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A pesquisa
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Analytical computation of marginal values for hydro generation for mid/long-term planning

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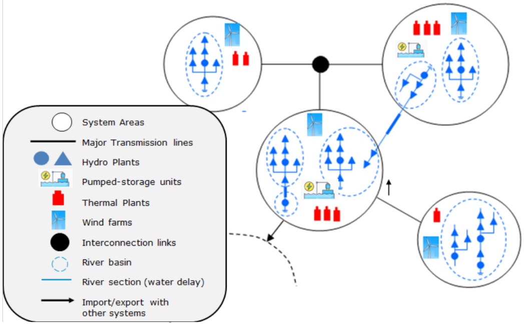
Midterm Hydrothermal Planning Problem (MTHTP)

- Multi-stage: **2 to 12 months** horizon divided **weekly or monthly**
- Stochastic: Joint **inflow** and **wind** scenarios generated by an auto regressive model
- Plants: **hydro, thermal** and **wind** plants in interconnected **subareas**
- Several electric and hydro constraints
- Modeled as piecewise linear optimization solved with decomposition techniques (Dual Dynamic Programming - DDP)
- The objective is to find a dispatch that minimizes the cost (present and future) under a risk criterion while respecting the system constraints



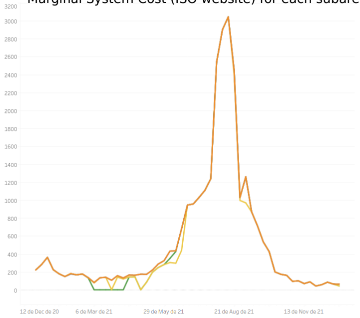
Given that problem, we aim to calculate marginal costs for hydro plants in order to better understand system operation and measure the price of a hydro generation

Marginal System Operating Cost (MSC)

MSC is the incremental cost ($\$/MWh$) to meet an increase in the system load

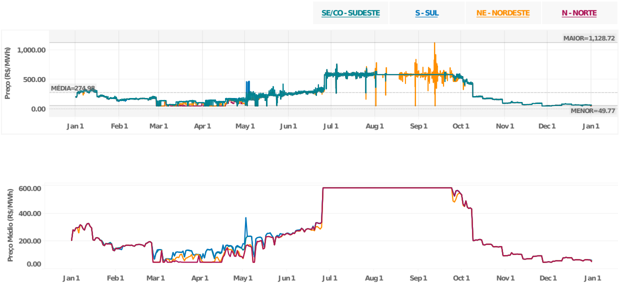
- Used for price definition (spot price) and market strategies.
- It is directly extracted from the dual values of the load balance equations in the optimal solution of the MTHTC problem

Marginal System Cost (ISO website) for each subarea



year: 2021

Spot prices (Market regulator website) for each subarea



Marginal Thermal Cost (MTC)

Represents the incremental cost ($\$/MWh$) of a thermal plant

- Given by the product of thermal fuel costs and consumption rate
- It is usually an input data on the MTHTC problem.

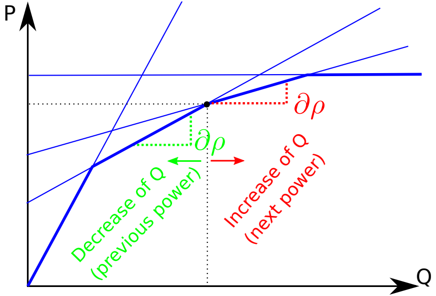
Marginal Productivity ($\partial\rho$) of a hydro plant

The sensitivity on **energy generated** by an infinitesimal increase of the **turbined** water (thus, a decrease on the **volume level** - upstream head), given in MWh/hm^3.

non-linear model of HPF: $\mathbf{P} = \eta \times (h_m(\mathbf{V}) - h_j(\mathbf{Q}, \mathbf{S}) - h_l) \times \mathbf{Q}$

piecewise linear model of HPF: $\mathbf{P} = \alpha \times (\gamma_0^{(k)} + \gamma_V^{(k)}\mathbf{V} + \gamma_Q^{(k)}\mathbf{Q} + \gamma_S^{(k)}\mathbf{S}), k = 1, ..., NCUT$

- $\partial\rho = \frac{\partial P}{\partial Q} - \frac{\partial P}{\partial V} = \alpha(\gamma_Q^k - \gamma_V^k)$
- Where k is the active cut on the approximated HPF.
- When there are more than one active cuts, the marginal productivity of the next generated power is different from the previous one.

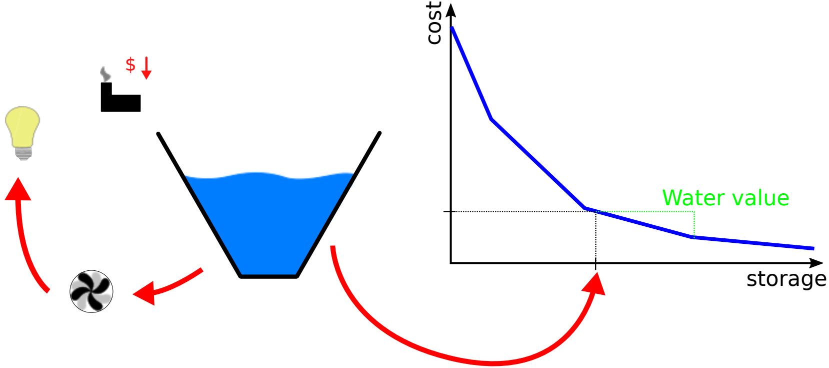


Water Values in a reservoir

Represents the incremental benefit ($\$/hm^3$) for the system on keeping the water stored for future usages.

Generate hydro ⟶ lower present cost

Store water ⟶ lower future cost



Marginal Hydro Cost (MHC)

Represents the incremental cost of the released water in a hydro plant ($\$/MWh$)

- Water is free, but deciding **when** to use that water may impact system prices
- Using the water to replace a cheap thermal plant in the present may be not the best police if its possible to store the water to replace the generation of an expensive thermal plant in the future.
- The Marginal Cost of a Hydro Plant depends on the system decisions:
  - the water value in the future at the current storage
  - marginal hydro productivity at the operation point

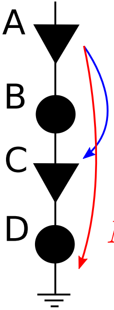
  These aspects are related to the solution of the MTHTP.

The MHC computation allows to compare hydro with thermal and system marginal costs and to evaluate the impact of hydro constraints in the system operation costs.

Computation of MHC

Isolated plant A: $MHC_A = \dfrac{WV_A \quad (\$/hm^3)}{\partial\rho_A \ (MWh/hm^3)}$

Plant A with downstream plants:



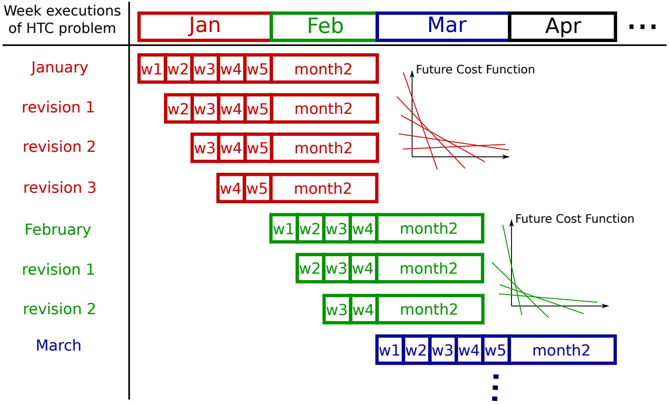
$$MHC_1 = \frac{WV_A - WV_C}{\partial\rho_A + \partial\rho_B}$$

$$MHC_2 = \frac{WV_A}{\partial\rho_A + \partial\rho_B + \partial\rho_C + \partial\rho_D}$$

$$MHC_A = \min(MHC_1, MHC_2)$$

Application on MTHTP

The midterm model is officially executed every week with a ”rolling horizon” scheme to calculate: weekly prices, the future cost function (FCF) for the short-term model, weekly operation of the plants and constraints



Week executions of HTC problem

Jan Feb Mar Apr ...

January: w1 w2 w3 w4 w5 month2

revision 1: w2 w3 w4 w5 month2

revision 2: w3 w4 w5 month2

revision 3: w4 w5 month2

February: w1 w2 w3 w4 month2

revision 1: w2 w3 w4 month2

revision 2: w3 w4 month2

March: w1 w2 w3 w4 w5 month2

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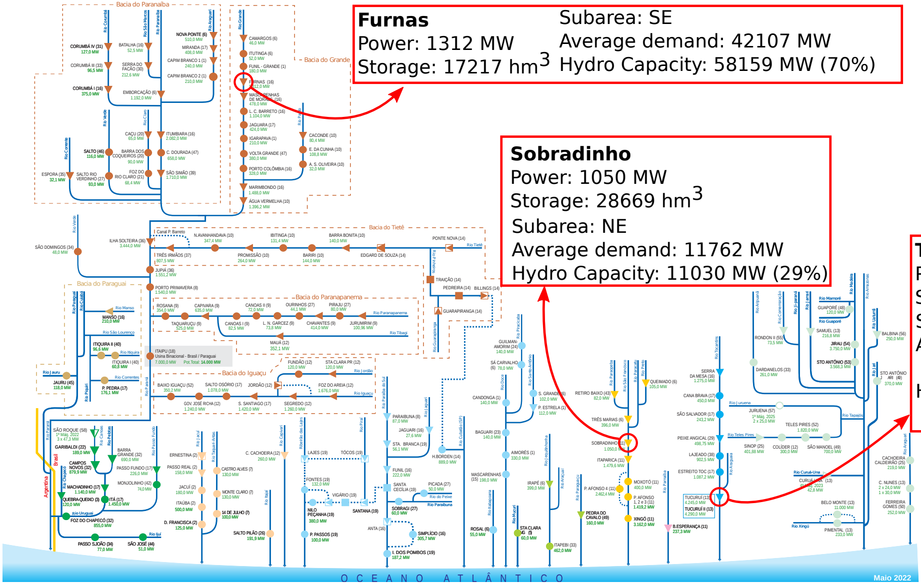
Every week updates (revisions):

- the forecasts
- initial volumes in the reservoirs

Every month updates:

- constraints (electrical and hydro)
- the long term FCF

Hydro system



Furnas
Power: 1312 MW
Storage: 17217 hm^3

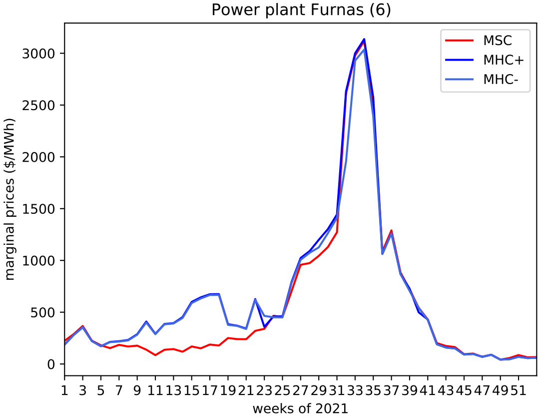
Subarea: SE
Average demand: 42107 MW
Hydro Capacity: 58159 MW (70%)

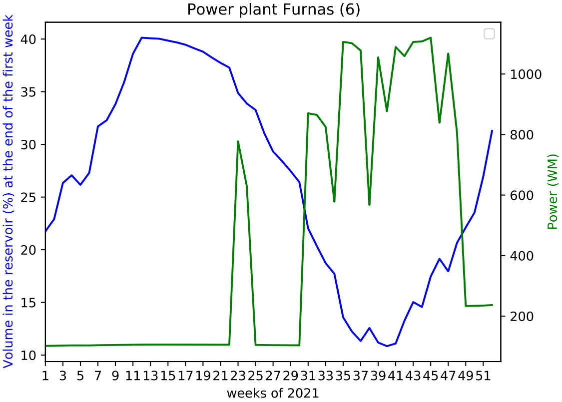
Sobradinho
Power: 1050 MW
Storage: 28669 hm^3
Subarea: NE
Average demand: 11762 MW
Hydro Capacity: 11030 MW (29%)

Tucurui
Power: 16283 MW
Storage: 38982 hm^3
Subarea: N
Average demand: 5595 MW
Hydro Capacity: 22259 MW (85%)

Results - Furnas - SE

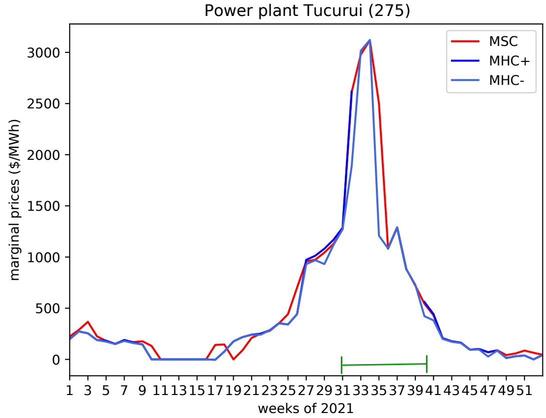
- A minimum outflow constraint is active most part of the year, the hydro cost is higher that the system cost, especially between week 5 and 22.

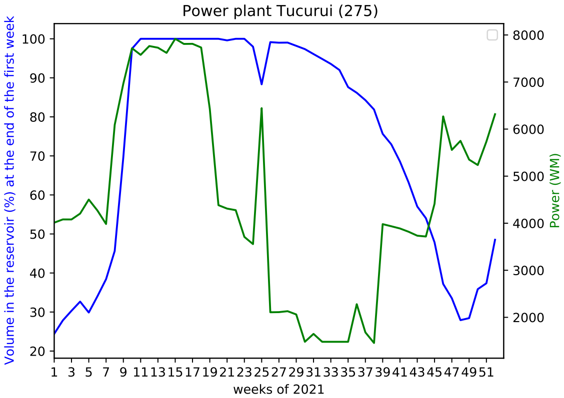




Results - Tucurui N

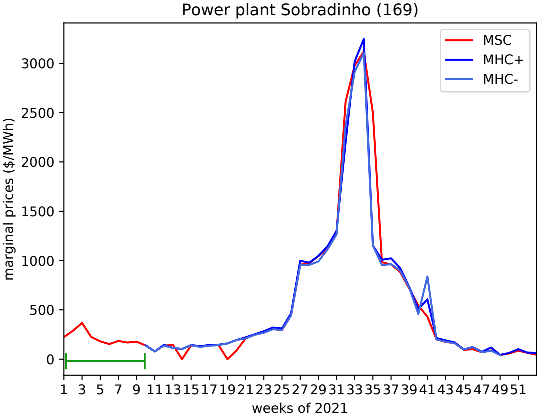
- There is a hard fixed storage constraint from week 31 to 41 which prevents the plant from generating (the MHC is not defined due to the constraint violation)

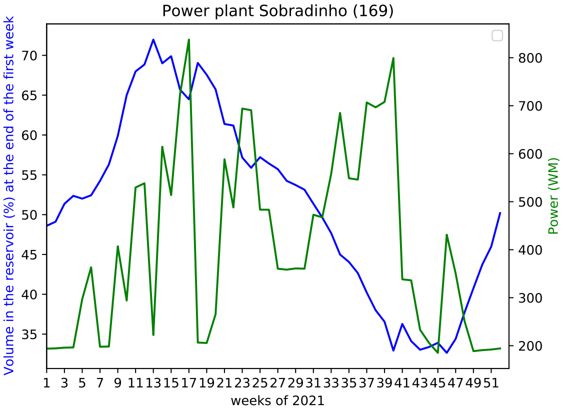




Results - Sobradinho - NE

- The plant and some downstream plants have minimum outflow constraints that impose the generation regardless the costs. These inflexibilities restrain the plant from storing for the critical season of the year.





Conclusions

- The operation of plants in large cascades is a challenge:
  - the complexity of the optimization problem, the plant operation has impact on the entire cascade.
  - the uncertainty on the inflows
  - several constraints related to other usages of the water and environment
  - large reservoirs play an important role on energy security (future)
- Large interconnected systems, like in Brazil, impose even more complexity to the problem.
- To be able to measure the Marginal Hydro Cost allows to better evaluate and understand the operation given by an MTHTP model.
- It also enables to measure the impact of constraints on the total system operation cost.