A new graph is created, with the same parameters as the original graph.

e) Eliminating graphs

- Select the graph from the list.
- Press the Remove Graph button.
- Confirm the graph elimination.

28.3 Stage selection

The selection is made from the stage list, as shown in the figure below:

Stages			
Initial	14	2000	
Final	13	2001	

28.4 Load block selection

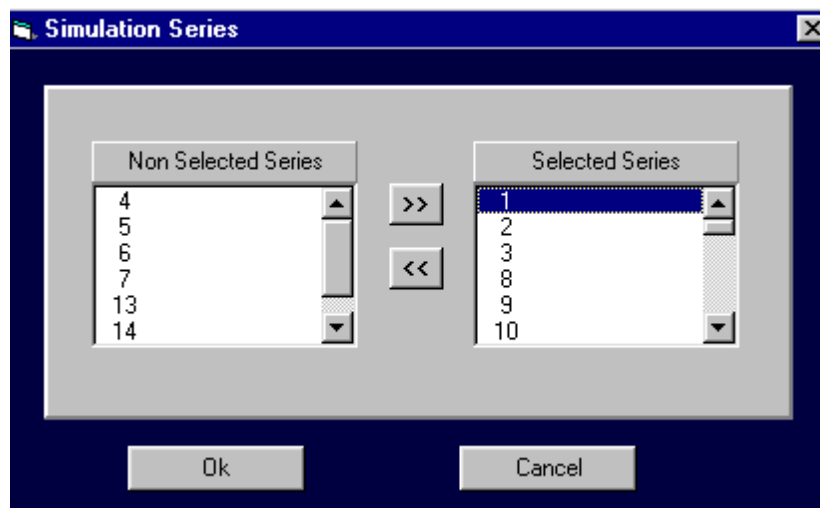
Press the load block buttons to select the desired blocks. To cancel a selection, press again the selected block. The next options are:

Sum up values per block	Add values per block
Sum up stages per year	Add stages per year

28.5 Series selection

If the *Select All* option is not chosen, the inflow series of interest can be chosen by pressing the button on the right of the checkbox:

Select all	<input type="checkbox"/>	
------------	--------------------------	--



The five remaining options of the Series module are described in the table below:

Graph series	Results for individual series will be plotted
Graph mean	The average result of the selected sequences will be graphed.
Graph standard deviation	Graphs the standard deviation of the selected series.
Graph superior quantity	Graphs the upper quantile of x%, that is the Qx value, such that $P(Q < Q_x) = x/100$, where Q is the selected variable.
Graph inferior quantity	Graphs the lower quantile of x%, that is the Qx value, such that $P(Q > Q_x) = x/100$, where Q is the selected variable.

28.6 Axis title (optional)

Enter the labels for the X axis, Y axis, and secondary axis. This information is optional.


28.7 Variables, agents and macro agents selection

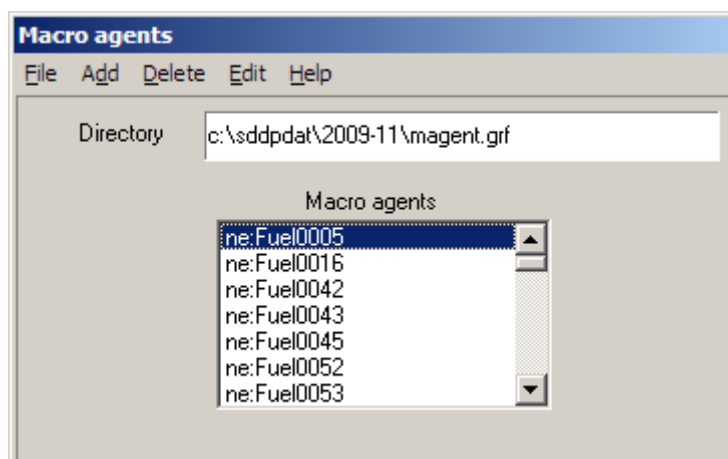
Variables are results obtained from an SDDP run, and are associated to the worksheet selection made in the execution screen. Agents are the entities associated with the output results. For example, *Hydro Generation* is a variable that applies to hydro plants, which are agents. Analogously, *Fuel Consumption* is variable that applies to fuels, which are agents.

Select variables by pressing the Variables button, in the main screen of the graph. A new screen will soon show up. Variables are selected or discarded with the buttons (<<) and (>>). By pressing the CTRL key and the up-arrow or down-arrow keys simultaneously, it is possible to choose multiple variables at once. The selected variables appear in the Selected Variables List from the main screen.

Selecting agents and macro agents follows the same logic as for the variables selection.

28.8 The macro agent editor

SDDP allows the creation of files with the definition of macro agents  – which gives more flexibility to the user since macro agents files can be “tailor-made” created for given studies. The module for the creation of macro agents can be accessed through the icon of Macro Agents Editor, located in the toolbar of the Graph module.



In order to read an existing macro agents file, choose the option **Open** in item File in the menu bar.

To create a new macro agents file, edit the existing macro agent and afterwards save it with a new filename (**Save as** option).

- **Adding macro agents**
 - Select the *Add* option from the menu.
 - Enter the name of the new macro agent. Press Ok.
 - Choose a variable that is applied to the new macro agent. Press Ok.
 - Select the agents. Enter their respective coefficients. If no coefficient is defined, SDDP assumes them as 1. This means that the linear combination is actually converted to a sum. Press Ok.
- **Removing a macro agent**
 - Choose the macro agent from the list.
 - Press the Remove button.
 - Confirm the macro agent elimination.
- **Editing a macro agent**
 - Select the macro agent from the list.
 - Press the Edit button.
 - Select the variable corresponding to this macro agent.

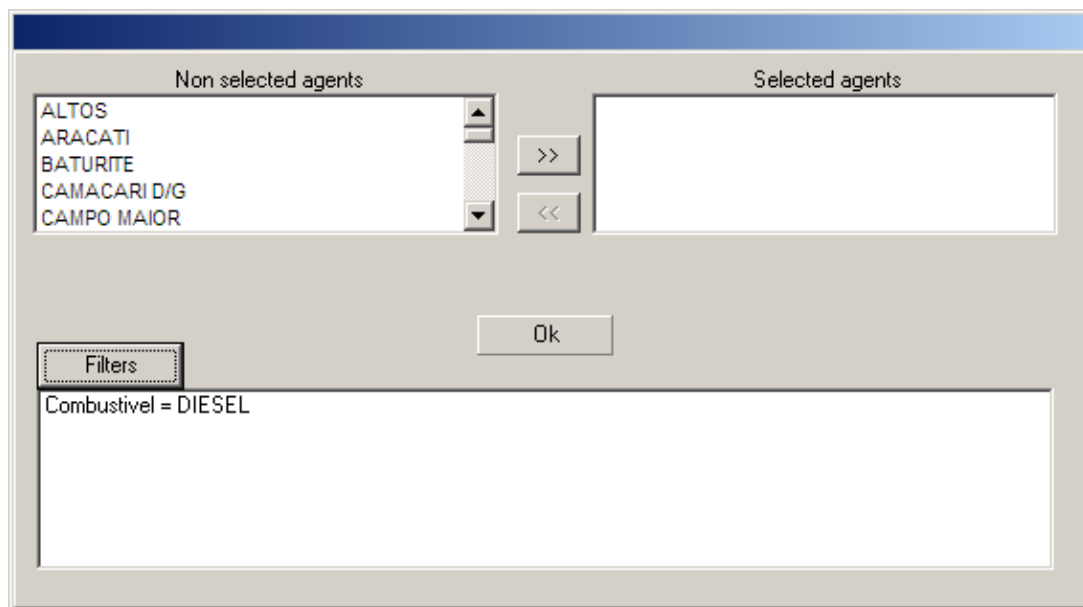
- Now add or remove the agents from the list, modify the coefficients, etc. Press Ok.

28.9 Filters

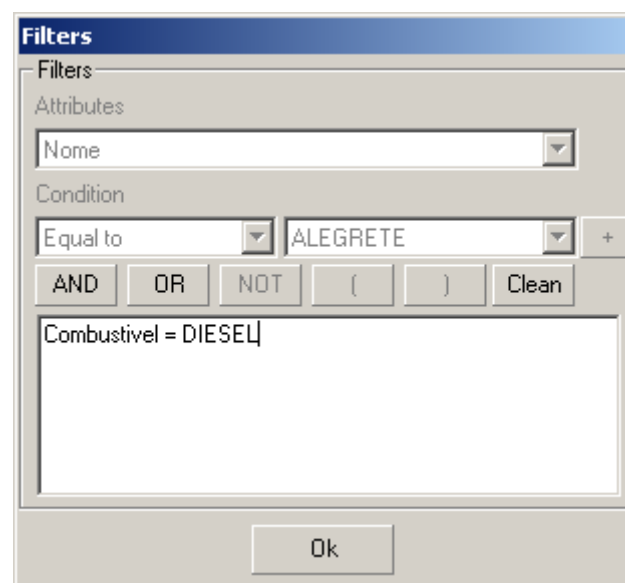
Filters are tools of the Graf program, which make the selection of Agents easier by the specification of Attributes of interest.

Given the concept of a *Variable* (thermal generation, circuit flows, load marginal cost, etc.) and *Agents* (hydro plants, thermal plants, busses, etc.), the *Filters* consist of some tools used to select *Agents* by the value of a given *Attribute* or by the combination of several *Attributes*.

The filter selection button, inside the agent selection screen, is shown below:

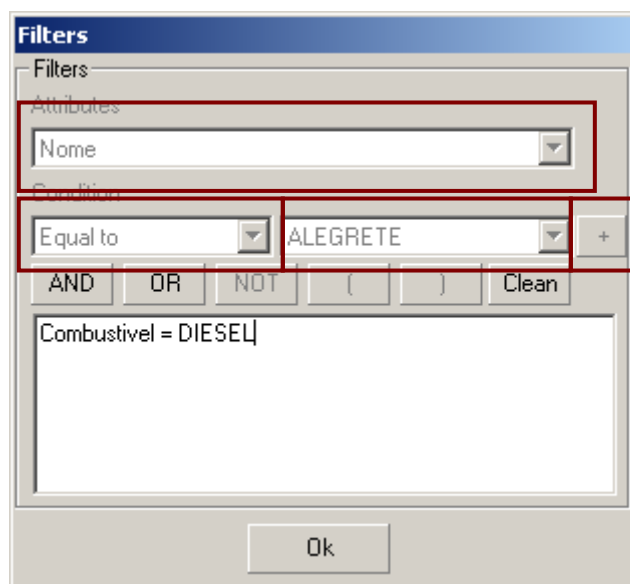



Once the Filters button is clicked, the following screen is presented:



This screen allows the creation of sophisticated filters for the selection of agents through logical expressions on the attributes, using the logical operators **AND**, **OR** and **NOT**; plus parenthesis **(** and **)**, to help the construction of the desired logical expression.

The following steps are used to add constraints to a given attribute:

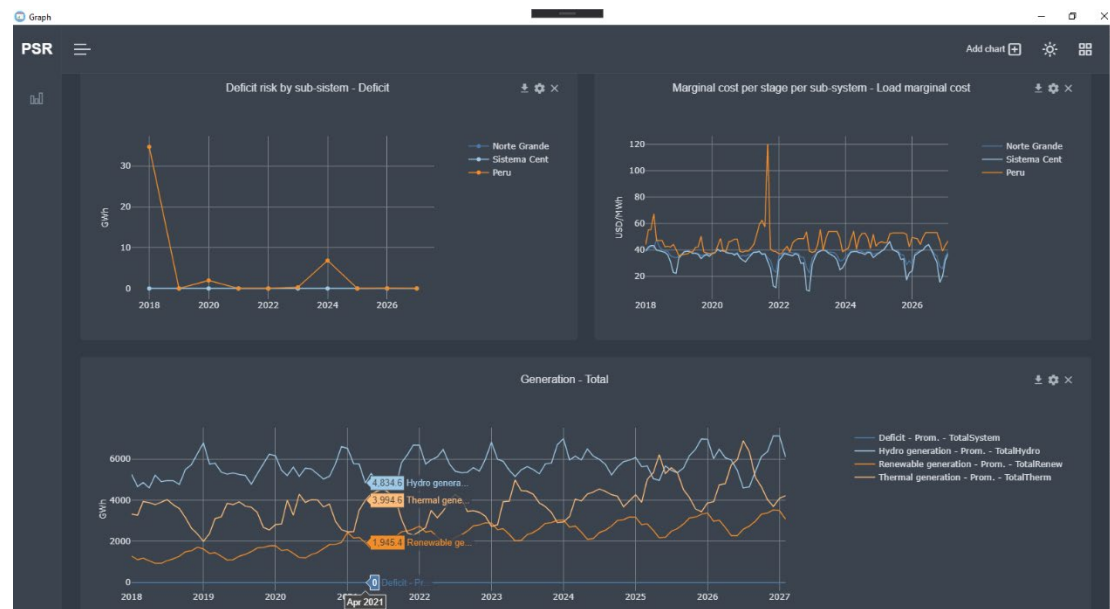



1. Select the attribute
2. Select the type of constraint:
 - **Between**
 - **Equal to**
 - **Greater than**
 - **Greater than or equal to**
 - **Smaller than**
 - **Smaller than or equal to**
3. Inform the value of the constraint
4. Press the Add button 

The button  eliminates the expression.

28.10 New visualization tool

A new tool for visualizing the SDDP results is available. The standard selection options for generating a new chart are mainly the same as for the traditional graph module, while the main interface was redesigned for a better user experience. The charts are organized in an intuitive and customizable dashboard to facilitate the visualization of the SDDP results:



To access it, click on the arrow next to the button of the graph module () and select the “Graph 4.0Beta” option.

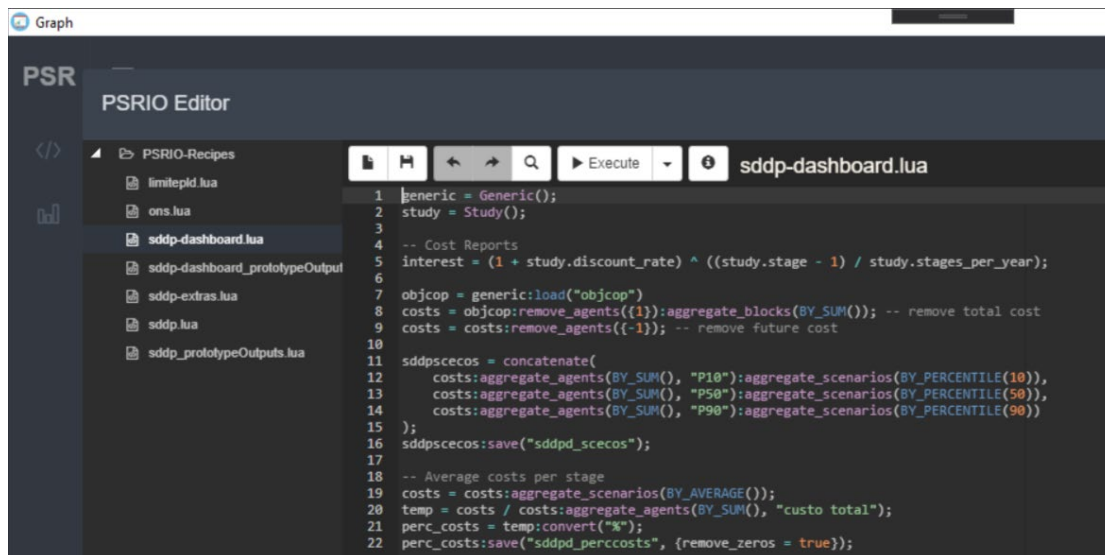
For further details, please check the Graph documentation at: <https://psren-ergy.github.io/graph-docs>.

29 PSRIO

The processing of input and output data is a fundamental step for understanding the results, preparing studies, and linking with other models. Using traditional tools such as Excel or custom-made routines for processing specific files is laborious, repetitive, and error prone. Additionally, they bring limitations related to scalability due to the increase in the volume of results originated from the greater complexity and detail in the representation of SDDP.

Focusing on this issue, we developed PSRIO to complement the PSR's processing and visualization toolkit. It is a script interpreter for the Lua language with extensions for handling PSR models databases (input and results) which performs several user-specified mathematical, statistical, and data processing operations in a fast, customizable, and extremely friendly way. It is possible to perform operations such as adding agents results, averaging scenarios, calculating percentiles, converting units, and several others with few script lines without worrying about formulas or programming loops for reading, processing, and writing files. Results are saved in the standard format, and the Graph tool can create dashboards from them, they can be used in Excel, directly in reports, or even as input for another model. The user scripts, known as "recipe files," are saved in the case directory and automatically processed after SDDP completes the execution.

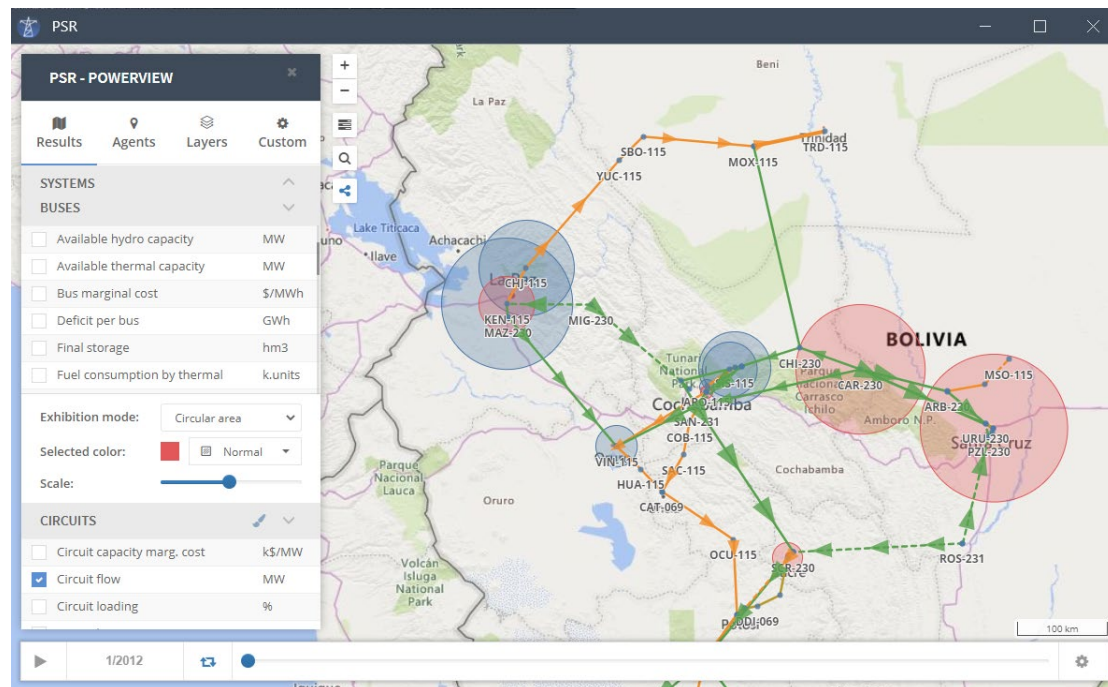
It is integrated with Graph 4.0, which contains a built-in PSRIO editor that allows the creation, customization, and execution of the recipe files, as shown below:




For further details, please visit PSRIO documentation at <https://psrenergy.github.io/psrio-docs/>.

30 POWER VIEW FOR TRANSMISSION-RELATED STUDY RESULTS

Power View is a tool for the graphical visualization of transmission-related study results of PSR models. This tool allows the visualization on a map, in a georeferenced and integrated environment, of animated circuit flows, circuit loading, and bus-related information such as bus generation and load. It is also possible to show an animated chronological evolution of the variables along the study period.



To access it, just click on the arrow next to the Power View button () and select the “Power View Beta” option.

For further details, please visit the documentation at: <https://psrenergy.github.io/powerview-docs/>.

31 SDDP DONGLE TROUBLESHOOTING

31.1 Error Code 03

The error message identified as *Error Code 03* is associated to a problem with the dongle and can be due to one of the following causes:

- The dongle was not properly connected to the computer or it is damaged;
- The user is not licensed to run the current version of SDDP.

These problems can be identified following the procedure described below:

Step 1) Verify if the dongle is properly connected to the computer (#1). Disconnect the dongle and connect in it again. If the problem persists, proceed to Step 2;

Step 2) Connect the dongle to a second computer (#2) that has the same SDDP version as installed in computer #1 and run SDDP. If it does not work, move to Step 3. If it works, the error might be due to a physical problem in the computer #1 port;

Step 3) Connect a second dongle that works properly to computer #1. If it works, it can be concluded that the dongle is damaged and must be replaced. Please contact PSR. In case it does not work, move to Step 4;

Step 4) SDDP checks if the user is licensed to use the current version of the program. The user must have the annual maintenance service of SDDP active. If the service is not active, the user will not be licensed to run the current version of SDDP, and the program will present the *Error Code 03* message.

31.2 Error Code 12

The error message identified as *Error Code 12* occurs when the driver associated to the dongle was not property installed. In general, this happens when SDDP is installed by a user without administrative rights.

In order to verify this possible problem, please proceed as follows:

Check if SDDP was installed with administrator rights (Windows NT, 200, 2003, XP and Vista). If not, please install SDDP again and try running it to see if the problem persists. In case the problem persists, please contact PSR.

32 PSR CLOUD

PSR Cloud is our web-based computational environment that can be used to run SDDP, avoiding thus the need for the users to invest in high-performance computers. It is a pay-per-run and per processor scheme in which the users may select the desired number of processors for each execution. The machines available for execution are constantly upgraded. For more details about PSR Cloud please visit <https://www.psr-inc.com/software-en/?current=p4083>.

PSR offers to all SDDP users the free use of up to 72 processor-hours in PSR Cloud; please contact PSR at sddp@psr-inc.com for more details.