



PSR

NETPLAN

GENERAL OVERVIEW

NetPlan is an integrated computational environment specialized for transmission network planning which includes:

- ✓ Data management tools (data editing, external data importation);
- ✓ Study management resources (data coherency checking and chronology);
- ✓ Visualization resources for the network and study results (schematic diagrams, circuit flows, overflow indicators, load marginal cost, contour plots)
- ✓ Graphical interface that allows interaction with the application.

The following planning applications are available in the NetPlan environment:

OptNet

for optimization of
expansion planning
with high voltage
transmission
systems

PSRFlow

for AC
transmission
network analysis

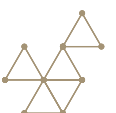
OptFlow

for planning
reactive power
resources (VAr)

Tariff

for power
transmission
cost allocation

All models use optimization tools are specially designed to solve large scale networks.



MODELING ASPECTS

The OptNet module - for transmission expansion planning - represents the transmission network system through linearized power flow model (power flow equations and circuit limits). Generation dispatch scenarios can be represented in order to account for uncertainties on generation production, e.g., renewable resources, inflows of hydro etc. Network expansion is formulated as a mixed integer linear optimization program, for each stage of the horizon (typically one year), where binary variables are used to represent investment decisions on pre-defined candidate circuits. OptNet module can represent the expansion process for the no contingency state (base case) as well as for a set of selected single contingencies.

The objective function consists in minimizing the investment costs (to install new transmission facilities as new AC transmission lines, transformers, series capacitors and DC transmission systems) and the supply reliability costs, providing the best investment x reliability trade-off solution. The solution of the optimization problem is performed by using advanced techniques of mixed integer programming, deriving additional constraints based on the transmission network topology and capacity.

The methodology combines a heuristic method that guarantees a feasible solution with a Bender's decomposition method that provides an optimal solution when the convergency is reached. Contingencies and dispatch scenarios are dealt by an incremental expansion strategy (a large number of dispatch scenarios and contingencies can be considered), which makes this algorithm suitable to be used with planning studies having a significant proportion of renewable generation.

The PSRFlow module is a suite of applications designed for steady state analysis of transmission networks. Two applications are included in the current version of PSRFlow module: a conventional power flow program and a contingency analysis program. The power flow application solves the load flow equations by use either a fast decoupled or a conventional Newton Raphson method, representing both, AC and DC controls. The contingency analysis application processes a list of contingencies with the objective to detect violations on the network (flow, voltage etc.).

The OptFlow module is the computational tool for reactive expansion planning. Different generation and load scenarios are represented to capture uncertainties in renewable sources, inflows of hydro, etc. The algorithm used by OptFlow models each OPF problem as a nonlinear optimization problem whose constraints include:

Kirchhoff laws active and reactive power balance in each node of the electric grid	Network operative limits such as bus voltage magnitude, active and reactive power flows in circuits, transformers tap and others;	Hydro, thermal and renewable generation constraints
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The objective function considers the minimization of the sum of shunt investment cost and the deviation of active power generation.

Decision variables include active and reactive power generation nodes voltage, transformers taps and capacitors/reactors susceptances. The solution methodology used by OptFlow model consists in applying a robust primal-dual interior point algorithm.

The investment solution provided by the model will guarantee the operation of each generation and load scenario, respecting its operating constraints and where all available reactive controls have been considered.



The Tariff module (coming soon) is a computational tool able to promote the allocation of costs related to the transmission system infrastructure among its users, based on sophisticated methodologies that can identify how users (producers and consumers) "use" the system and allocate costs accordingly. Three different transmission cost allocation methodologies are available in the tariff module.


Nodal


**Average
Participation
Factors**


**Aumann-
Shapley**

Tariff module can allocate the costs of use transmission network considering an extensive range of operating scenarios under multiple allocation strategies, making tariff calculations more adherent to the actual electrical system operation and planning.

The ability to allocate transmission costs and forecast tariffs represent a powerful capability. It can be handy for system **planners and regulators** since, with a proper cost allocation, they can reveal the actual costs of the integrated **Generation and Transmission (G&T) expansion** and promote cost allocation and determination of tariffs. Besides, **generators and consumers** can forecast their expenses with charges for using the transmission system, which can support its investments decision and planning.

GRAPHICAL INTERFACE

The NetPlan graphical interface, shown in Figure 1, is an integrated environment providing data editing and visualization tools such as:

- ✓ 1- A menu and a toolbar area at the top;
- ✓ 2- The main graphical window that shows the transmission system drawing;
- ✓ 3- A visualization filtering toolbar at the left;
- ✓ 4- A status bar at the bottom.

The area of the menu and toolbar implements the management of:

Data editing;

Transmission system elements visualization;

Analysis and expansion plans cases;

Scenarios definition;

Execution control of the models.



The main graphical window shows the transmission system drawing, which includes nodes (located by their geographic coordinates) with different types of connected devices (generators, shunts and static VAr compensators), transmission lines, transformers, series capacitors and DC transmission systems. Nodes and circuits are represented by a set of colors based on their nominal voltage. Line color, style and thickness are used to distinguish register, planned and candidate circuits. Several functionalities are available directly over the diagram, like:

- ✓ View and Edit any data of the transmission system elements;
- ✓ Visualize connections of a node (using a detailed view);
- ✓ Estimate transmission line lengths and distance between nodes;
- ✓ Illustrate the results produced by the models (see the section Results).

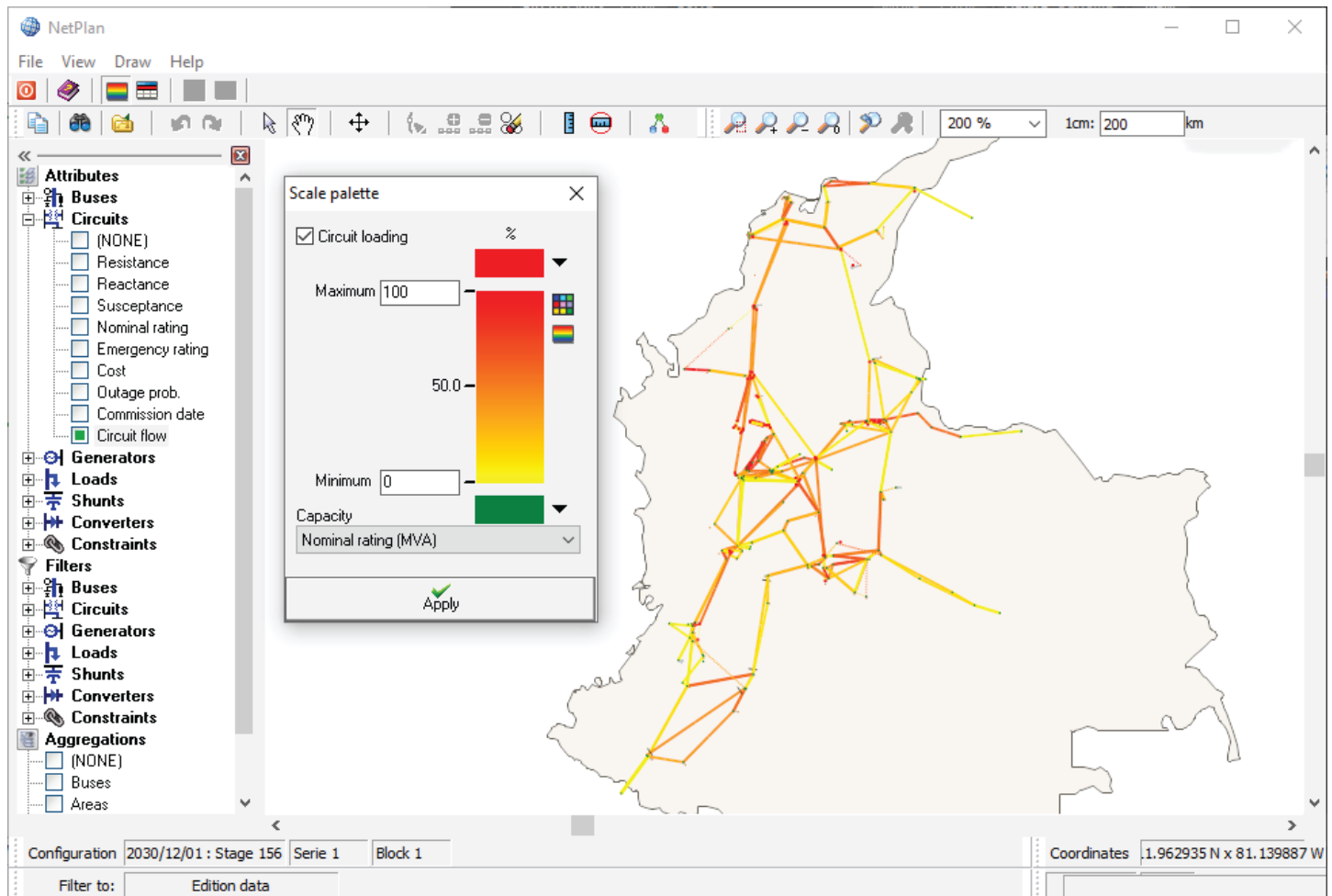
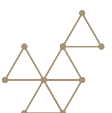


Figure 1 - NetPlan graphical interface

The visualization filtering toolbar, at the left, controls the objects (elements) that are displayed in the main graphical window, allowing a fast and simple reconfiguration of the network diagram, in order to highlight or hide parts of the drawing. Moreover, abstract representations of the grid are available, i.e.,

nodes, areas or even regions can be displayed in an aggregated way, for a clean visualization. The status bar shows information about the stage, generation scenario of the current configuration, latitude and longitude coordinates of the cursor and the variable selected to be shown in the network diagram.



RESULTS

NetPlan can display the results of the models directly on the transmission network diagram using a color schemes to highlight magnitudes of the selected variables. Circuit coloring and nodal contouring plot are available to illustrate, for example, the following results:

✓
Circuit flow and overloading

✓
Power injections (active/reactive)

✓
Losses on transmission branches

✓
Bus marginal costs

✓
Bus voltage

Figure 2 shows the power flows on the circuits for the WECC system - colors are used to illustrate the usability of the circuits, while highlighted-red circuits represent overloads.

NetPlan also displays nodal results like voltages, marginal costs, generation, and loss of load, among others. Nodal results can be used to build nodal contouring plots, for example, the Figure 3 illustrates bus marginal costs which, according to the colors legend, shows in blue the minimum values and in red the maximum values for the displayed results. The colors pallet also allows specifying minimum and maximum bounds for values.

Alternative views of the network can be created to highlight any area(s), any region(s) or even groups of buses selected through filters. Figure 3 presents a view zoom in on a part of the transmission network.

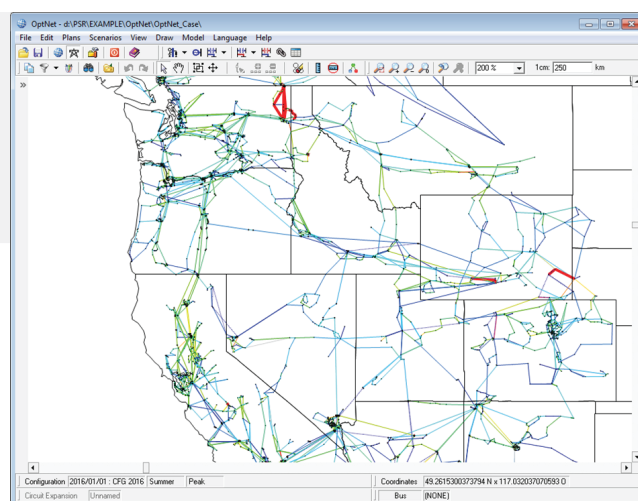


Figure 2 – Network diagram with geographical map in background

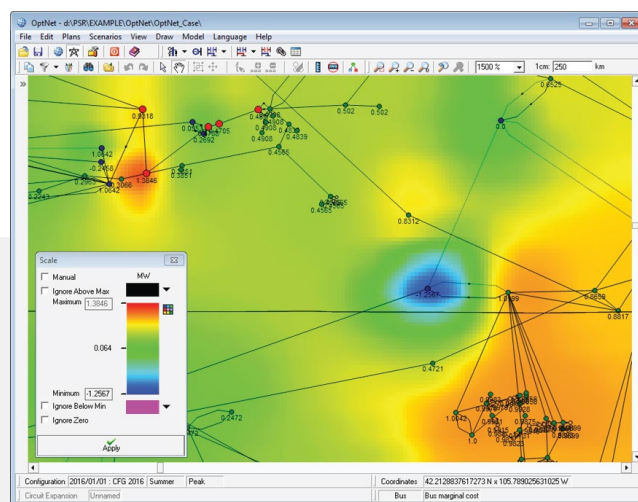


Figure 3 – Contour Plot with color coded bus marginal costs

Besides the results showed in the diagram, the models also produce detailed and summarized text, spreadsheet, and graphical reports:

- ✓ Transmission expansion investments;
- ✓ Circuit power flows and circuit loadings;
- ✓ Active and reactive power generation, voltage magnitude and angle, transformers tap, phase shifter angle, shunts installed and connected, operation of static var compensator;
- ✓ Marginal cost associated to the active and reactive power balance in each node.
- ✓ Severity report for selected contingencies.

Figure 4 shows examples of spreadsheet plots of expansion plan outputs.



Figure 4 – Plots of investments in transmission lines and transformers

DATA BASE

NetPlan provides facilities to import data from other transmission network modeling tools. In the current version the NetPlan data base can be automatically created from PSR Stochastic Dual Dynamic Programming (SDDP), Siemens PTI Power Flow Program (PSS®E), GE Power Systems Analysis Software (PSLF), and CEPEL Network Analysis Program (ANAREDE).

RECENT APPLICATIONS

<p>Designing alternatives for the future development of the Chilean National Transmission System, for the horizon 2019-2040. NetPlan application OptNet was used to optimize the expansion of the transmission network for each generation expansion scenario, considering the insertion of variable and intermittent energy resources (wind and solar photovoltaic) and batteries.</p>	<p>NetPlan application OptNet was used to optimize the network expansion for the Brazilian system for the horizon 2035, considering a large degree of renewable energy sources (wind and solar).</p>	<p>Analysis and regulatory proposals for the Ancillary Services required in the Colombian National Interconnected System (SIN), considering the insertion of variable energy renewable resources and new technologies in high and low voltage. NetPlan was used to study the expansion of the Colombian transmission system for the horizon 2019-2040.</p>
<p>Renewable integration of South America (SINEA - Southern Cone). NetPlan were used to optimize the transmission expansion (2017-2035) in nine South America countries: the Andeans: Chile, Colombia, Ecuador and Peru; and the Southern Cone: Argentina, Brazil, Paraguay and Uruguay; and Bolivia.</p>	<p>Expansion planning of the transmission network of WECC for a 15-year horizon, peak yearly dispatch scenarios and 960 projects.</p>	<p>Analysis and regulatory proposals for transmission cost allocation mechanisms in Brazil. NetPlan was used to simulate the transmission tariff calculation using different methodologies in order to assess the impacts over tariffs of generators represented by the Brazilian Wind Power Association.</p>

