OVERVIEW

SDDP is a stochastic dispatch model for electrical systems with the representation of the transmission and gas networks, used in long, medium and short-term operation studies. It is highly flexible in terms of its temporal and spatial levels of detail. In the temporal dimension, it can represent very long decision horizons (several decades) with weekly or monthly stages and intra-stage resolution of load blocks, hours or infra-hours (5-30 minutes). Spatially, it can handle the detailed operation of small islands up to the study of regional markets integrating several national power systems. The model represents the following elements:

Hydroelectric plants

- Detailed representation for each reservoir
- Storage and flow rate limits through turbines, spillways, head effect, infiltration and others;
- Stochastic inflow model representing seasonality, time and spatial correlations
- Modeling of specific climatic phenomena (such as El Niño), etc.
- Ramping constraints

Thermoelectric plants

- Unit commitment constraints
- Fuel availability
- Fuel contracts (including take-or-pay clauses)
- Thermal efficiency curves
- CO_2 and other pollutants emission
- Ramping constraints

Variable Renewable Energy *(VRE)*

Time Series Lab Model

- Definition of VRE historical generation through global reanalysis database
- Stochastic VRE power production model, generating future synthetic scenarios with hourly resolution
- VRE scenarios are temporally and specially correlated with hydro inflows

Transmission Network

- Kirchhoff laws
- Power flow limits
- Quadratic losses
- Security constraints
- Limits on export and import among electric areas, sum of flow constraints and others;

Natural Gas Network

- Gas production and transportation constraints
- Production capacity in the fields
- Pipeline flow limits and losses

Batteries and others fast response storage devices

- Storage capacity
- Charge/discharge capacities
- Efficiencies
- Ramping constraints.

OBJECTIVE

The objective of SDDP is to minimize the sum of costs for purchase and transportation of fuels for thermal plants, pollutant emission costs, hydro and thermal plants' O&M costs, transmission wheeling rates, cost of energy not supplied and other penalties. In order to do so, the model calculates the least-cost operation policy of the system. Furthermore, the following aspects are considered by the model:

- Study horizons from 1 year up to several decades
- Detailed representation with a temporal resolution as low as 5 minutes
- Demand Side Response: response to price signals by segment at system, area or bus level
- Co-optimization of energy and reserves, representing both energy and reserve markets

PARALLEL COMPUTING

Since the solution methodology is based on decomposing the original problem into smaller-size sub-problems (with one stage), computational efficiency may be increased if the parallel version of SDDP is used. The sub-problems can be solved simultaneously by several computers connected by a local network or in a multi-task computer.

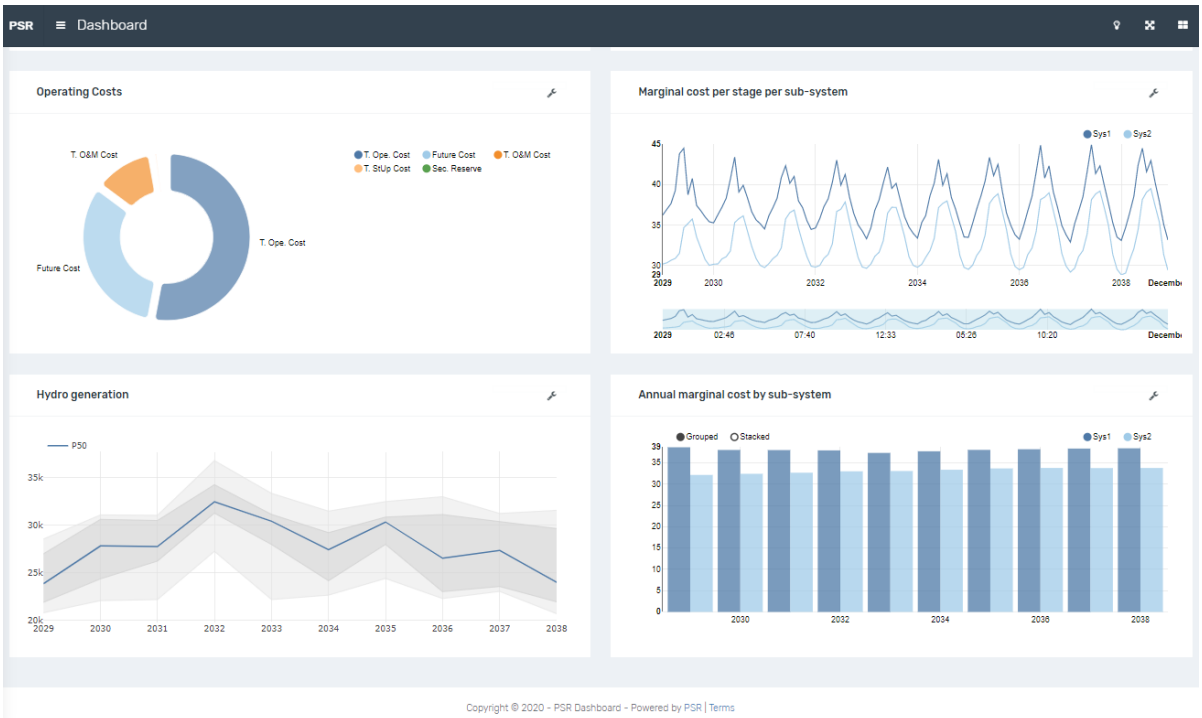
Additionally, it is possible to run SDDP using PSR Cloud which is a platform conceived to manage remote executions in a distributed process environment on PSR servers, taking full advantages of cloud computing capabilities.

SDDP MAIN RESULTS

SDDP produces over 350 reports in Excel-friendly formatted files. The results are managed by the graphical interface that extracts the desired statistics and creates charts directly in Excel.
SDDP's main results are:

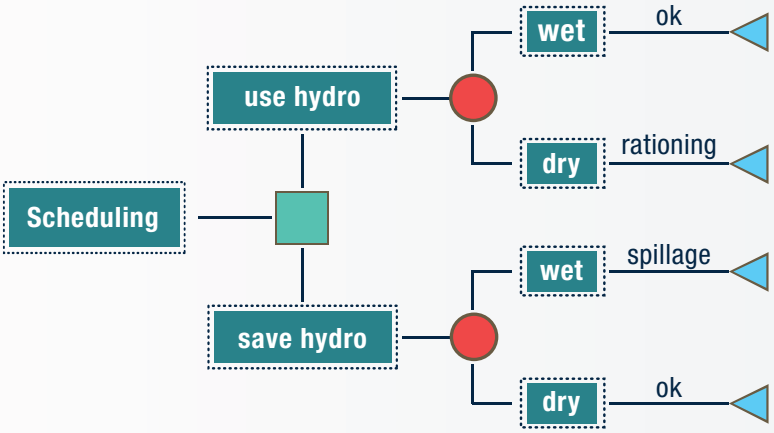
System operation statistics: deficit risks, transmission flows, emissions, production and respective costs among others	Locational marginal costs (for each region or bus)	Capacity marginal costs (measures the benefit of reinforcing a resource)	Transmission congestion costs	Water values in each hydroelectric plant	Marginal costs of pollutants with emission budgets

Furthermore, aggregated results such as average marginal costs, total generation and total costs are produced in CSV-format reports and can be visualized through a dashboard, shareable via internet link:



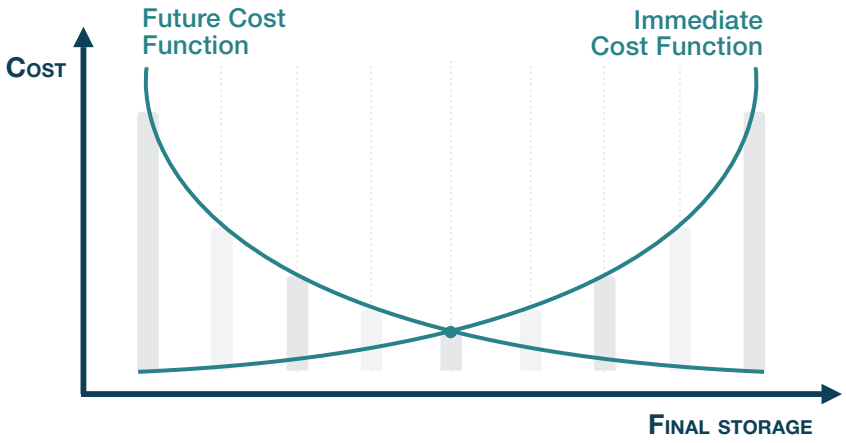
METHODOLOGY

Since hydro plants have no direct operating costs, one could think that they would come first in the merit order curve. However, there is an uncertainty regarding future inflows, as illustrated in the figure below.



Although hydro plants do not have a direct operation cost, they have an opportunity cost that reflects the benefit resulting from energy production in the future, and this cost depends on an analysis of the consequences of the decision of storing/using the water in all future scenarios.

The solution methodology traditionally used to solve this dispatch problem is known as Stochastic Dynamic Programming (SDP). Traditional SDP methods require the discretization of reservoir storage levels to represent the future cost function of each stage. However, due to this discretization, the computational effort of SDP grows exponentially with the number of reservoirs, which constrains the application of the traditional SDP for real large-scale systems.



SDDP stands for Stochastic Dual Dynamic Programming, an algorithm developed by PSR in the 1980s for solving large-scale multi-stage optimization problems under uncertainty. Unlike the traditional SDP, it's not necessary to enumerate the combinations of reservoir levels and the future cost function approximation is made through a Benders decomposition scheme. SDDP algorithm has been extended to several areas and became the global industry standard, with over 1.200 citations in the scientific/engineering literature. It has been successfully applied for more than thirty years for mid- and long-term optimal stochastic scheduling of very complex real systems with multiscale storage (hydro reservoirs, pumped hydro, batteries, fuel reservoirs, integral fuel contracts, multistage emission budgets constraints, etc.) and probabilistic modelings such as hydro inflows, renewable intermittency, demand, and fuel prices.

USES OF SDDP

The SDDP model has been used in studies for valuation of companies, international interconnections and analysis of new hydro, thermal and renewable power plants. It has also been used in operations studies in several countries in all the five continents:

AMERICAS	EUROPE	ASIA	OCEANIA	AFRICA
All countries in South and Central America, Dominican Republic, Mexico, United States and Canada	Austria, France, Italy, Germany, Spain, Norway (Nordic region), Belgium, Turkey, Greece, Iceland, Georgia and the Balkan region (Albania, Bosnia y Herzegovina, Bulgaria, Macedonia, Montenegro, Serbia, Kosovo, Romania and Slovenia)	Provinces in China (province de Shanghai, Sichuan, Guangdong and Shandong), Vietnam, Kirgizstan, Tajikistan, India, Sri Lanka, Philippines, Malaysia, Pakistan and Nepal	New Zealand and New Caledonia	Morocco, Tanzania, Namibia, Egypt, Sudan, Ethiopia, Mozambique and Ghana