SDDP VERSION 17.0

Modeling enhancements

HYDROGEN & 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.

Starting with this release, 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.

As in all SDDP features, the study horizon can span several decades with hourly resolution. Check it out!

FLEXIBLE DEMAND

Because of the explosive insertion of renewables, flexibility has become an essential resource in power system planning and operation. From its very beginning, SDDP has represented in detail flexible elements such as hydro plants, batteries, managed fuel reservoirs, contracts, and transmission components.

In this version, we add demand-side resources to the flexibility portfolio:

- **Modeling of energy consumption delays/anticipations** in the industrial, commercial, and residential sectors, which allow the representation of Demand Side Management (DSM) programs and flexibility aggregators. The load shifting is subject to minimum and maximum load increase/decrease factors in each timestep (block or hour).
- **It is also possible** to specify a shifting window[1] (in hours), determining the timespan in which the load can be shifted.
- **Finally,** there is an integrality constraint: the sum of the shifted loads along the time steps must be equal to the original total consumption.

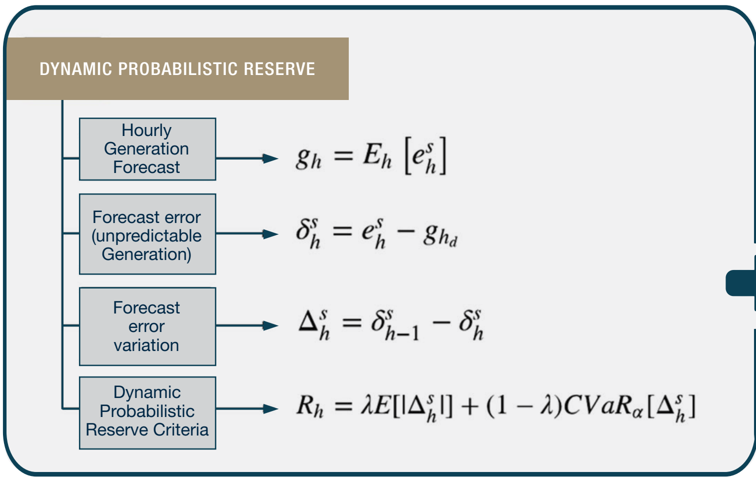
Another flexible demand feature is a consumer "tolerance factor" for load reduction (not shifting). This reduction may result, for example, from air conditioning control by a flexibility aggregator. This tolerance has a maximum value (in p.u. of the reference load) and a premium (in $/MWh).

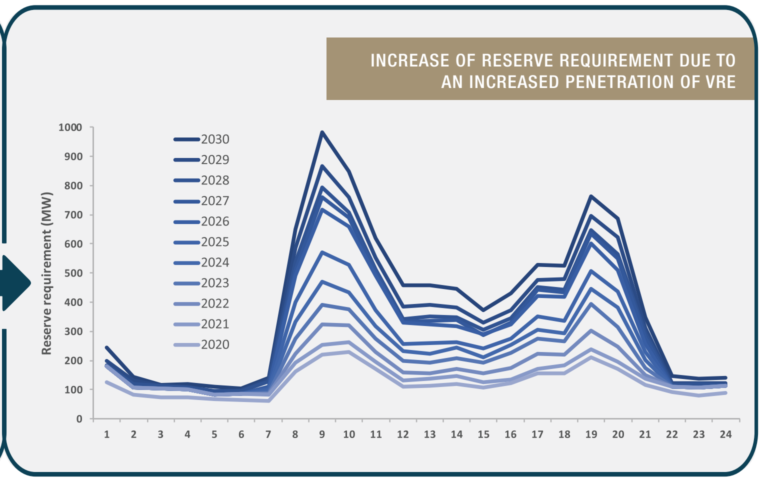
This new feature is available at the "Basic data > Load > Flexible demand configuration" screen.

DYNAMIC PROBABILISTIC RESERVE (DPR)

The fluctuations of variable renewable energy resources (VREs) such as wind and solar require increased generation reserve requirements. Note that these reserve requirements are related to the forecast errors rather than the VRE generation itself. In other words, if it were possible to predict with 100% accuracy the VRE production for the next day or week, no generation reserve would be necessary. One interesting example was the occurrence of a total solar eclipse in Europe a few years ago. Although the eclipse made all solar generation go to zero, its time and spatial evolution could be predicted accurately, and the detailed scheduling of other plants was prepared and deployed. Therefore, an important question is: how do we calculate VRE-related reserves considering forecast errors?

PSR has developed a new methodology for this matter, called Dynamic Probabilistic Reserve (DPR). It aims to provide a probabilistic and dynamic evaluation of the VRE forecast errors, translating these errors into the systemic reserve requirement. The DPR calculation methodology is summarized and exemplified below:





For further details, please refer to this article: https://arxiv.org/abs/1910.00454.

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? In PSR's experience of applying RH to many systems with different storage capacities and generation mixes, the answer is: the total execution time will probably be the same or even smaller.

This new feature is available at the "Execution options > Economic dispatch > Rolling horizon" screen.

CHRONOLOGICAL BLOCKS

SDDP represents the process of operational decision-making (generation of each plant, interconnections 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.

There is a new intermediate option for the representation of chronology between blocks of hours in this new version. 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.

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.

This feature is only available for weekly cases.

IMPROVED REPRESENTATION OF NON-CONVEXITIES

In the forward simulation step of the SDDP algorithm, it is possible to represent in detail nonconvex functions such as hydro plant variable production factors and binary operating decisions such as 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. Previous SDDP versions achieved convexity by creating linear approximations of the nonconvex elements. In this version, we implemented an improved strategy to handle nonconvexities in the FCF calculation.

There is a new option in the "Execution options > Economic dispatch > Solution strategy" screen, which activates this strategy from an initial iteration of the algorithm.

NETPLAN: DETAILED STUDIES OF TRANSMISSION NETWORKS

SDDP 17.0 is fully integrated with NetPlan 4.0, a tool that allows carrying out studies of:

1- detailed planning of the expansion and operation of transmission networks with the representation of contingencies

2- expansion of voltage support

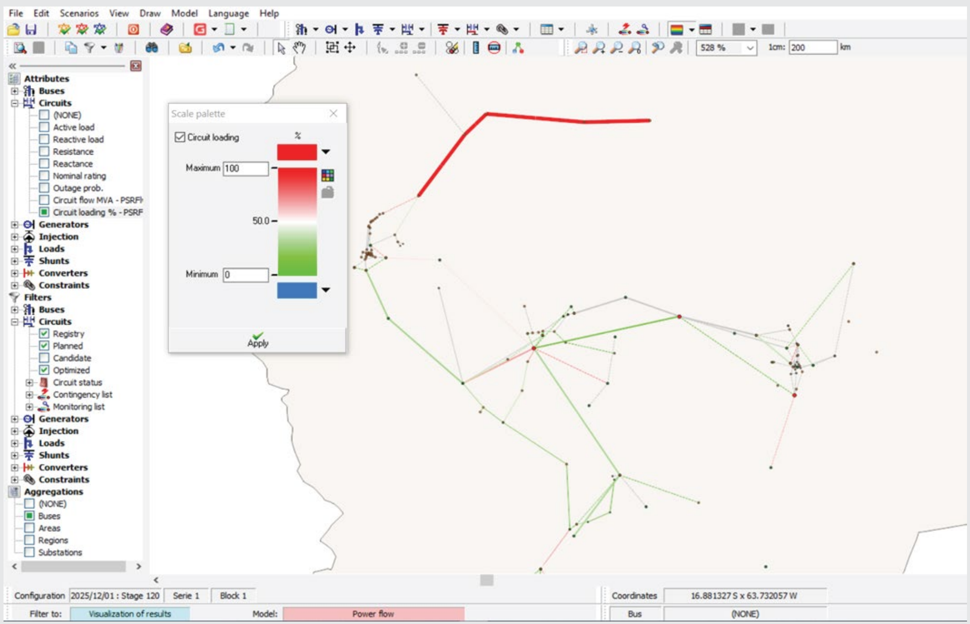
3- power flow

4- allocation of costs for the use of the transmission system to end users (demands and generators).

The decisions to expand the generation and interconnections of the OptGen[2] and the operative decisions related to the dispatch of the generation units calculated by SDDP are incorporated, automatically, in the detailed analysis of the transmission network with the optimization and simulation modules. This makes it possible to define the necessary reinforcements to the transmission network, taking into account the uncertainties in the production of renewable plants (hydroelectric, wind, solar, etc.) through sets of generation and demand scenarios obtained by SDDP. At the end, the transmission network expansion decisions obtained by the NetPlan are automatically incorporated into the database for the analysis of the operation in SDDP or planning of the integrated generation-transmission expansion that can be performed through OptGen.

NetPlan has a friendly graphical interface that allows you to view the network diagram, verify/modify element data, and view the results produced by the models directly on the diagram.

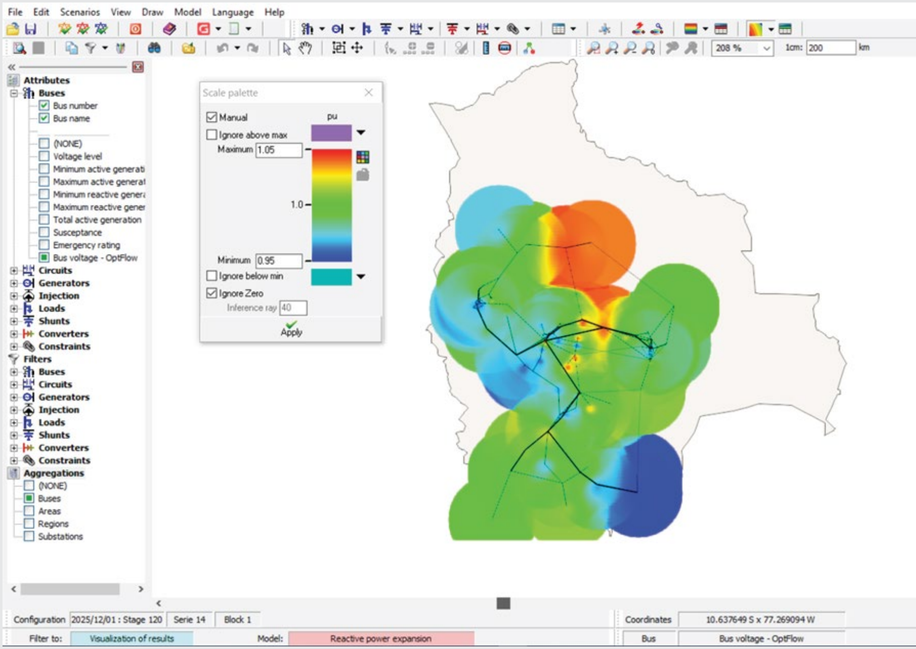
For example it is possible to visualize the circuits that operate in overload according to the SDDP dispatch schedule, which allows to identify the circuits of the network where it would be indicated to add candidate projects for the OptNet expansion module. In turn, the transmission expansion plan decisions obtained by OptNet are also illustrated in the diagram.



[2] *OptGen is the planning model for the expansion of the generation and interregional interconnections.*

For more information, visit https://www.psr-inc.com/softwares-en/?current=p4040

In addition, nodal results such as generation and demand per bus, marginal costs, angle and voltage magnitude can be viewed. The figure to the side illustrates the "countouring" graph for the magnitude of voltage across the buses, calculated by the OptFlow optimum power flow module. This type of result makes it possible to identify regions that present reactive power deficiencies (blue and red colored regions in the diagram to the side); and whose buses would be candidates for expansion of capacitors and/or reactors in planning studies of the expansion of voltage support.

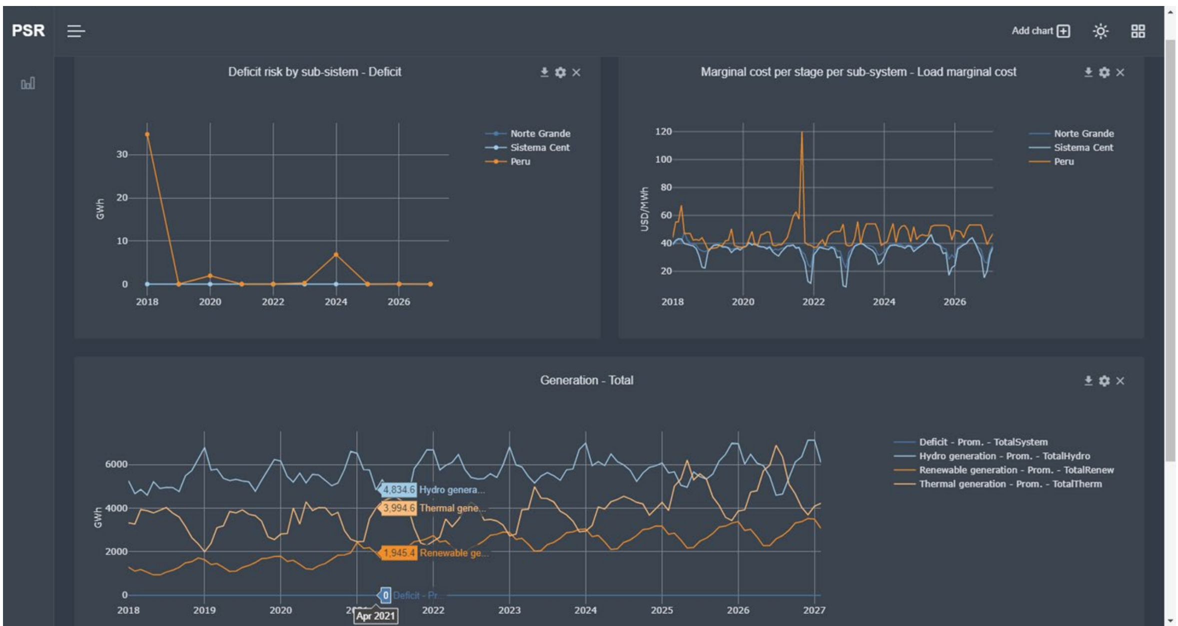


For more details, visit our website https://www.psr-inc.com/softwares-en/?current=p4046 or contact us directly netplan@psr-inc.com.

Visualization, data & output handling

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 4.0 Beta" option. For further details, please check the Graph documentation at: https://psrenergy.github.io/graph-docs

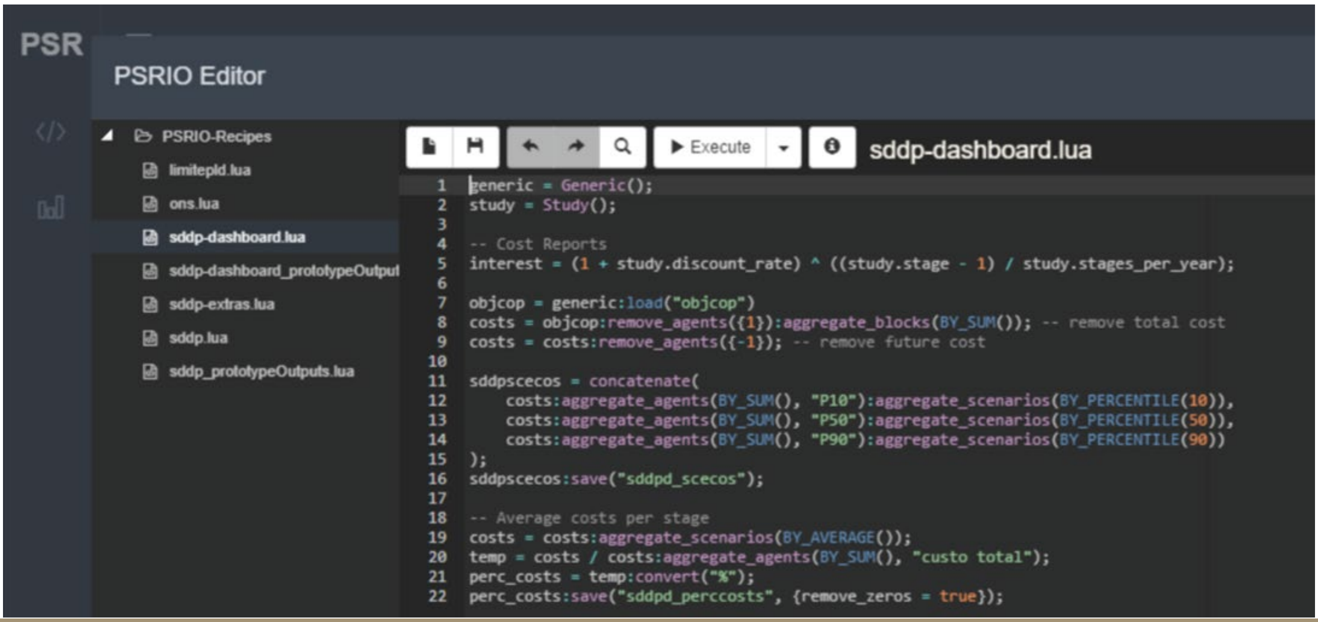
ENJOY!

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.

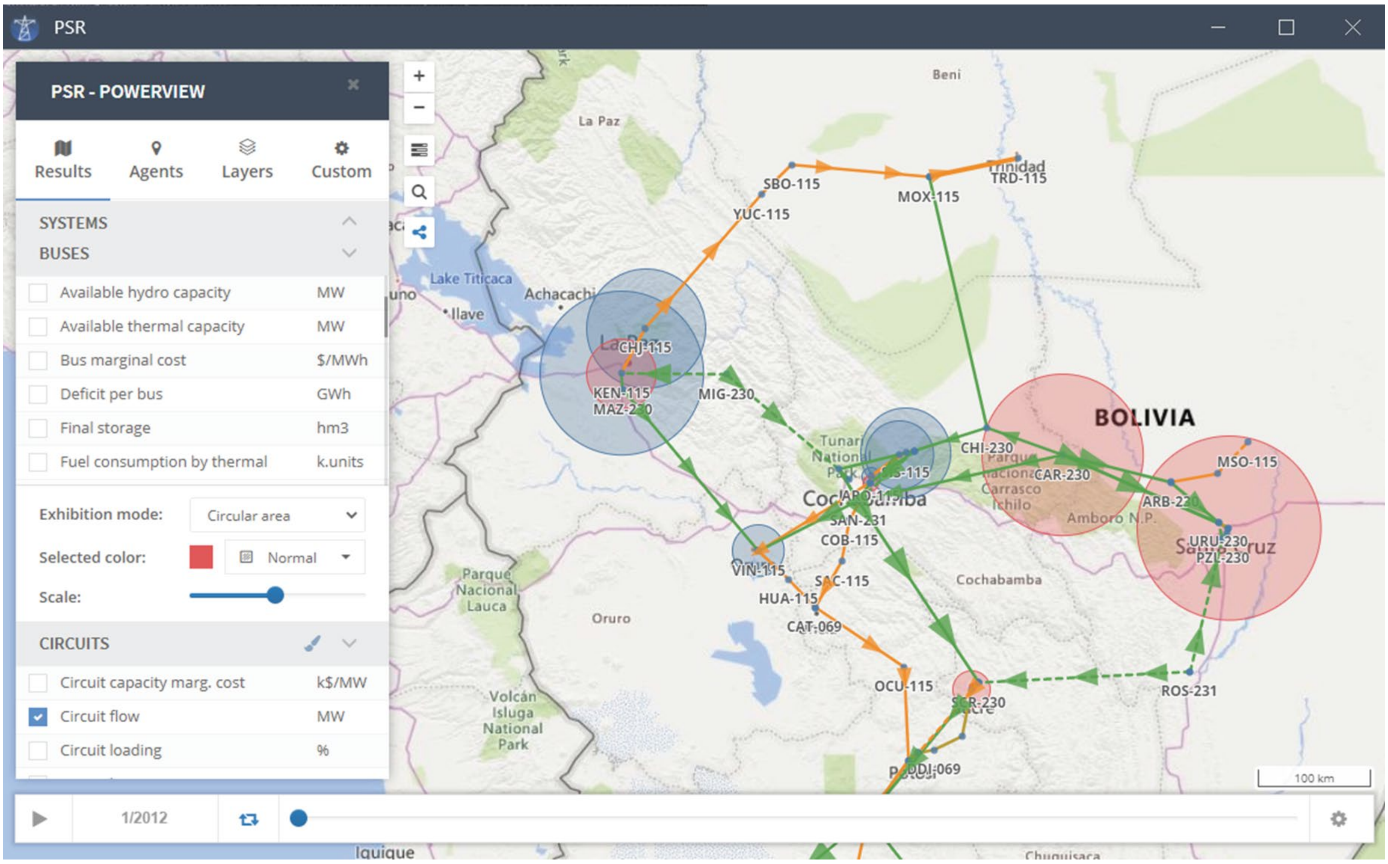
It is integrated with Graph 4.0, which contains a built-in PSRIO editor that allows the creation, customization, and execution of the recipe files, as shown below:



For further details, please visit PSRIO documentation at http://psr.me/psrio.
CHECK THIS FEATURE OUT!

New Power View tool

Power View has been completely rewritten and redesigned, making it much faster, more modern, and beautiful.



It is available in Beta version for users to try. 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/.
We plan to retire the old version of the Power View in the next major release of the SDDP. TRY IT OUT!

Integrated clustering tool

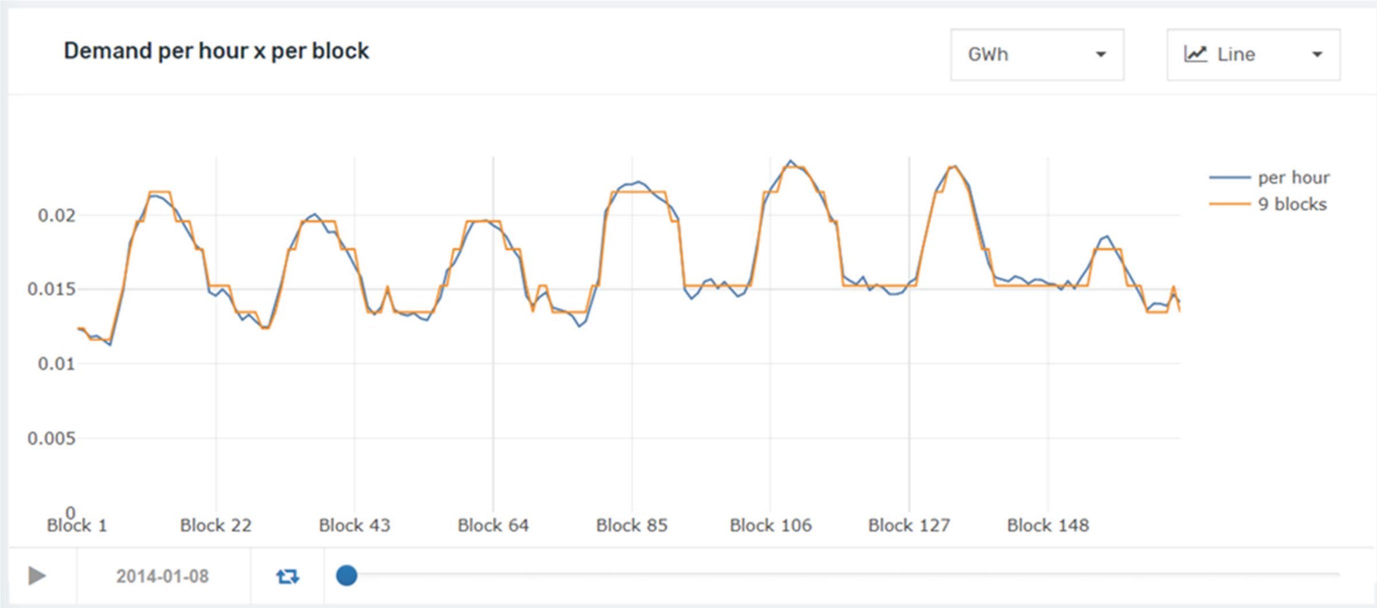
One of the first steps required to build an SDDP database from scratch is the definition of the number of blocks. The blocks represent sets of hours within each week or month in which the system parameters are similar. This feature allows the consideration of different configurations in each stage without inputting a vast amount of data. The association between hours and their corresponding blocks is informed in the so-called "hour-block mapping" data.

In this new version, two new features relative to the hour-block mapping are available:

- **Block representation:** this feature helps creating from scratch or replacing the hour-block mapping for the selected number of blocks. It is accessed on "Execution options > Clustering > Block representation".

- **Hour-block remap:** this feature helps creating 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:



For further details, please refer to the SDDP User's Manual.

Other improvements

The Dashboard has been redesigned, having now two worksheets:

Solution quality:
1- the convergence report;
2- pie chart of the operating costs (different non-zero terms of SDDP's objective function);
3- the 2D heatmap that shows the share of violation penalties and deficit in the cost of each stage/scenario; and
4- the 2D heatmap that shows the convergence processes per iteration and stage.

Results:
1- annual marginal cost by sub-system;
2- deficit risk by sub-system;
3- marginal cost per stage per sub-system; and
4- the generation graphs.

New data for demand:

Different demand scenarios: hourly scenarios for the energy demand of both inelastic/elastic and flexible demands can now be introduced.

In previous versions it was only possible to define a single demand data resolution for all demands, which is selected in the "Execution options > Data resolution" screen. Now it is possible to choose a resolution for each demand, allowing more flexibility in the data definition. The resolution options are block, hourly, hourly scenarios, and general (equal to the option defined in the "Data Resolution" screen).

Phase shifters:

In the "Basic data > Electric network > Circuit configuration" screen, the users may inform the minimum/maximum angles of phase shifters to be contemplated in the linearized power flow runs performed by the SDDP model;

Quadratic losses in DC Links:

Now besides the linear factors, the user may directly select the new "Quadratic" option, introduce the resistance value in %, and the SDDP model will automatically calculate the quadratic losses;

Hydro basin configuration:

The user can now define the hydro basins in the "Hydro basin configuration" and associate the gauging stations to the hydro basins;

New options available for general constraints:

New variables[3] can be added as constraint terms in the generic user-defined constraints:
(1) generation of thermal plants, (2) flow in DC links, (3) generation of hydro plants, (4) incremental inflow of hydro plants, (5) demand, (6) renewable generation, and (7) net battery injection;

New data/constraints of hydro plants:

- **New (chronological) flow table:** in previous versions, only one "Outflow × Elevation" table could be defined in the "Basic data > Hydro plants > Hydro plant configuration" screen. Now, more than one table can be defined to model seasonal behavior[4].
- **New option for defining** the joint reservoir constraints as a percentage of the maximum stored energy of the reservoir set in the "Complementary data > Hydro plants > Joint reservoir constraints" screen.

New data/constraints of fuel contracts:

- **The "contracted amount" data** becomes optional and is assumed as limitless when it is not defined.
- **New option** for defining the "consumed amount" unit in "fuel units".
- **New availability constraint**, which can be defined chronologically in the "Complementary data > Fuel > Fuel contract availability" screen.

Final simulation with selected scenarios:

The simulation of selected scenarios is available for the policy option avoiding the need for a separate run as required in previous versions.

[3] *Our goal is to extend this functionality to cover all agents. Tell us your favorite ones and help us to prioritize the next developments.*

New features for the hourly representation:

- **Fuel price scenarios:** the uncertainty in the fuel prices, defined in the "Complementary data > Fuel > Fuel price > Chronological by scenario" screen, can now be represented in hourly executions.
- **Hydro (chronological) flow tables:** the "Turbining x Efficiency" and the "Storage x Maximum turbining" tables, defined in the "Basic data > Hydro plants > Hydro plant configuration" screen, can now be represented in the hourly executions. More than one table can be defined to model seasonal behavior.

"Check data" option ( ):

When the user clicks on this button, all SDDP input data is checked so that possible inconsistencies are found and shown to the user to be fixed before running the model.

For further details, please refer to the SDDP User's Manual.

RESTRUCTURING OF INPUT DATA FILES

- The circuit data file (DCIRC.DAT) and the circuit modification data file (MCIRC.DAT) have been versioned to contemplate phase shifter data.
- The fuel contract data file (FUECNTXX.DAT) has been versioned to contemplate the previously mentioned changes.

SDDP's interface opens a case and automatically applies the new data format, creating a backup subfolder (named BAK) before the conversion process. We strongly recommend checking the converted data before deleting the backup folder.

PSR CLOUD

PSR Cloud is our web-based computational environment that enables running SDDP without the need of investing 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.

More details about PSR Cloud at http://psr.cloud/.

PSR offers to all SDDP users the free use of up to 64 processor-hours in PSR Cloud; Please contact PSR at sddp@psr-inc.com for more details.