Programa de Pós-Graduação em
Engenharia Elétrica
Mestrado - Doutorado (Conceito 4 CAPES)

Hydrothermal system operation planning considering hydroelectrical plant production non-linearities

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Agenda

- Introduction
- Proposed Methodology
- Problem Formulation
- Results
- Conclusion

Introduction

- Hydrothermal System

The main objective of the hydrothermal system operation planning is to minimize the expected operating cost of the system over the considered period.

These costs are composed by thermal generation and deficit costs

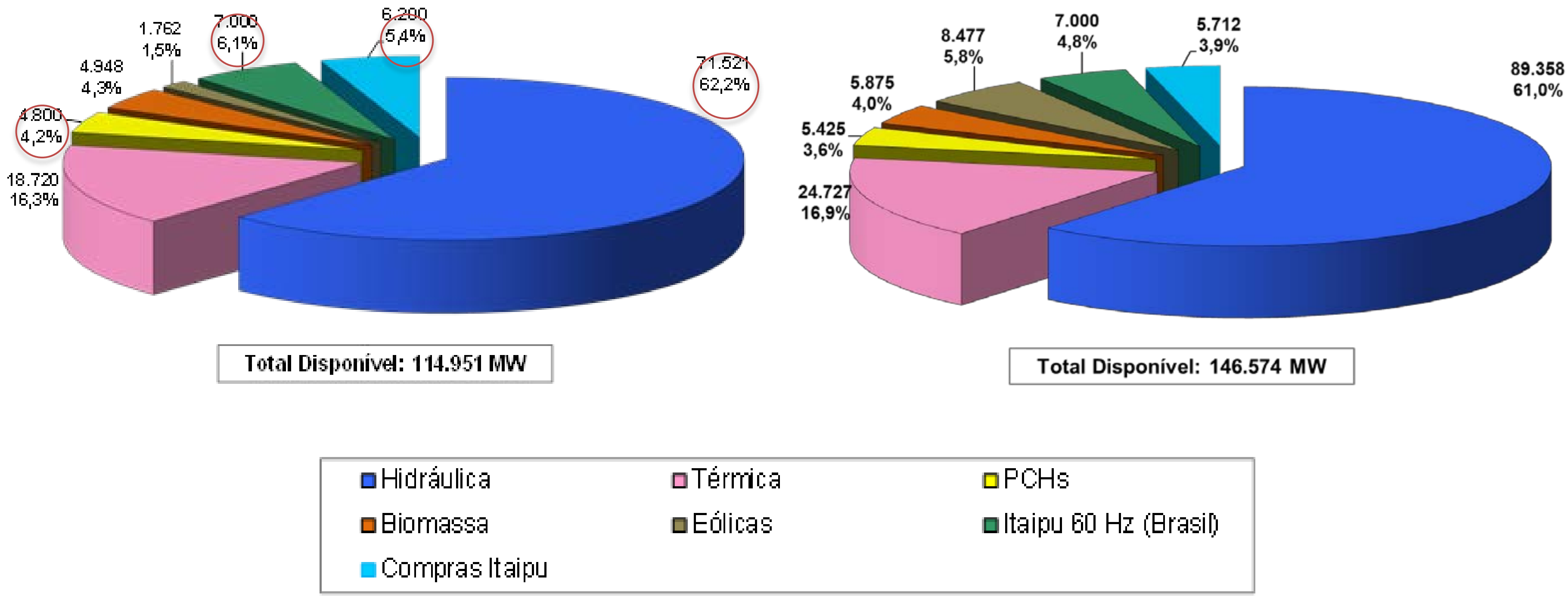
Brazilian System Characteristics

Installed Capacacity

31/12/2012

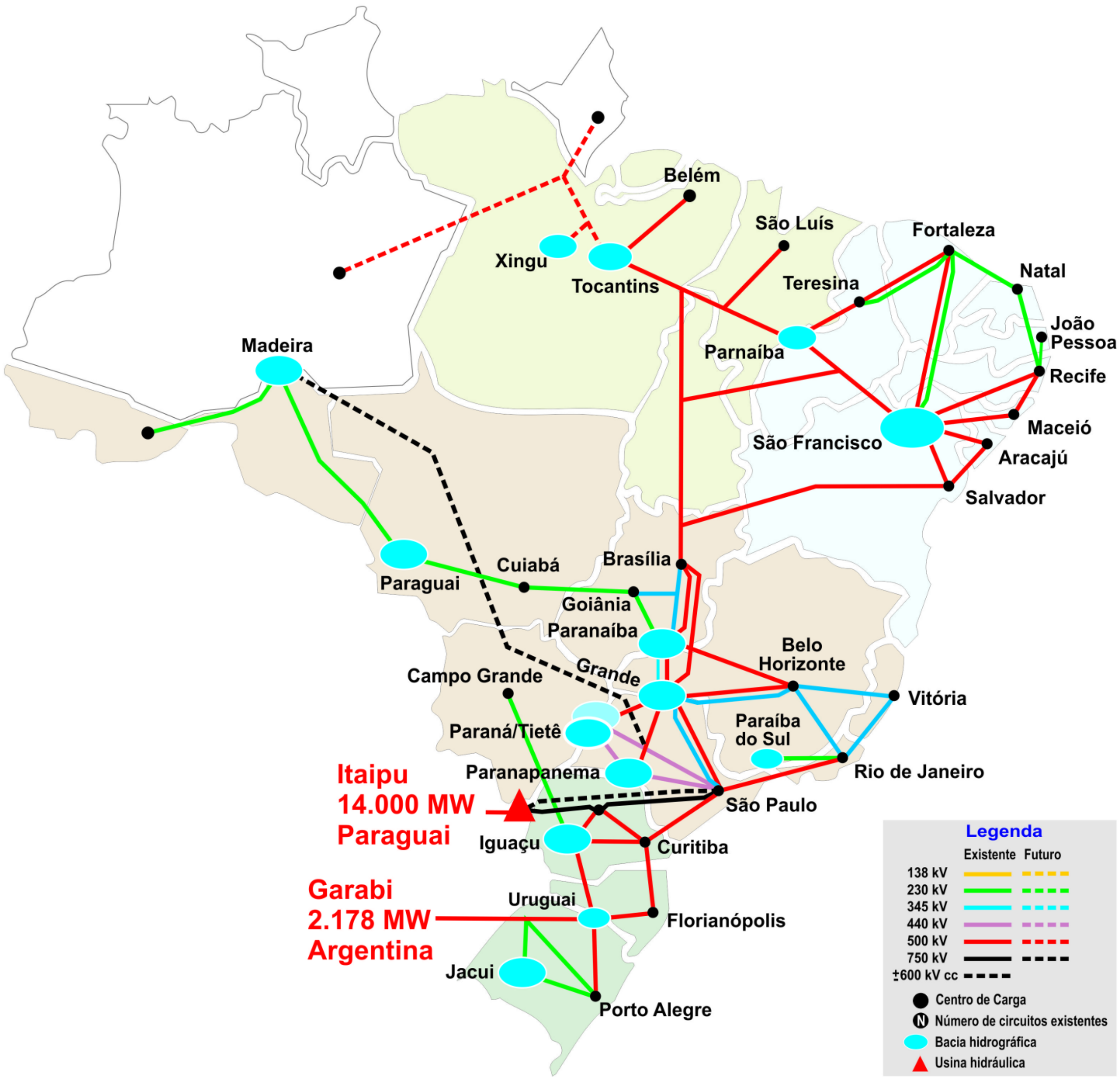
Installed Capacity

31/12/2017



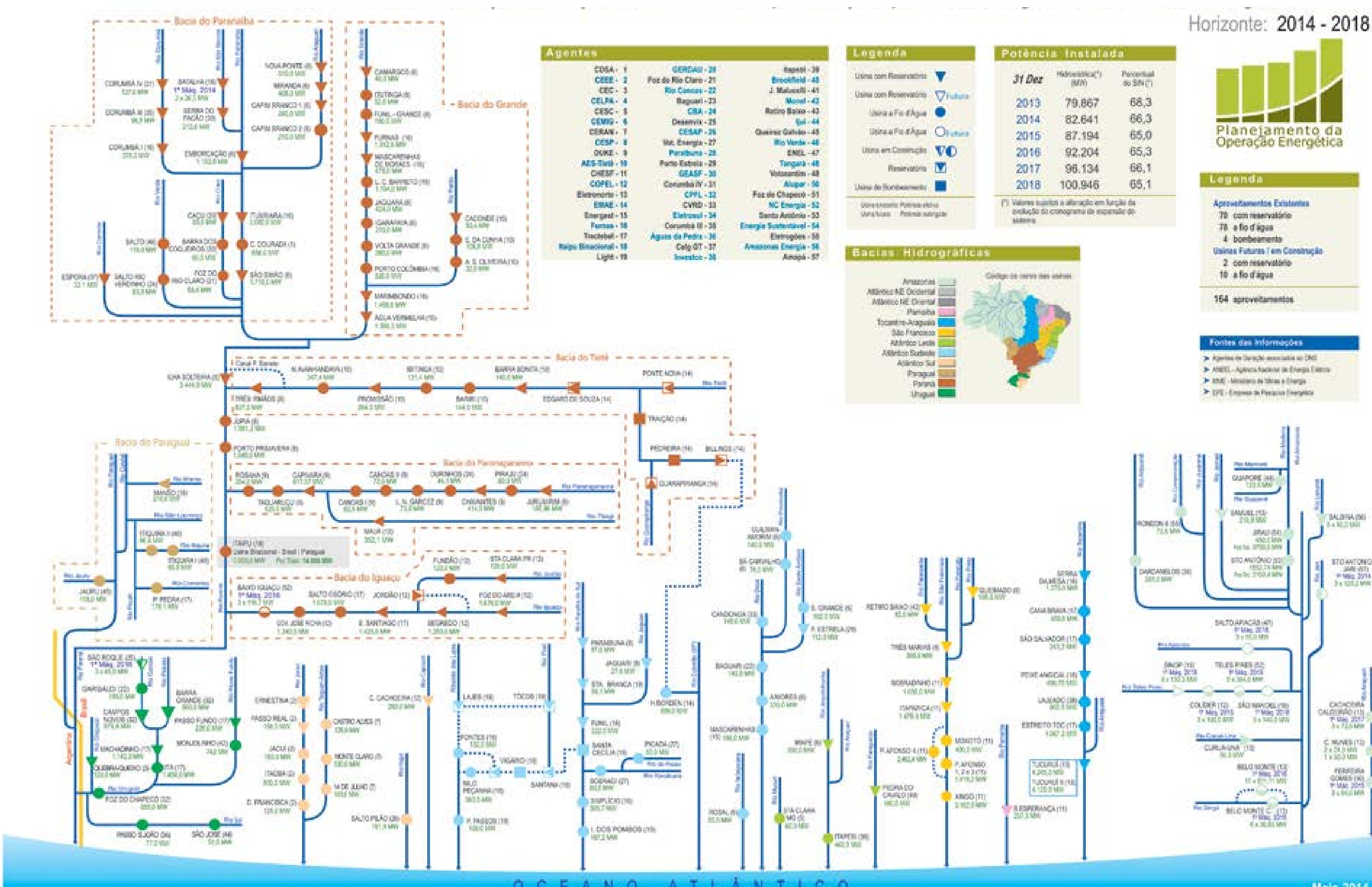
Fonte: PEN 2013, ONS

Introduction



Introduction

SCHEMATIC DIAGRAM OF HYDRO PLANTS



Introduction

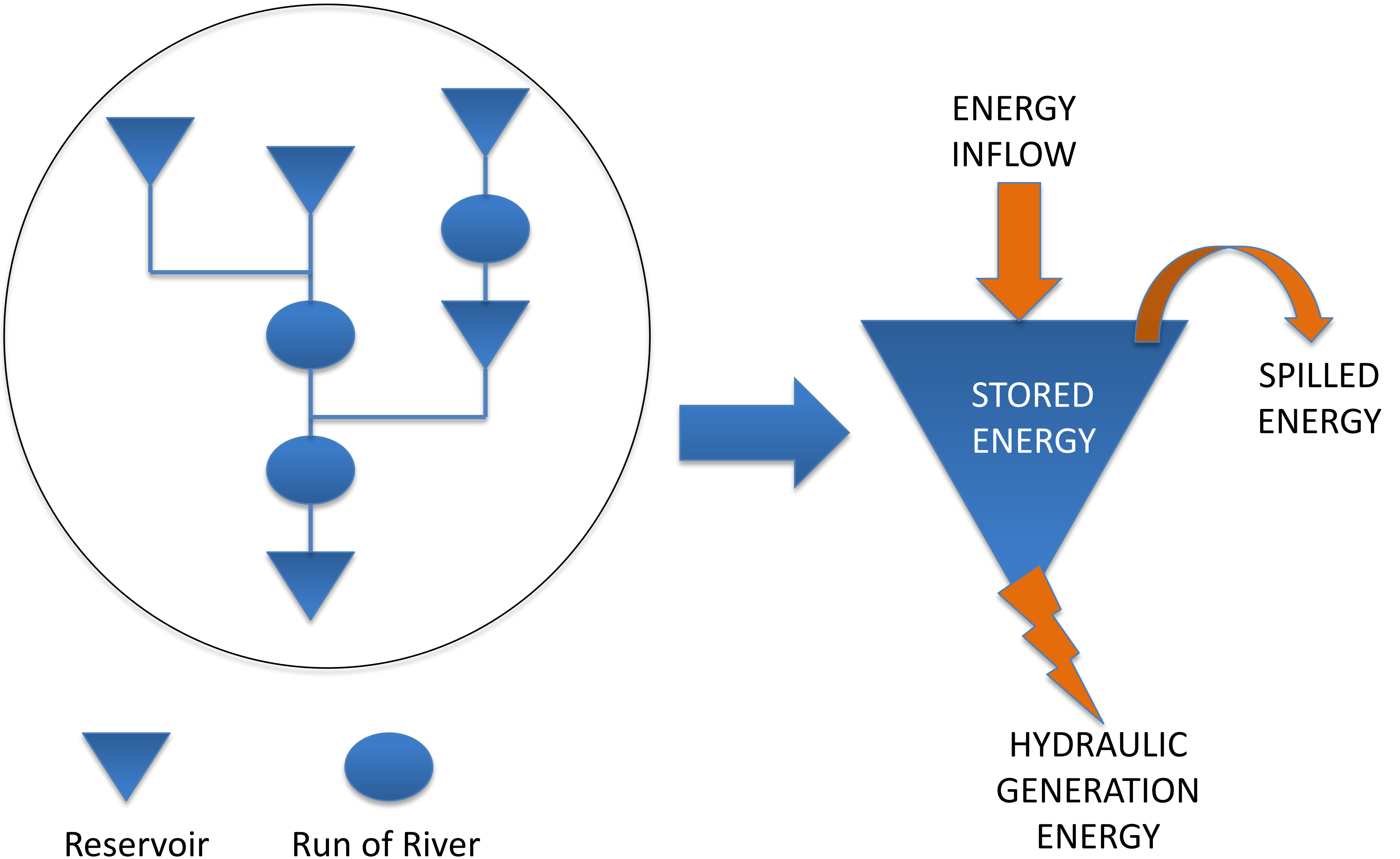
- Brazilian Systems Uses:

✓ Aggregation of the hydroelectric system into energy equivalent system.

✓ Stochastic Dual Dynamic Programming (SDDP).

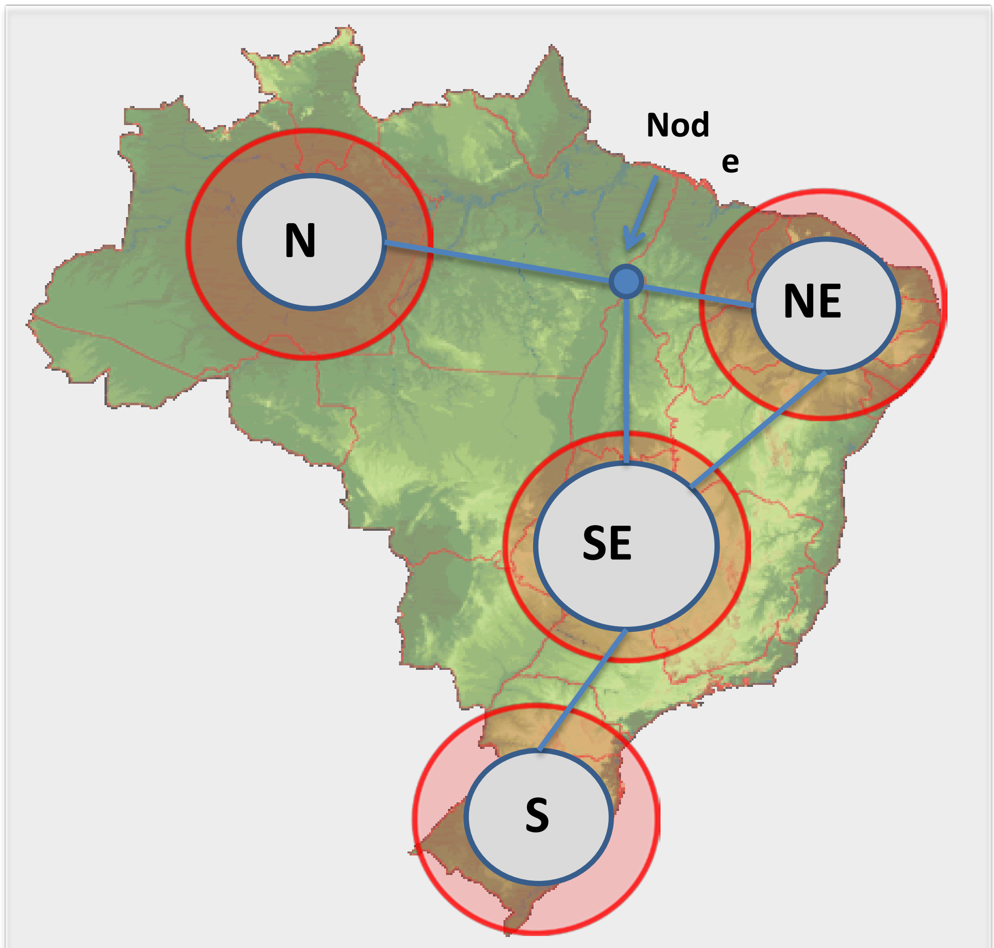
Introduction

- Energy Equivalent System

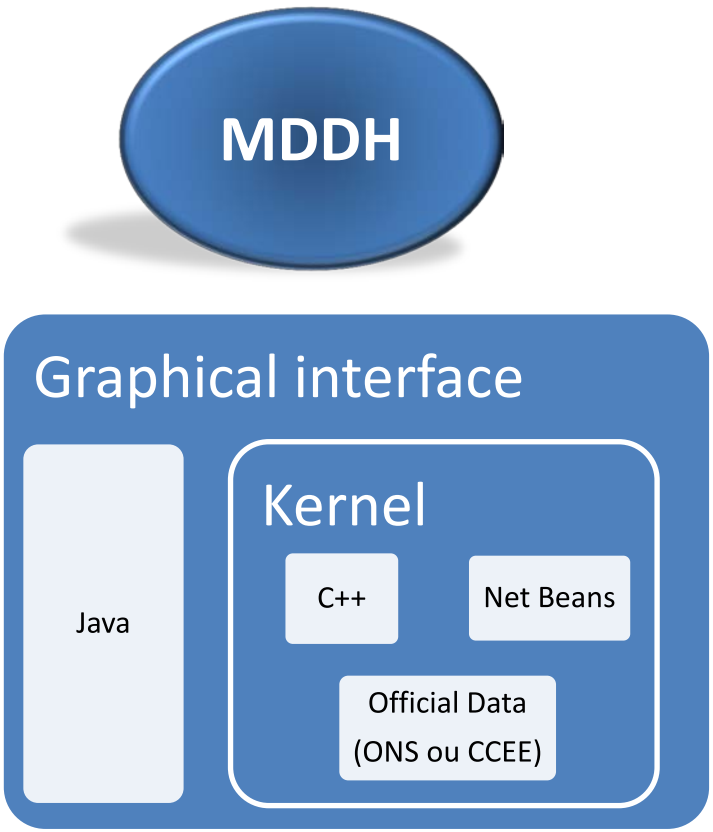


Introduction

- Energy Equivalent System

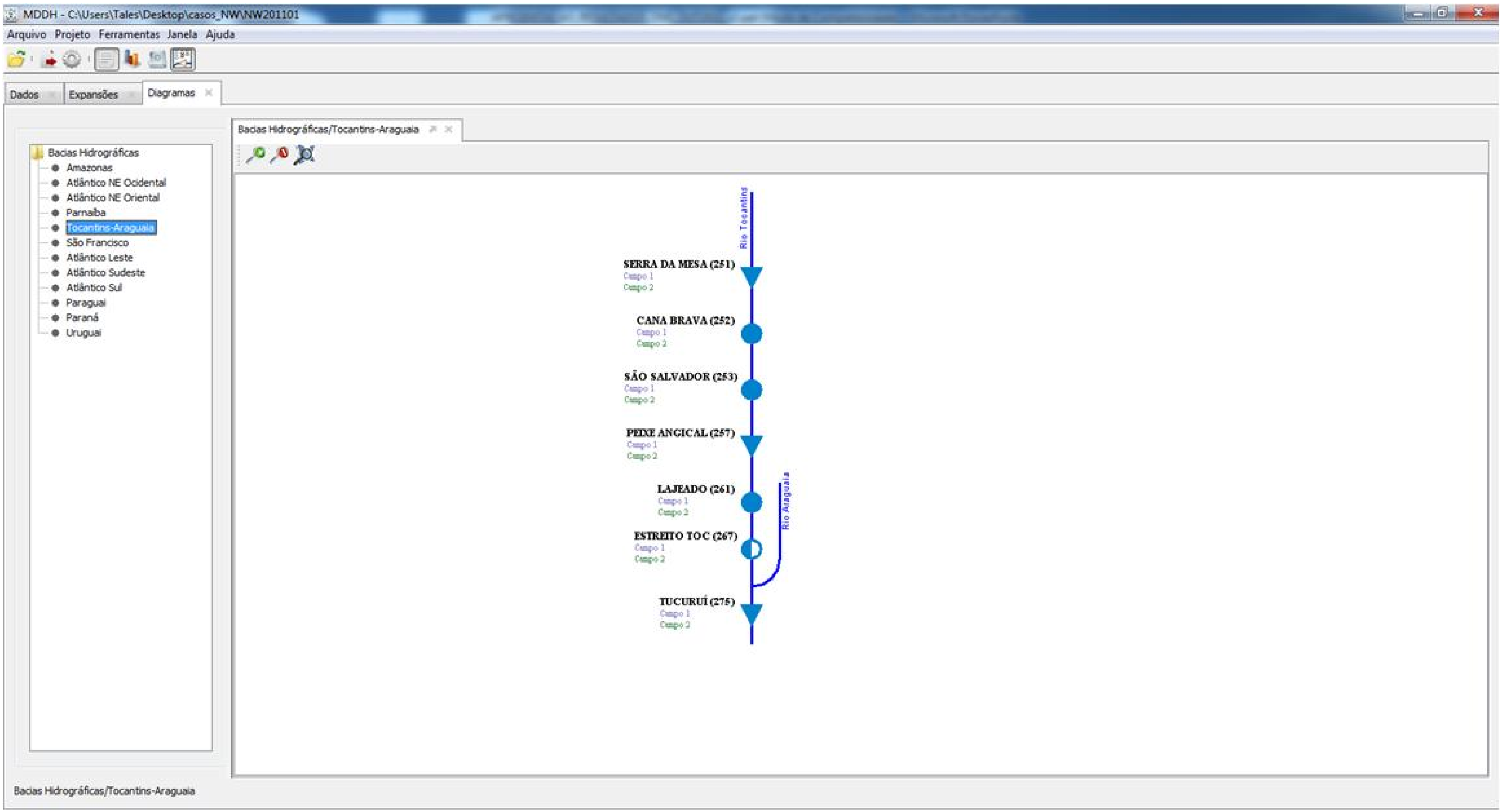


Computational Platform



- Windows or Linux
- Parallel Processing (SDP and SDDP)
- Running Desktop computer, remote or distributed
- Wind Plants and Solar Plants (under development)
- Synthetic Scenarios
- Energy Equivalent System, Individualized plants, Hybrid

Computational Platform



Proposed Methodology

The long term operation planning can carried out:

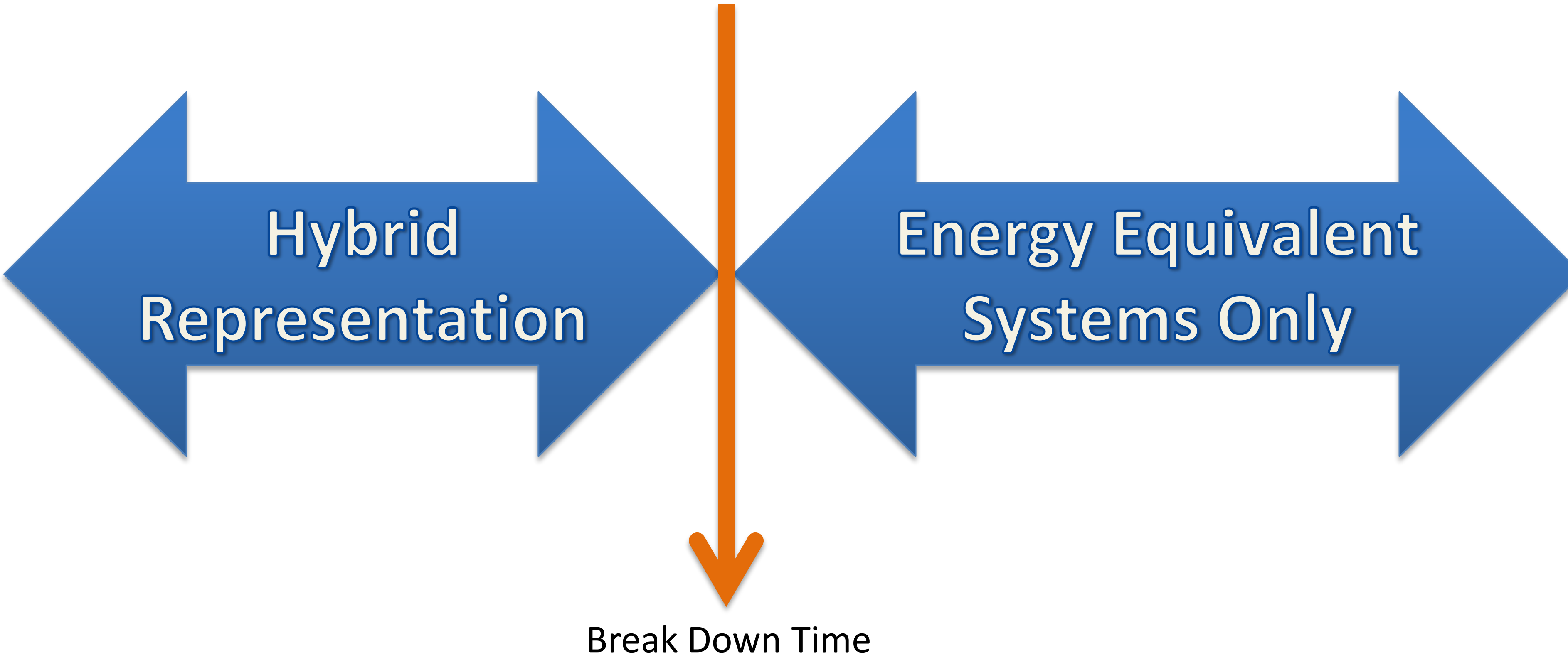
- only representation through energy equivalent systems;
- part of the system is represented by energy equivalent systems and the remaining system by individualized plants;
- All hydro power plants are individualized

The planner can choose a point in the time horizon when, before this time a hybrid representation is used and after this time, the representation is by equivalent systems.

For individualized plants, It is considered all non-linarites of the hydraulic production function

Proposed Methodology

- Temporal Coupling



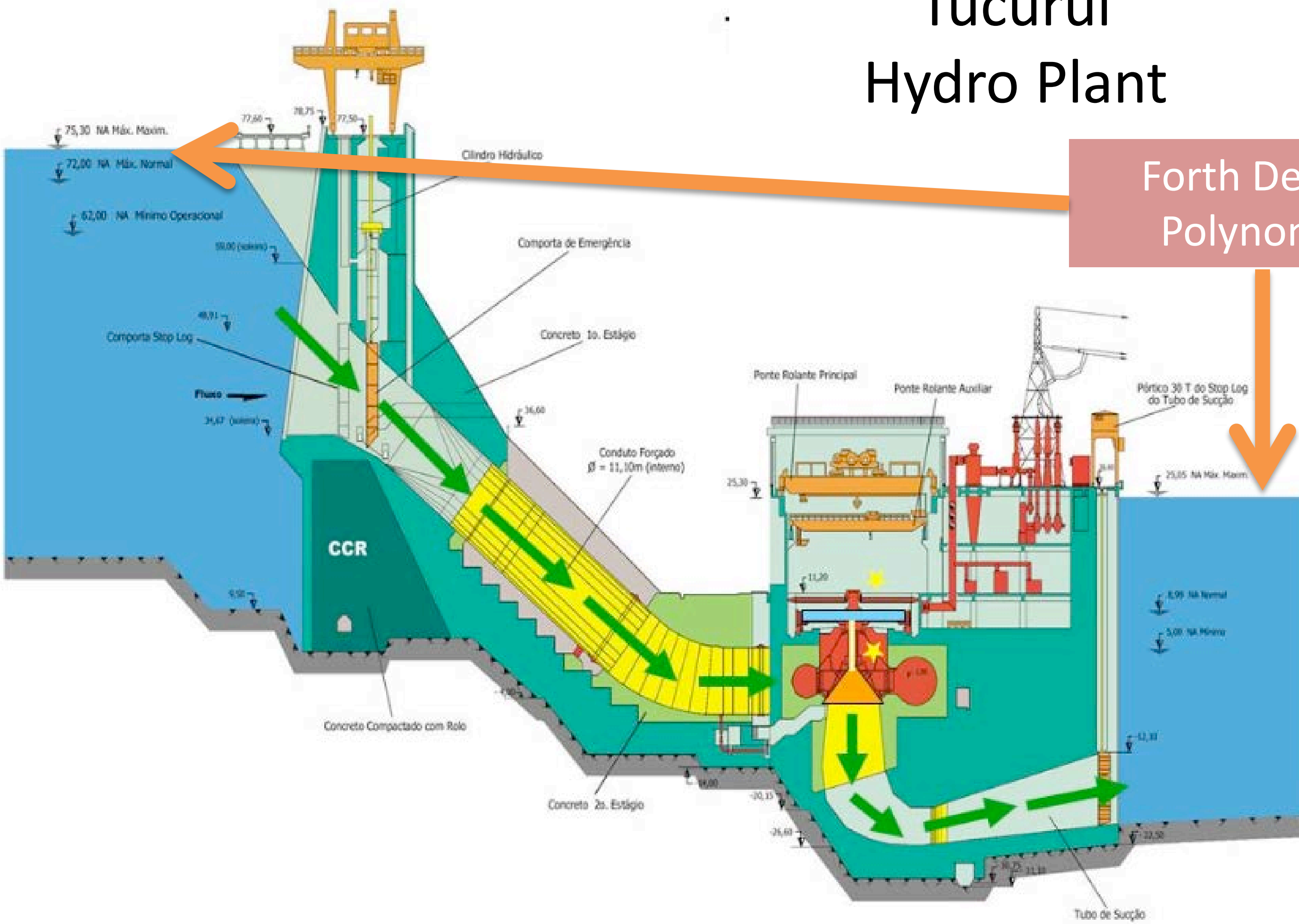
Proposed Methodology

Non-linearity's of Hydro Plants

Piecewise linear function to approximate HPF obtained by convex hull algorithm

Hydraulic Production Function- HFP

Tucuruí
Hydro Plant



Forth Degree Polynomial

Hydraulic Production Function - HFP

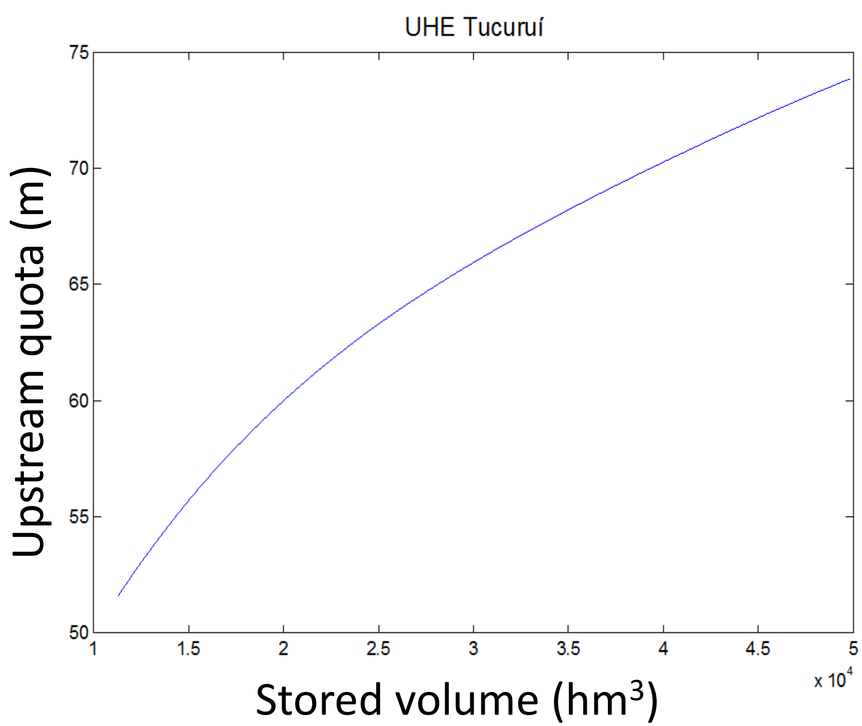
$$\underbrace{HG}_{MW} = \overbrace{\underbrace{\rho_{esp}}_{\eta \cdot g \cdot w_d} \times h(V, Q, S)}^{\rho} \times Q$$

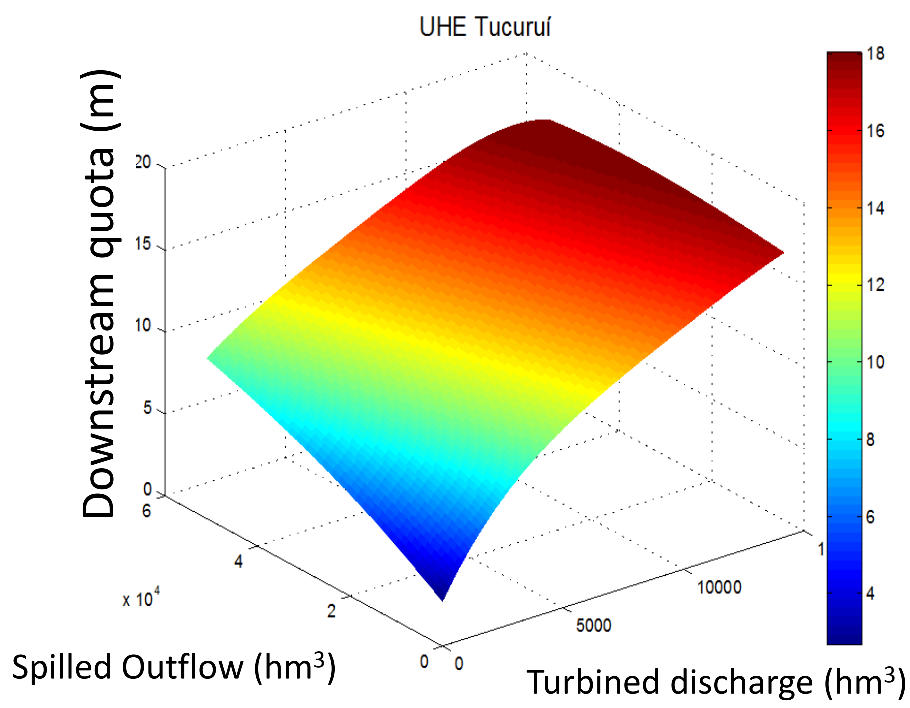
Head (m)

Flow rate or turbined flow (m^3/s)

The piecewise linear function must be a convex polynomial

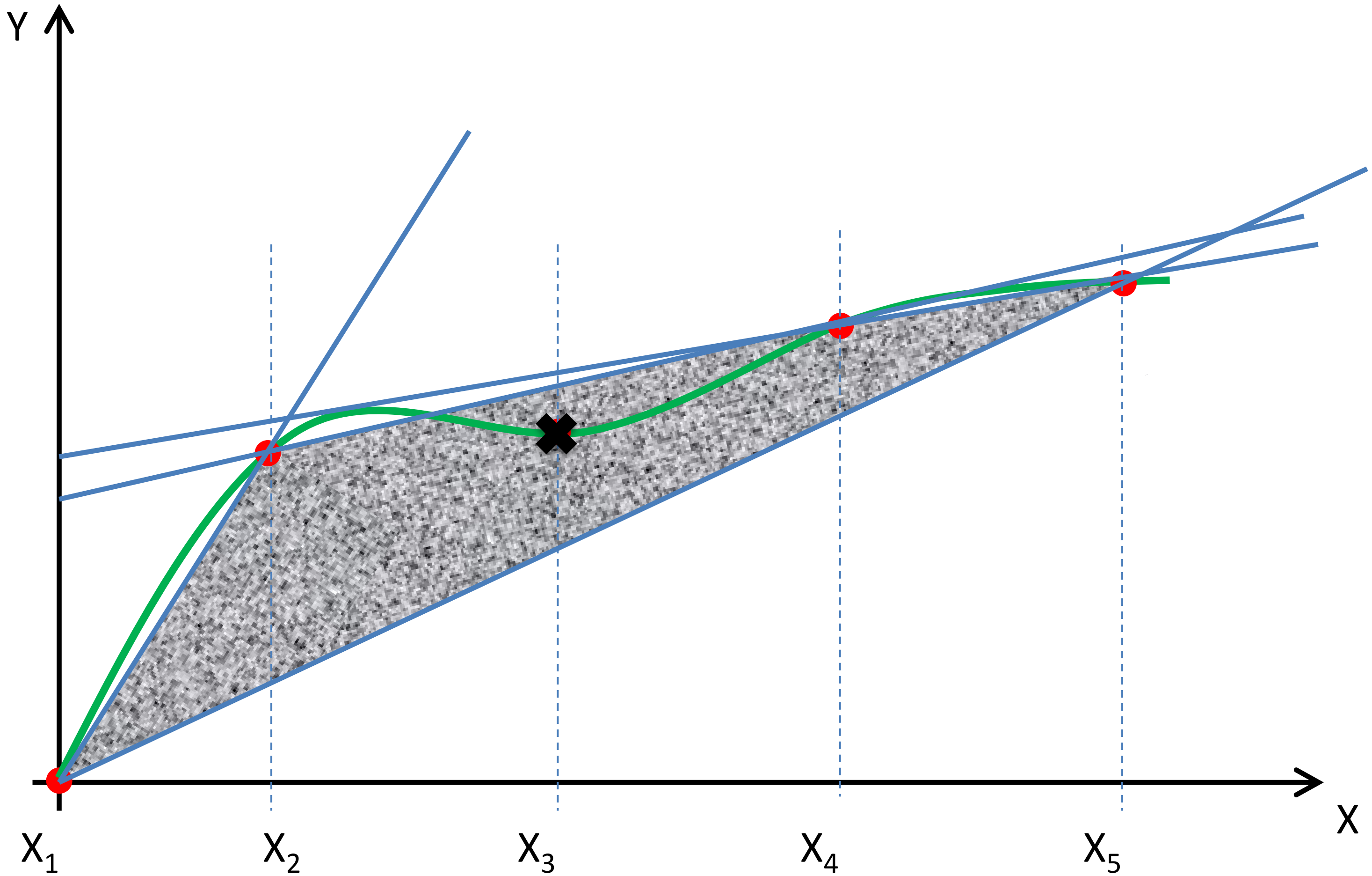
Hydraulic Production Function- HFP



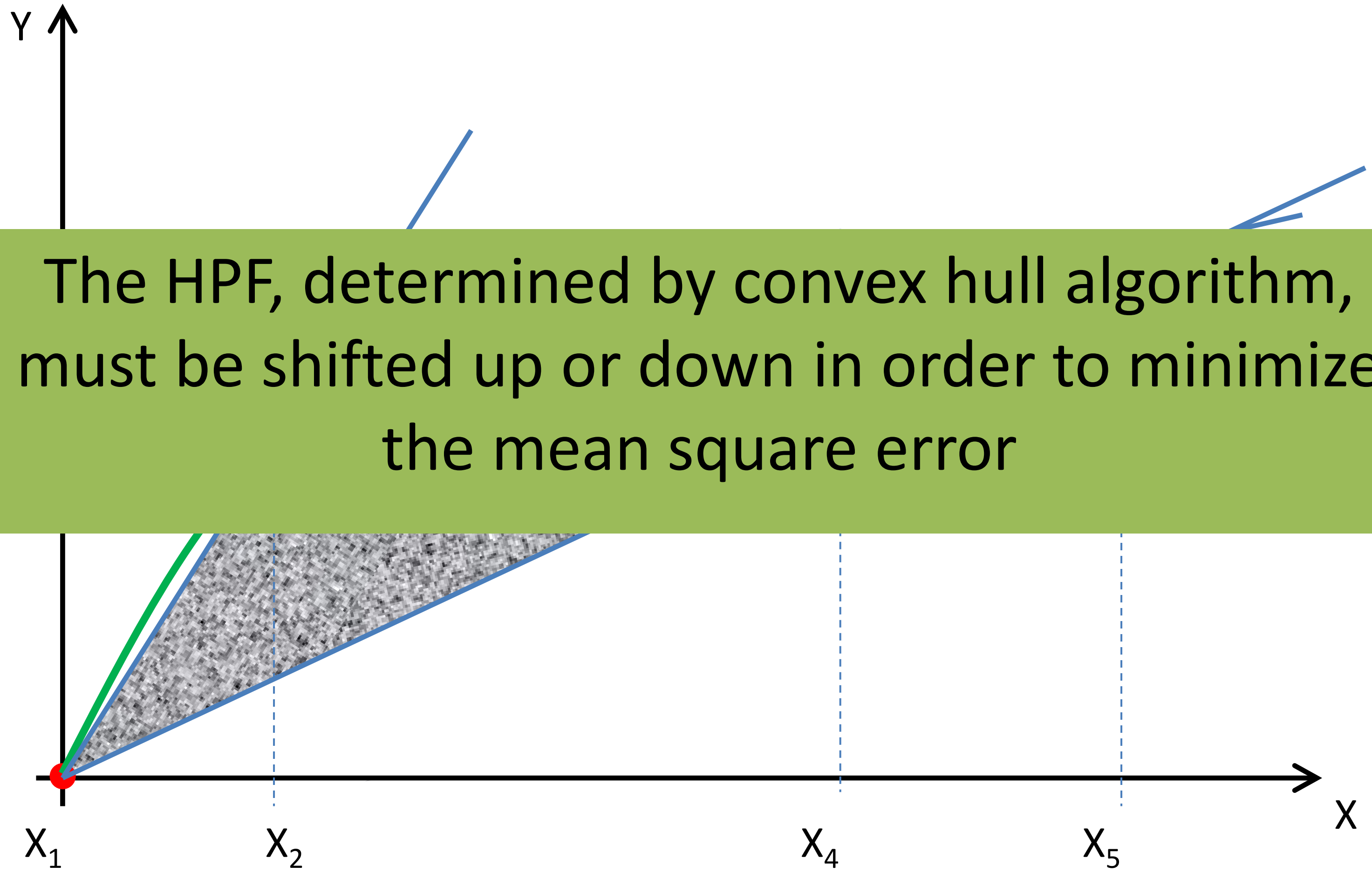


Hydraulic Production Function- HFP

- Convex Hull Algorithm:



Hydraulic Production Function- HPF



The HPF, determined by convex hull algorithm, must be shifted up or down in order to minimize the mean square error

Problem Formulation

- The SDDP is formulated as the following optimization model:

$$\alpha_t(X_t) = E_{v_t|X_t}\left(Min\left[\sum_{i=1}^{NT} C_i \cdot thermalg_t^i + Cdef \cdot def_t + \alpha_{t+1}(X_{t+1}) \right] \right)$$

subject to:

PIECEWISE LINEAR FUNCTION

Hydraulic Balance

$$v_{t+1}^j = V_t^j + INFLOW_t^j - turb_t^j - spillage_t^j$$

Load Balance

$$\sum_{i=1}^{NT} C_i \cdot thermalg_t^i + \sum_{j}^{NH} \cancel{\rho^j \cdot q_t^j} + def_t = LOAD_t$$

$$HG_t^j$$

$$\underline{v_{t+1}} \le v_t \le \overline{v_{t+1}}$$

$$\underline{turb_t} \le \overline{turb_t}$$

$$\underline{thermalg_t} \le thermalg_t \le \overline{thermalg_t}$$

Hydraulic Production Function - HPF

$$HG_j^t \leq \left(\gamma_0^{j,p} + \gamma_V^{j,p} \cdot V_i^t + \gamma_Q^{j,p} \cdot turb_j^t + \gamma_S^{j,p} \cdot S_i^t\right)$$

$$\underline{HG_j} \leq HG_j^t \leq \overline{HG_j}$$

$$\underline{V_j} \leq V_j^t \leq \overline{V_j}$$

$$\underline{Q_j} \leq Q_j^t \leq \overline{Q_j}$$

$$j = 1, \cdots, \text{ Number of Hydro Plants}$$

$$t = 1, \cdots, T$$

$$p = 1, \cdots, \text{Number of Hyper Planes}$$

Results

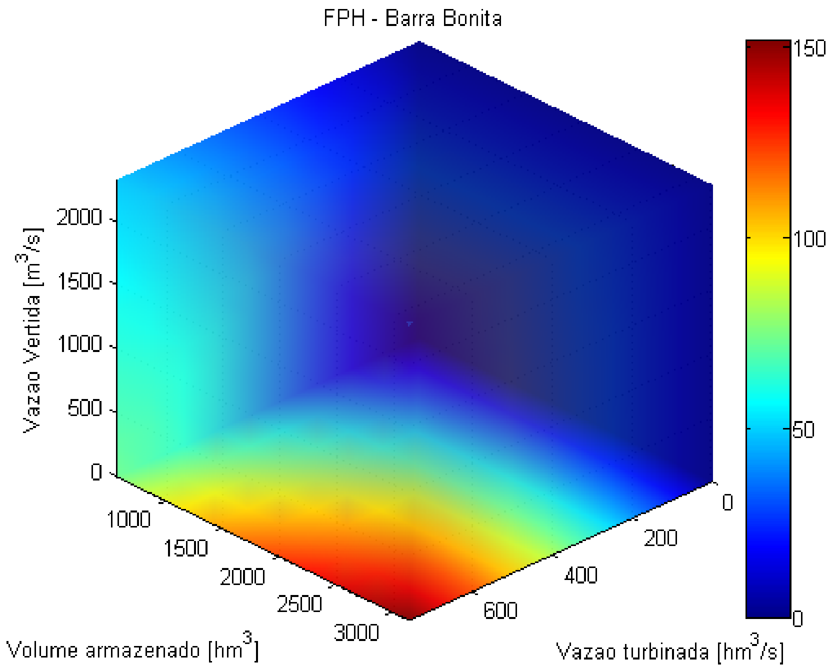
- Evaluation of the approximated HPF

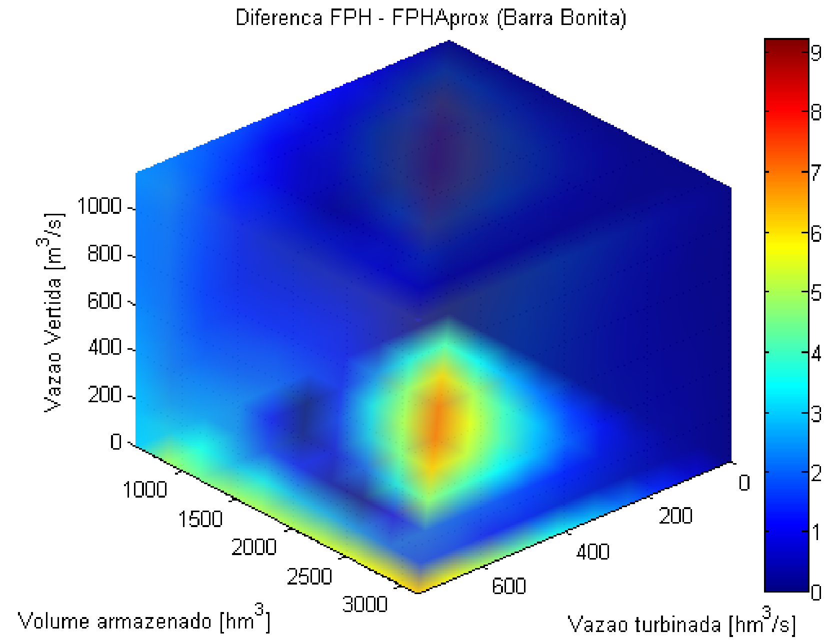
$$\Delta FPH_p = \frac{\left|FPHA_p - FPH_p\right|}{FPH_{max}} \times 100\%$$

NUMH	*NOME*	*Erro Máximo (%)*	*Erro Médio (%)*	*Desvio Padrão (%)*
1	CAMARGOS	8.01147	2.54732	2.0653
2	ITUTINGA	0.0853443	0.0318999	0.0262842
7	M. DE MORAES	5.84823	1.53877	1.26733
20	BATALHA	5.94327	1.68161	1.37936
37	BARRA BONITA	9.19784	2.53948	2.09807
66	ITAIPU	6.44E-15	6.44E-16	1.94E-15
169	SOBRADINHO	7.48555	1.99897	1.62874
275	TUCURUI	5.99319	1.6	1.30939

Results

- Evaluation of the approximated HPF



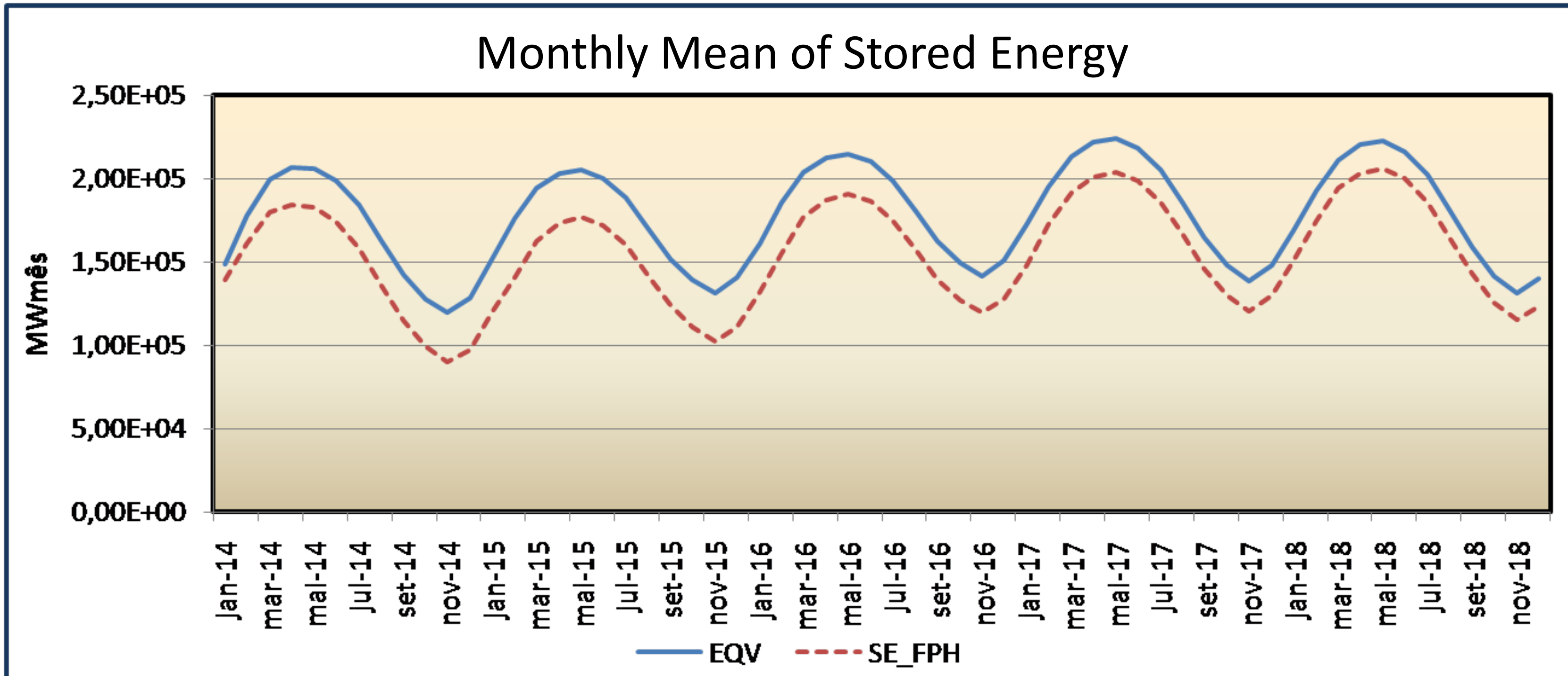


Results – Brazilian System – Mean of Final Simualtion

- Time horizon: 5 years
- Final simulation with 70 scenarios
- All results corresponds to monthly mean

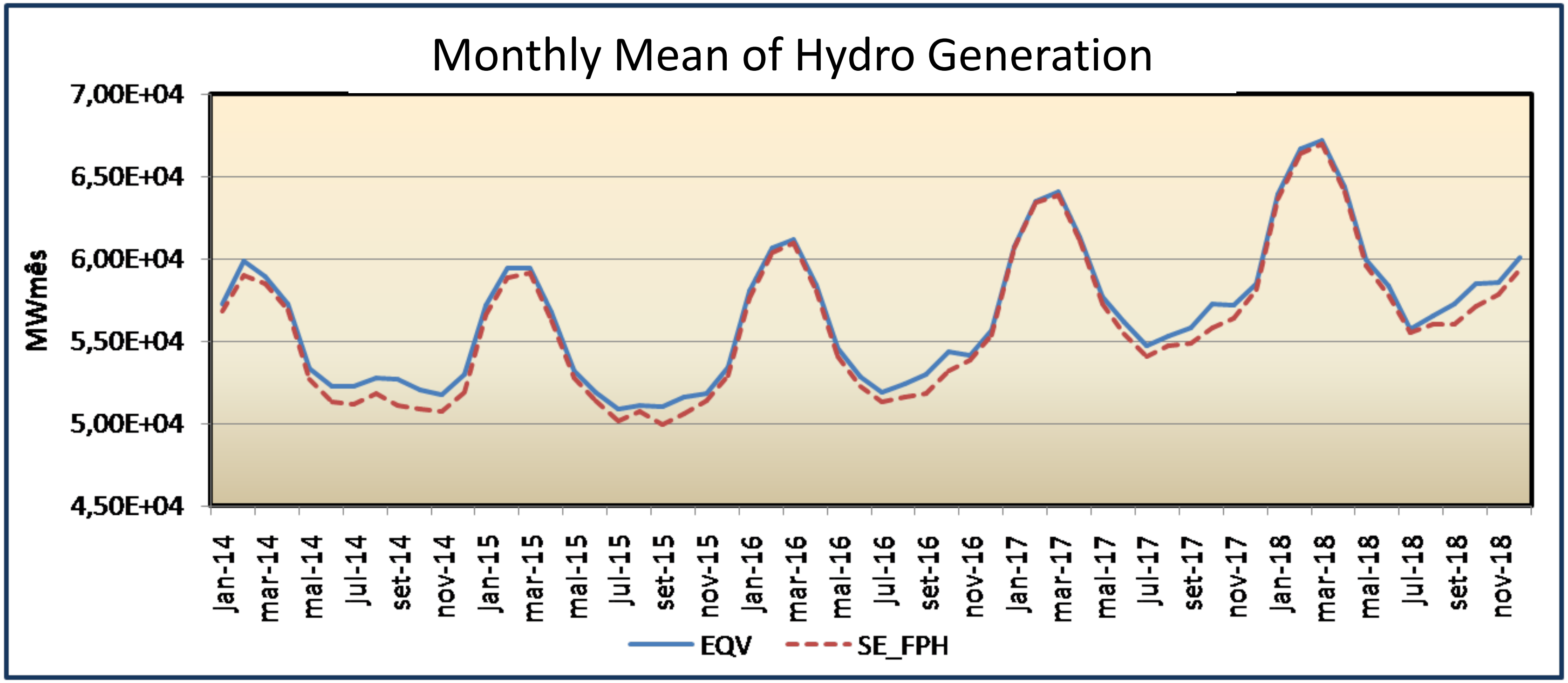
- Two Cases:
  - EQV: representation by energy equivalent systems only;
  - SE_FPH: only Southeast subsystem was individualized

Results – Brazilian System



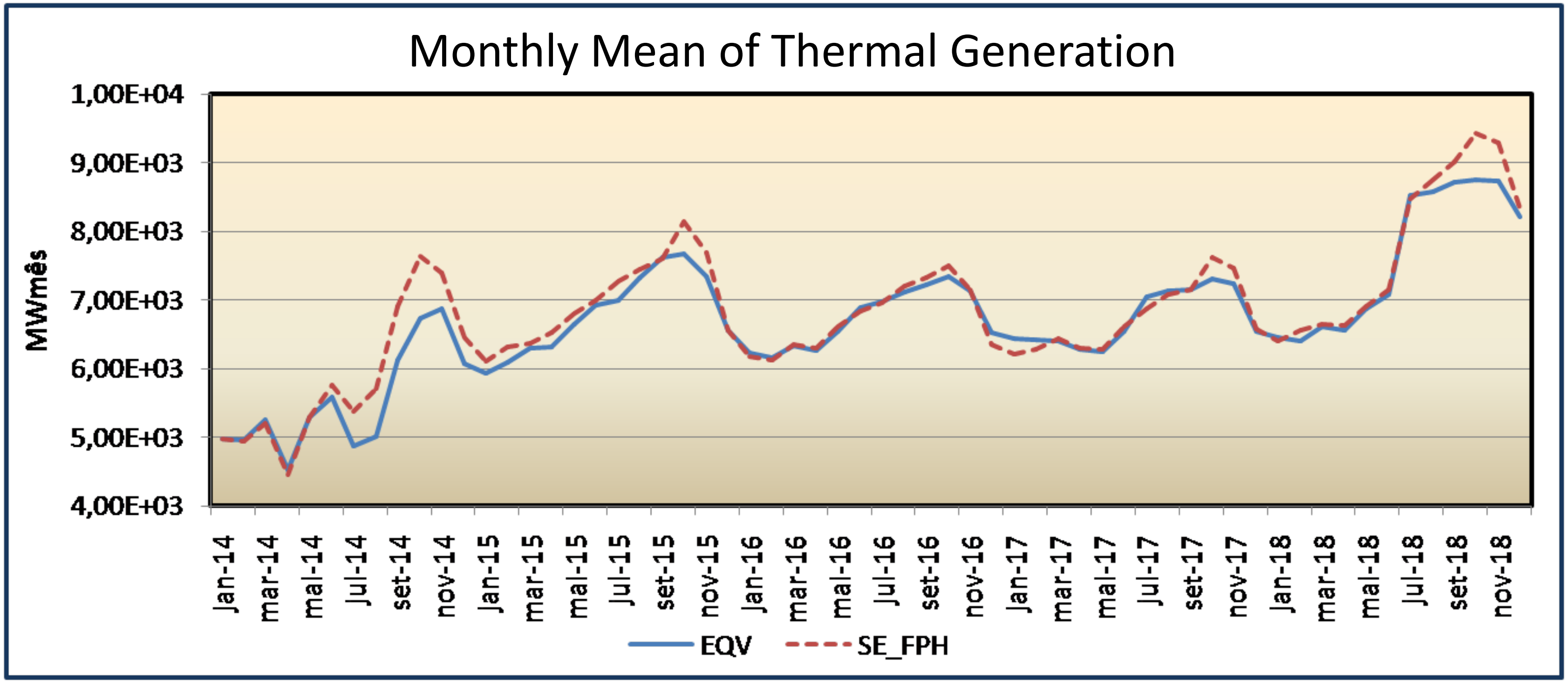
Equivalent reservoir representation presents a higher stored energy when compared to the hybrid representation.

Results – Brazilian System



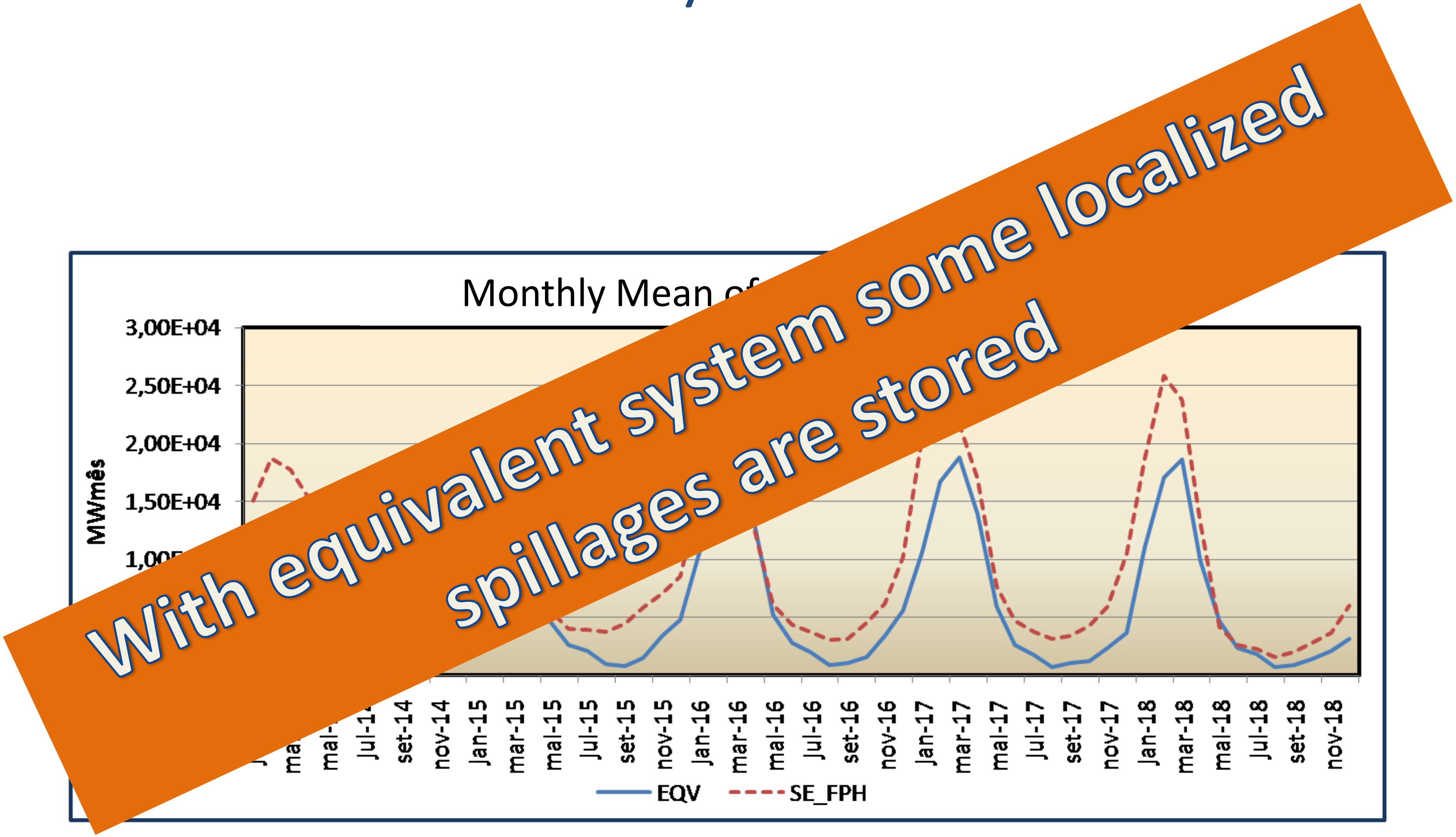
There is no significant difference in both methods and the equivalent system is a little higher

Results – Brazilian System



Equivalent representation presents a smaller amount. This is due to the higher hydro generation presented before.

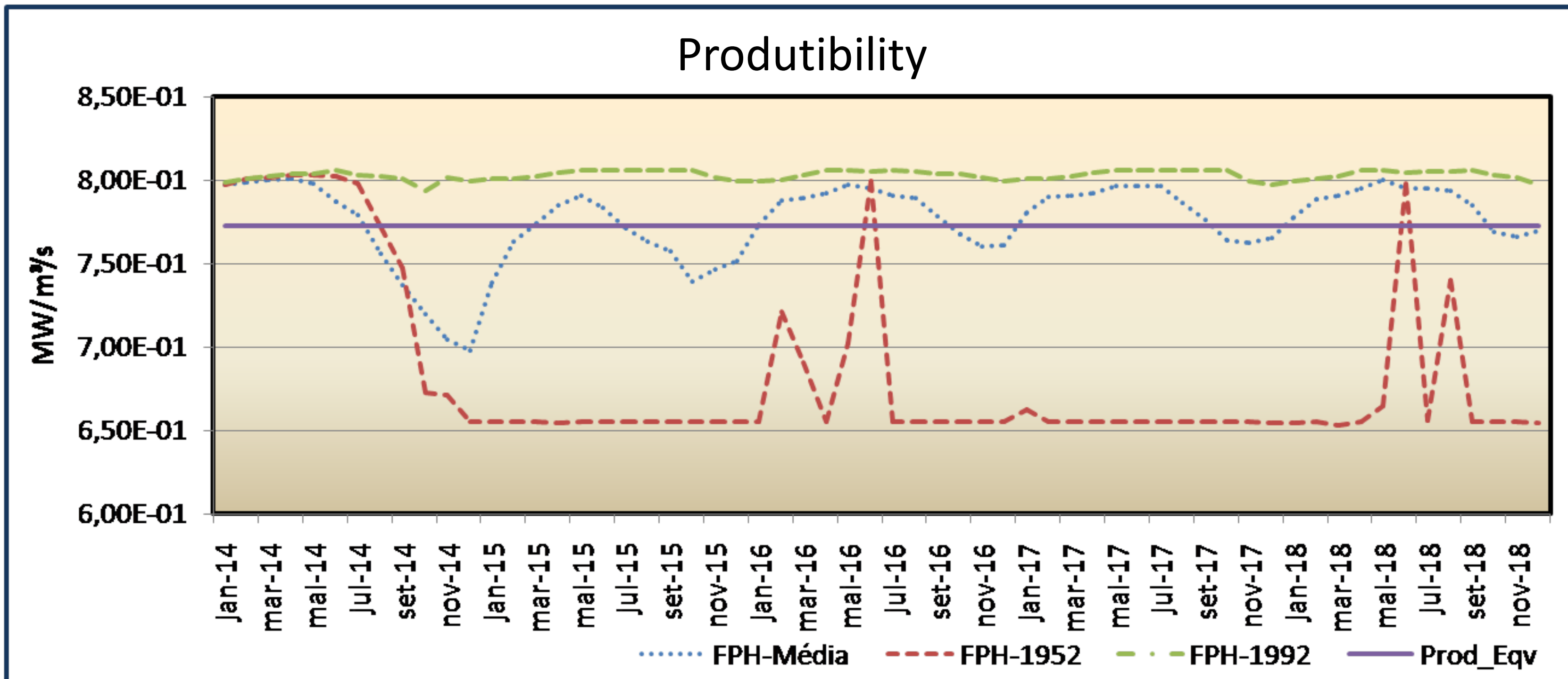
Results – Brazilian System



The spilled energy amount is higher when the southeast is modelled by individual plants

Results - PMO 01/2014

$$\overbrace{\underbrace{\rho_{esp}}_{\eta \cdot g \cdot w_d} \times h(V, Q, S)}^{\rho}$$



Conclusions

Hybrid Representation	Piecewise linear function to approximate the HPF

- Nowadays, with the hardware/software advances, we must invest in new approaches to use more and more the individualized representation instead of energy equivalent representation.

Acnowledgements:

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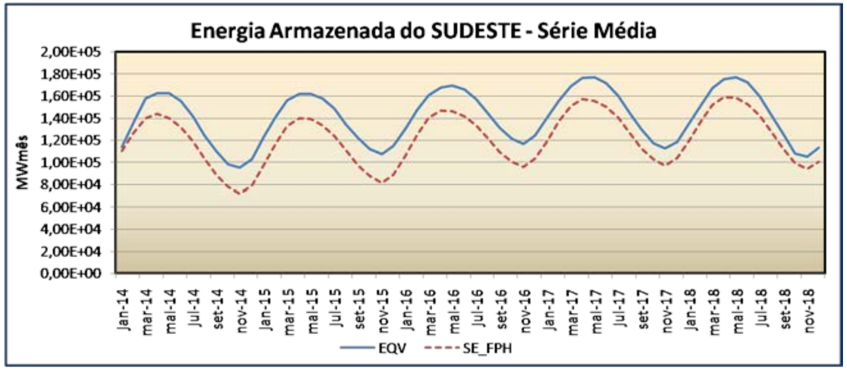
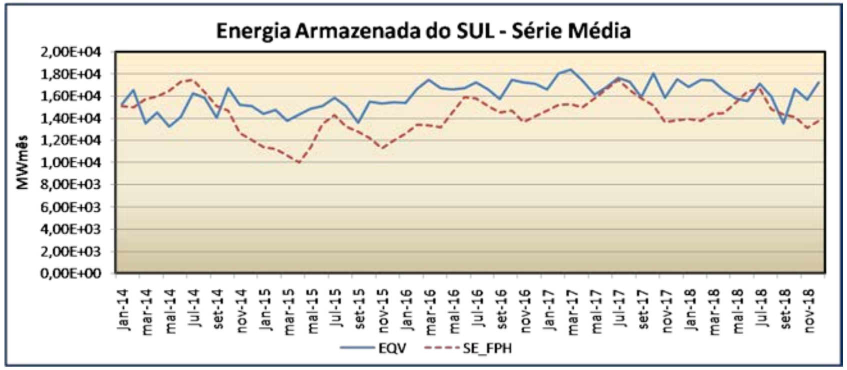
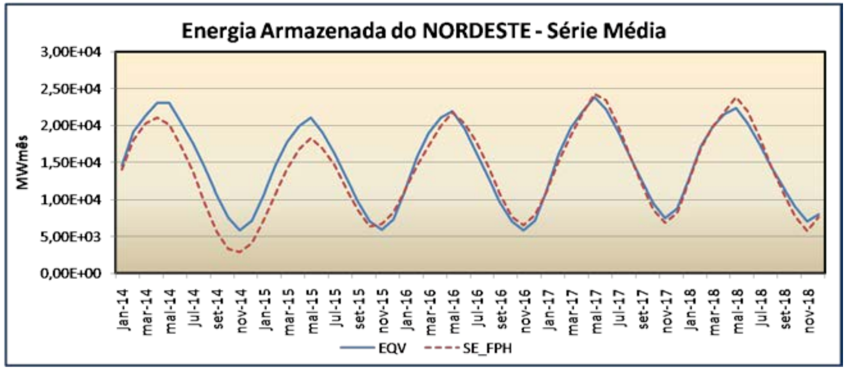
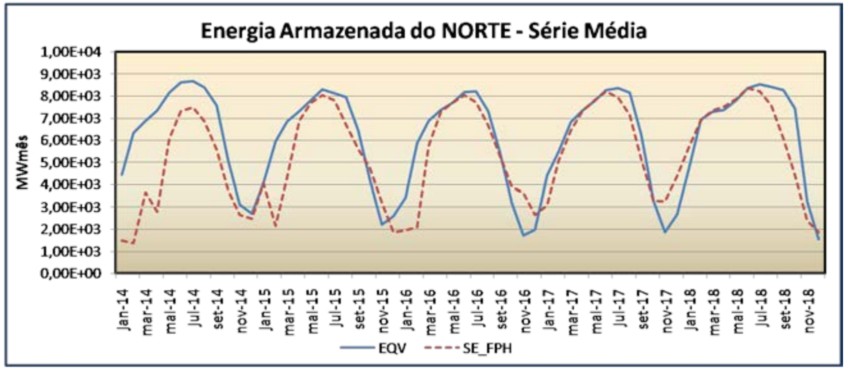
Resultados PMO 01/2014

- Energia Armazenada



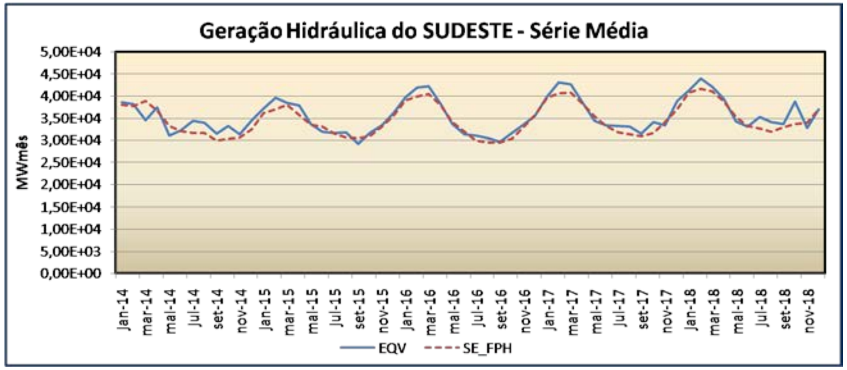


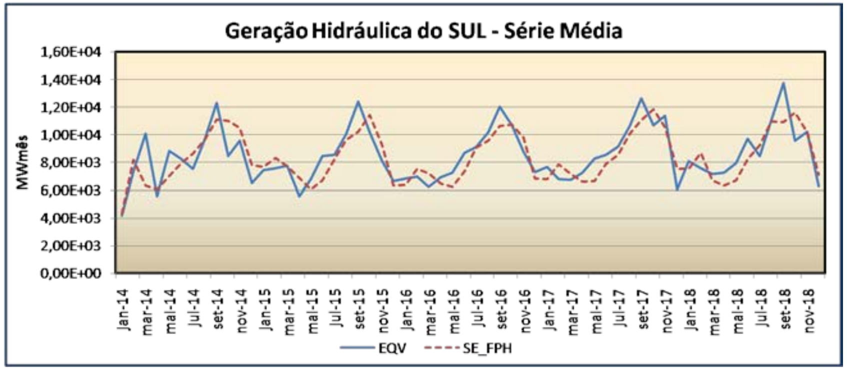


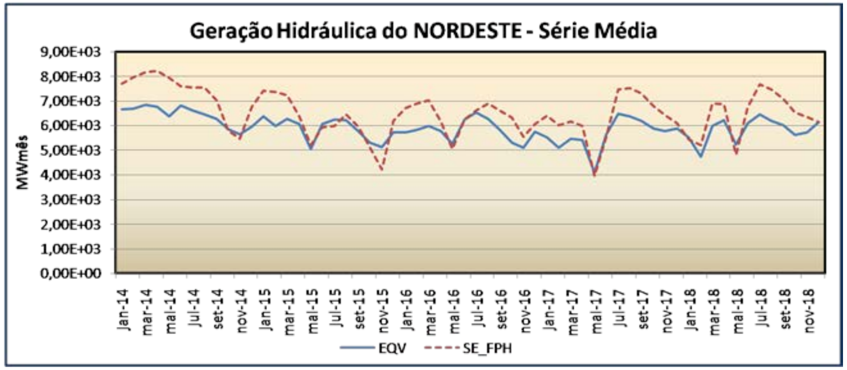


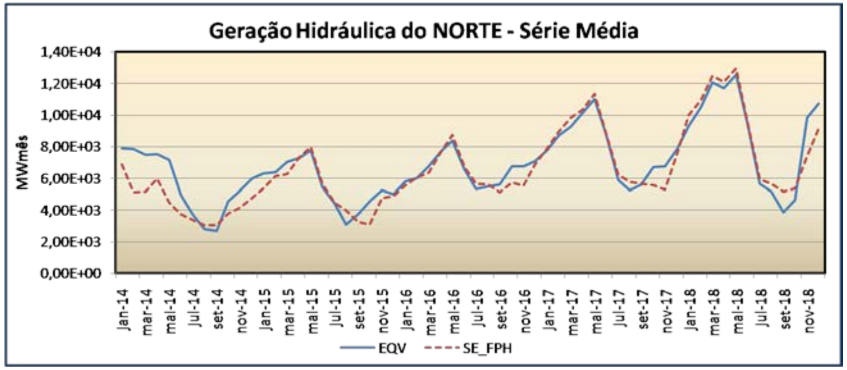
Resultados PMO 01/2014

- Geração Hidráulica



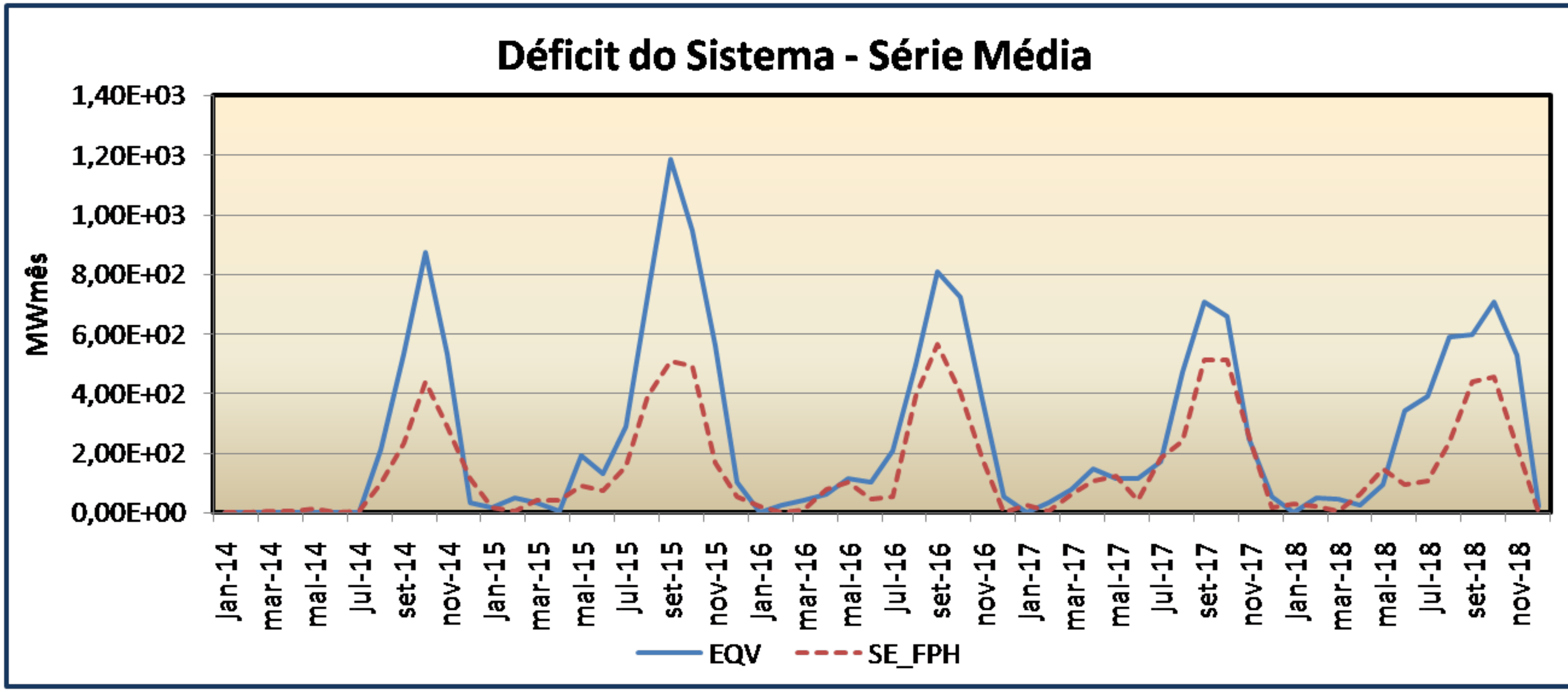






Resultados PMO 01/2014

- Déficit



Resultados PMO 01/2014

- Déficit