Energy-related optimization challenges and approaches in Colombia

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Topics of this talk

Robust hydrothermal scheduling

Integrated Generation-Transmission Expansion Planning

Hydrothermal Scheduling

Goal

Satisfy electricity demand by scheduling a set of hydro and thermal generators in a cost-efficient manner via the following optimization problem:

- Minimization of operating cost of electricity production
- subject to:
    - Total electricity production must meet electricity demand.
    - Reservoir dynamics.
    - Operational limits of thermal power plants.
    - Operational limits of hydro power plants.
    - Operational limits of the transmission network.
    - Operational and environmental limits of reservoir.

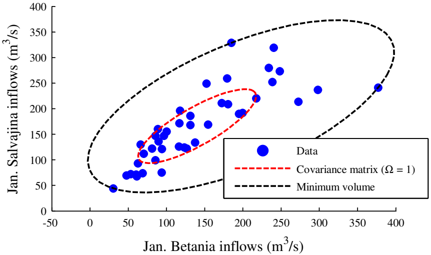
General mathematical formulation

$$
\begin{aligned}
\underset{x^d, x^a}{\text{minimize}} \quad & \sum_t \left(c_t^\top x_t^d + d_t^\top x_t^a \right) \\
\text{subject to} \quad & \sum_{\tau \le t} \left(A_\tau x_\tau^d + B_\tau x_\tau^a \right) \le b_t + \sum_{\tau \le t} D_\tau \tilde{I}_\tau , \\
& \forall t \in 1, \ldots, T, \text{ and } \forall \left[\tilde{I}_1 ; \tilde{I}_2 ; \ldots ; \tilde{I}_T \right] \in \mathcal{U}_\Omega
\end{aligned}
$$

- Vector x_t^d represents the *actual* decisions the planner has to make at time t (hydro and thermal generation)
- Vector x^a: variables *needed* to fully describe the mathematical model do not represent a real decision (voltage angles, power flows).
- Equalities are avoided. That is the reason why time coupling is reflected from $\tau = 1, \ldots, t$.
- $\tilde{I}_t$ refers to uncertain water inflows at time t.
- $\mathcal{U}_\Omega$ is the uncertainty set for water inflows.

Uncertainty sets

- Points represent historical data (monthly inflow)
- Several approaches were considered to construct an uncertainty set:



- Mathematical representation:

$$\mathcal{U}_\Omega = \left\{ \tilde{I} \in \mathbb{R}^k : \left\| Q^{-1/2} \left(\tilde{I} - \bar{I} \right) \right\|_2 \leq \Omega \right\}$$

- Ω controls the level of uncertainty.

Robust vs Adjustable Robust Optimization

- Traditional RO focuses on making decisions under wrost-case realizations of uncertainty.
- It is really conservative when it comes to make decisions over time.
- All decisions are "here and now".
- "Adjustable" means that decisions are not necessarily static over time. That is,

$$x_t = f_t\left(\zeta_{[t]}\right)$$

  where $\zeta_{[t]}$ refers to available information at time t.
- f_t is a function that maps data into a time t decision.
- Finding the optimal f_t is difficult problem.
- We stick to the affine case given acceptable arguments presented in the literature.

Affine decision rules

- Problem is less difficult since need to find parameters of an affine function:

$$x_t^d = \gamma_t^0 + \mathbf{1}_{\{t \geq 2\}} \sum_{\tau=1}^{t-1} \Gamma_t^\tau \tilde{I}_\tau, \ \forall t = 1, \ldots, T$$

$$x_t^a = \pi_t^0 + \sum_{\tau=1}^{T} \Pi_t^\tau \tilde{I}_\tau, \ \forall t = 1, \ldots, T$$

- Coefficients are the new decision variables of the optimization problem
- If $Gamma_t^\tau = 0$ and Pi_t^τ, the model is nothing but a static RO model.

RC of ball uncertainty set

Consider $\mathcal{Z}$ is a circle, i.e.,

$$\mathcal{Z} = \left\{ \zeta \in \Re^L : \|\zeta\|_2 \leq \Omega \right\}$$

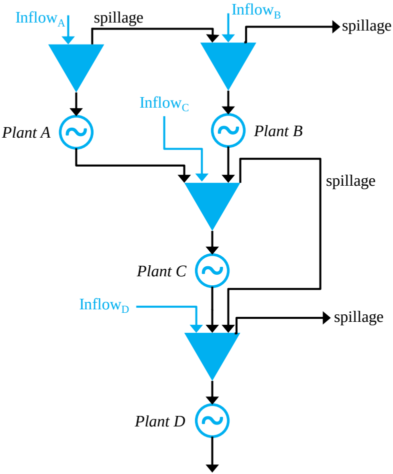
The uncertain constraint:

$$(a^0)^\top x + \sum_{l=1}^{L} \zeta_l (a^l)^\top x \leq b^0 + \sum_{l=1}^{L} \zeta_l b^l, \ \forall (\zeta : \|\zeta\|_2 \leq \Omega)$$

becomes

$$(a^0)^\top x + \Omega \sqrt{\sum_{l=1}^{L} ((a^l)^\top x - b^l)^2} \leq b^0 : \text{ second-order cone}$$

Results



- Typical hydro chain in Colombia
- 12 months and 4 hydro power plants (dimension of $\mathcal{U}$ is 48).
- 6 buses and 8 transmission lines were considered.
- The static solution was obtained only for $\Omega \leq 0.1$, i.e., this solution is protected against random inflows realizing at the mean $\pm$ 0.1 standard deviations.

Price of robustness

- PoR is seen as extra cost needed to protect the solution against uncertainty.
- Static model is not even feasible for $\Omega = 1$

Ω	Cost	
	Expected	PoR
0.0	180.67	N.A.
0.5	184.53	2.1%
1.0	212.49	17.6%
1.5	218.22	20.8%
2.0	229.58	27.7%

Affine decision rules results

$$
\begin{bmatrix} g_3^A \\ g_3^B \\ g_3^C \\ g_3^D \end{bmatrix} = \begin{bmatrix} 409.6 \\ 97.6 \\ 160.3 \\ 489.3 \end{bmatrix} + \begin{bmatrix} -0.6 & -0.7 & -4.3 & 2.1 \\ 0.6 & -0.6 & 3.0 & -2.0 \\ 0.1 & -0.2 & 0.2 & -0.2 \\ 0.1 & -0.9 & 4.0 & -3.0 \end{bmatrix} \begin{bmatrix} \tilde{I}_1^A \\ \tilde{I}_1^B \\ \tilde{I}_1^C \\ \tilde{I}_1^D \end{bmatrix}
+ \begin{bmatrix} 6.7 & -6.0 & 2.2 & -3.9 \\ -2.3 & 3.2 & -2.8 & 1.9 \\ -0.1 & 0.3 & 0.3 & 0.2 \\ -0.7 & 2.8 & 0.5 & 6.0 \end{bmatrix} \begin{bmatrix} \tilde{I}_2^A \\ \tilde{I}_2^B \\ \tilde{I}_2^C \\ \tilde{I}_2^D \end{bmatrix}
$$

- generation of plant A g_3^A has a strong fixed component of 409.6 MW;
- Results also show temporal dependence with inflows.
- Results can provide some intuition about what happens between plants.

Conclusions

- Historical data can be used to tune the uncertainty set.
- Conservatism can be reduced when considering correlations between. uncertain parameters.
- Affine decision rules provided a wider range of solvability to a problem that is almost unsolvable using the traditional static RO.
- Decomposition/distributed techniques are required to improve computational performance.
- This approach can be extended to renewable generation uncertainty.

Integrated Transmission-Generation Expansion Planning in Colombia (ITGEP)

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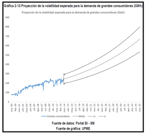
- Research project dedicated to construct a decision-making model to support the expansion planning process in Colombia.
- Need to decide whether or not to construct generation and transmission projects.
- Tool designed to the Colombian planning entity—UPME.

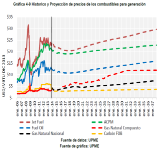
Integrated Transmission-Generation Expansion Planning in Colombia (ITGEP)

Inflow



Demand

Renewable resources



Fuel prices

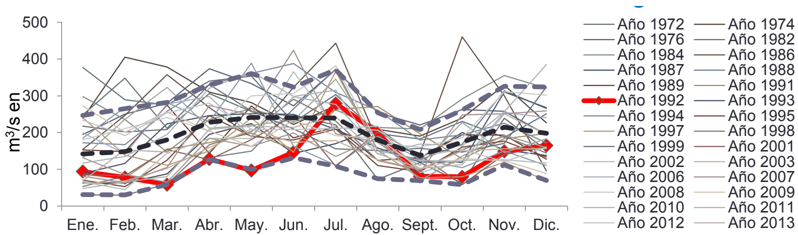
ITGEP (gams)

Expansion Plan G-T

-Where and how much G?
Where and how much T?

Motivation

- Need to coordinate decisions.
- Environmental constraints imposed to transmission projects have become more stringent.
- Need to consider more small-scale generation projects and renewable technologies (solar PV and wind).
- Need to prepare for critical energy supply conditions.



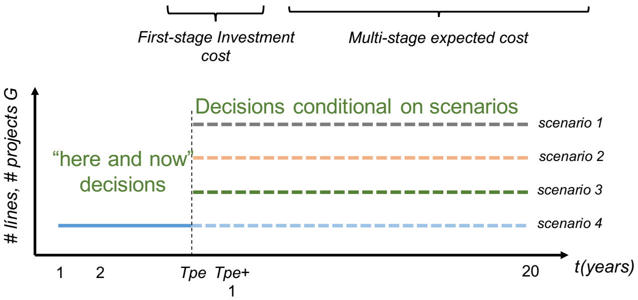
Stochasticity

- Hydrological uncertainties coded through scenarios
  - Multiple reservoirs
  - No weather seasons in Colombia. Only rain and dry season.
  - Power system operation is really sensitive to hydro resource changes.
- Fossil fuel price uncertainties
  - Coal price fluctuactions.
  - Natural gas price fluctuactions.
- Demand uncertainty.
- Renewable resources variability is also considered.

Stochastic Planning

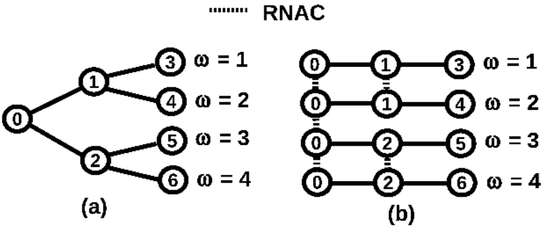
- Minimization of present value of expected investment and operation costs.
- Nonanticipativity conditions guarantee first-stage decisions fulfill needs of all scenarios.

$$\text{minimize: } \textit{Cost Inv}^{(1)} + \mathrm{E}[\textit{Cost Inv}^{(2)}\,(w) + \textit{C. Oper}\,(w)]$$



Scenario decomposition

- Progressive hedging.
- Useful approach for understanding individual effects of each scenario.
- Every optimization instance is as difficult/easy as the deterministic model.



The algorithm

Let $\chi_s \in \Re^{n_1}$, $\forall s \in \mathcal{S}$ be the decision variable vector $x^{\mathrm{G}}_{g_c,t,s}$ and $x^{\mathrm{T}}_{l_c,t,s}$ for $t \in \left[1,\, T^{\mathrm{PE}}\right]$.

$$\left(\nu_s^{k+1}, \chi_s^{k+1}\right) := \underset{(\nu_s,\chi_s)\in\mathcal{X}_s}{\operatorname{argmin}} \left(f_s\left(\nu_s, \chi_s\right) + y_s^{k\top}\left(\chi_s - \bar{\chi}^k\right) + (\rho/2)\left\|\chi_s - \bar{\chi}^k\right\|_2^2 \right)$$

$$y_s^{k+1} := y_s^k + \rho\left(\chi_s^{k+1} - \bar{\chi}^{k+1}\right),\ \forall\, s \in \mathcal{S}$$

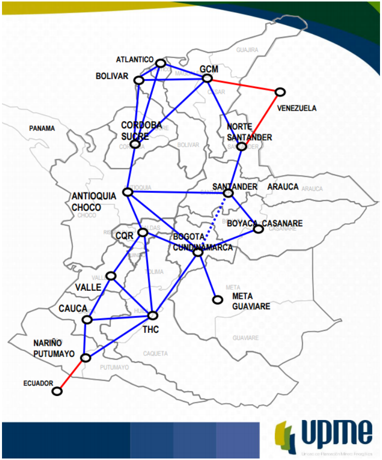
where

$$\bar{\chi}^k = \sum_{s\in\mathcal{S}} p_s \cdot \chi_s^k.$$

- Nonconvexity of the problem worsens the computational performance.
- Several improvements proposed by J.P. Watson and D. Woodruff were considered.

Experiments

- Planning horizon 20 years
- Yearly investment decisions
- Reduced network employed by UPME.
- N-1 contingencies considered.
- Ten scenarios (for now).
- Three different loading levels in a typical day.
- Three operating conditions per year.



Conclusions

- The ITGEP model is the first optimization model constructed for the Colombian planning process.
- The tool can handle multiple user-defined scenarios. Limits are imposed by CPU time available.
- Need to refine the tunning process of decomposition algorithms.
- We expect to keep improving the model from both the research and practical standpoint.

Collaborators

UNIVERSIDAD DE ANTIOQUIA 1803

PLANEACIÓN INTEGRADA GENERACIÓN-TRANSMISIÓN EN COLOMBIA

Convocatoria COLCIENCIAS No. 643 de 2014

GMEL

upme
Unidad de Planeacion Minero Energetica

COLCIENCIAS
Departamento Administrativo de Ciencia, Tecnología e Innovación

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DECISION TOOLS

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