Brasil

Improvements in Hydrothermal System Operation Planning Considering Cut Selection and Multiplicative PAR(p)

Hydro Power Scheduling Workshop 2018

Prof. André Luís Marques Marcato
Prof. Ivo Chaves da Silva Junior
Prof. Rafael Bruno da Silva Brandi
Prof. Bruno Henriques Dias
Ph.D. Candidate Alessandro Castro

Stavanger, 12-13 September, 2018

Outline of Presentation

- Introduction
- Benefit Values of the Benders cuts
- Work in Progress using Benefit Values
- Multiplicative x Additive PAR(p)
- Conclusions

Introduction

- Long-term operation planning (LTOP) problem
- Stochastic Dual Dynamic Program (SDDP)
- Multi-objective problems (Cost x Risk)
- Convergence Criteria

Risk Aversion Mechanism

- Extreme events have a greater weight in the objective function of the optimization problem.

↓

- Conditional Value at Risk (CVaR)

Risk Aversion Mechanism

- CVaR: Conditional Value at Risk

$$\mathrm{CVaR}_{\alpha}\left[Z\right] = \mathbb{E}\left[Z|Z > \mathrm{VaR}_{\alpha}(Z)\right]$$

- Expected value of operative cost considering only scenarios with a risk level **α**.

SDDP and CVaR

- **Objective Function**: Convex combination between expected value of operation costs and CVaR.

$$\rho[Z] = (1-\lambda)\mathbb{E}[Z] + \lambda \mathrm{CVaR}_{\mathfrak{a}}[Z]$$

SDDP and CVaR

- Objective Function: Convex combination between expected value of operation costs and CVaR.

$$\rho[Z] = (1-\lambda)\mathbb{E}[Z] + \lambda \mathrm{CVaR}_{\alpha}[Z]$$

  - λ: Weight for the portion of risk in the objective function
  - α: Risk Level

SDDP and CVaR

- Objective Function: Convex combination between expected value of operation costs and CVaR.

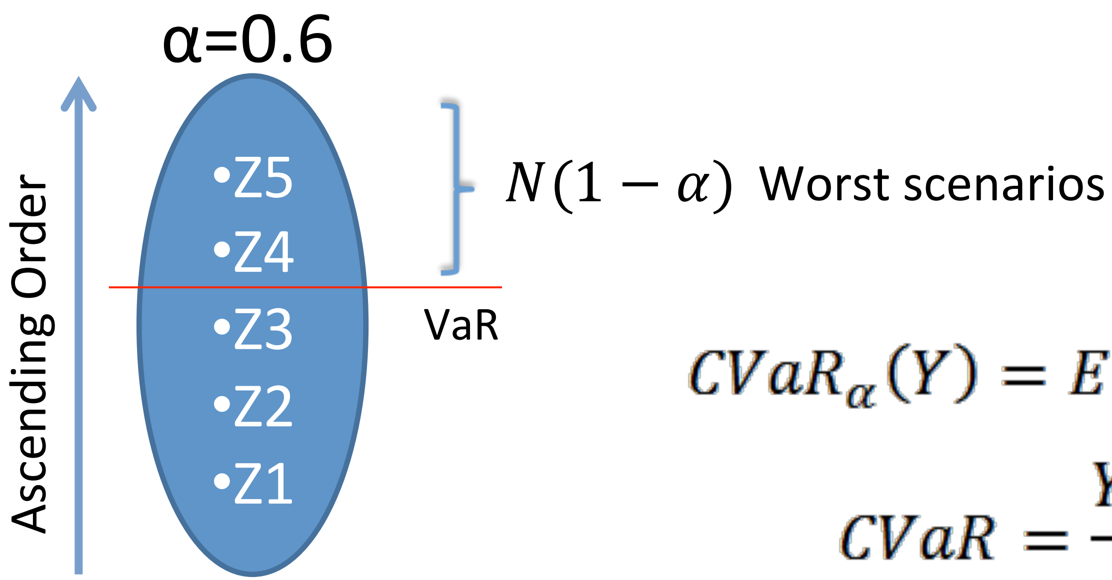
$$\rho[Z] = (1-\lambda)\mathbb{E}[Z] + \lambda \mathrm{CVaR}_{\alpha}[Z]$$

  - λ: Weight for the portion of risk in the objective function
  - α: Risk Level

λ=0,40 ; α = 0,50

SDDP and CVaR

- Direct Evaluating of the CVaR: 100(1-α)% of the most extreme cost values

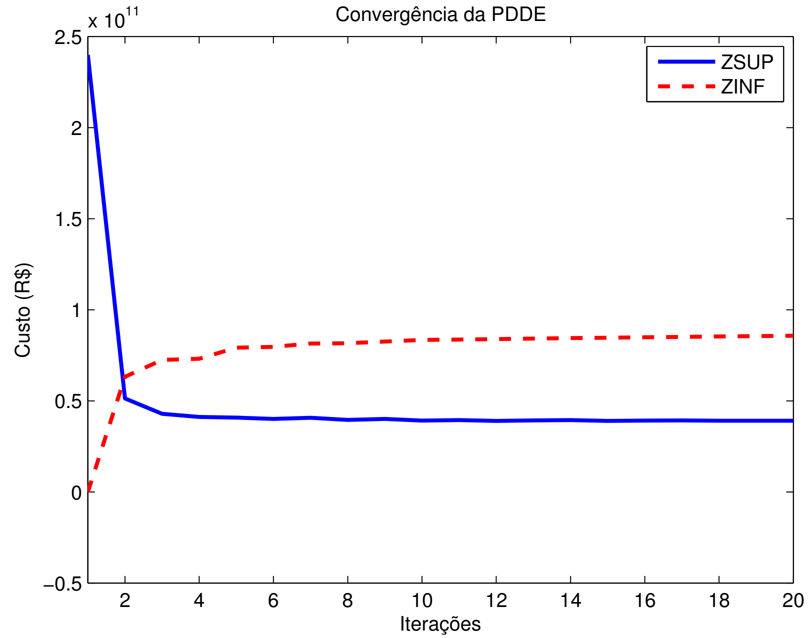


$$CVaR_{\alpha}(Y) = E[Y|Y > VaR_{\alpha}(Y)]$$

$$CVaR = \frac{Y4 + Y5}{2}$$

SDDP and CVaR

- Taking together SDDP and CVaR: Main Challenge!
  - Convergence criterion: It is hard to estimate the upper bound.



Some Alternatives to Tackle the Problem

- Exhaustive search on tree
- Sample Average Approximation
- Convergence of the neutral risk case
- Upper bound estimation via *inner approximation* (*convex hull*)
- Stability of the lower bound estimation

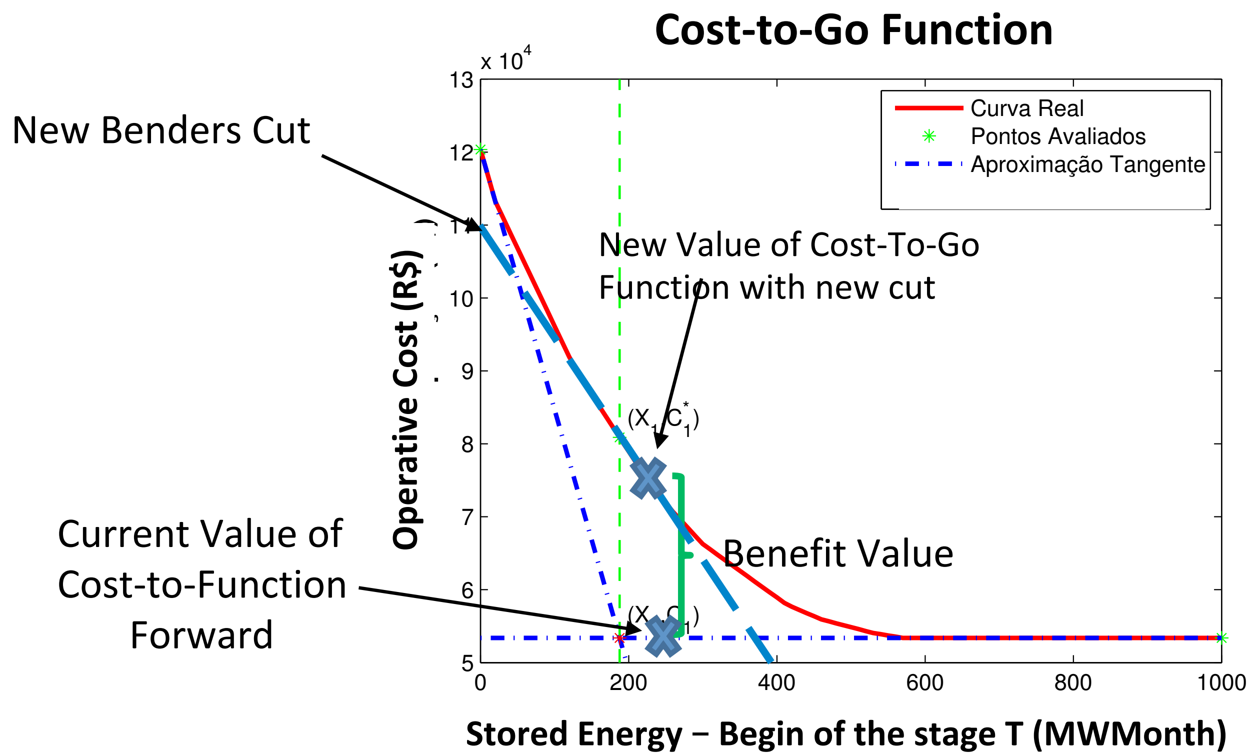
Convergence Criterion Proposed

– To evaluate the benefit indexes for each forward scenario during the SDDP iterative process

– When all forward scenarios have benefit values below a specified tolerance: The process will be converged.

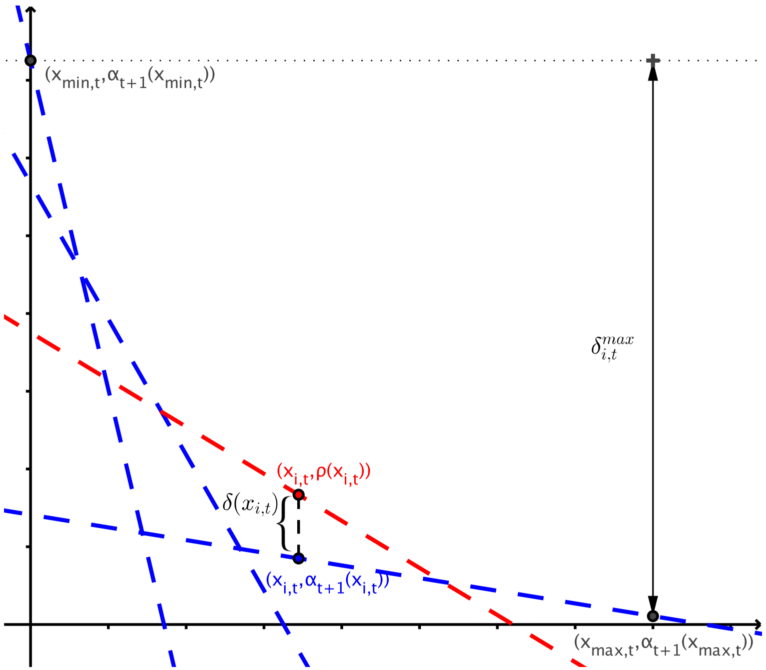
Convergence Criterion Proposed

- Understanding the benefit value:



Convergence Criterion Proposed

- Benefit Value:



Percentage Values:

$$\mathfrak{B}^{k}_{i,t} = \frac{\delta_k(x_{i,t})}{\delta max_{k,i,t}} \text{ x100}$$

ufjf Universidade Federal de Juiz de Fora

Convergence Criterion Proposed

Benefit Value:

<u>Given a scenario and stage:</u>

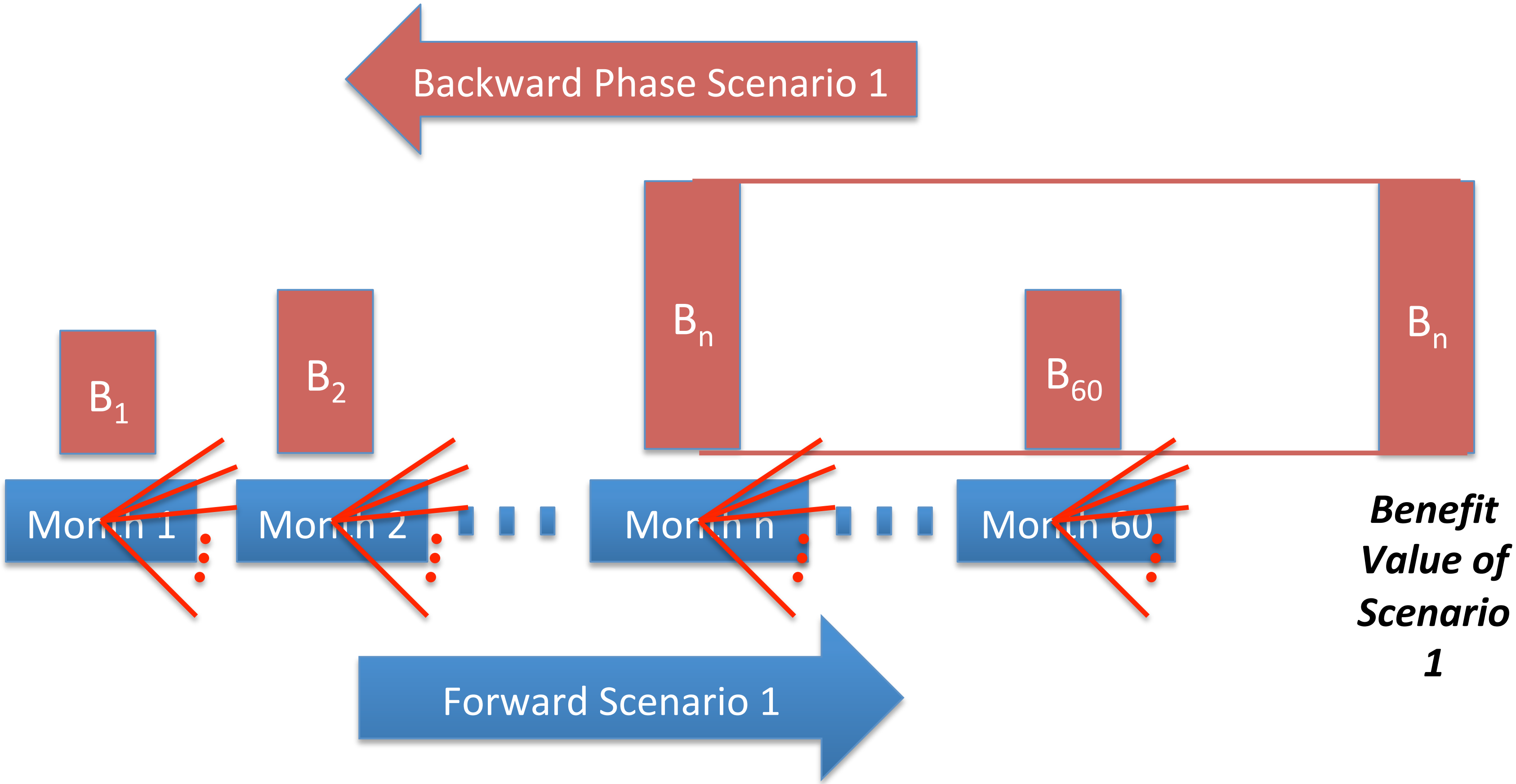
When new cut is added: one benefit value is computed.

<u>Given a scenario</u>:

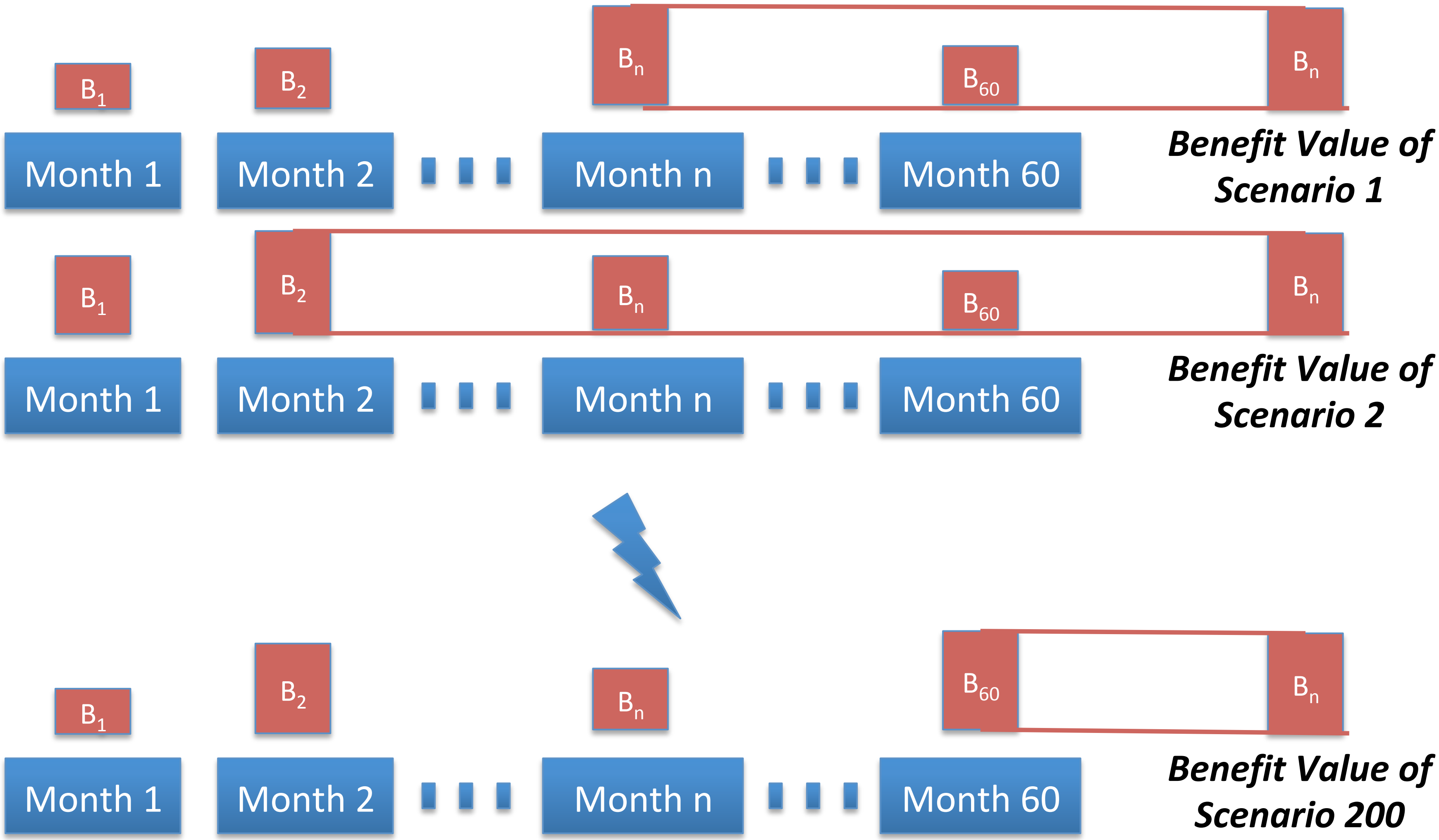
Compute the maximum benefit value in the 60 month-long backward process.

$$\mathfrak{B}_i^k = \max\left(\mathfrak{B}_{i,2}^k, \mathfrak{B}_{i,3}^k, \cdots, \mathfrak{B}_{i,T}^k\right)$$

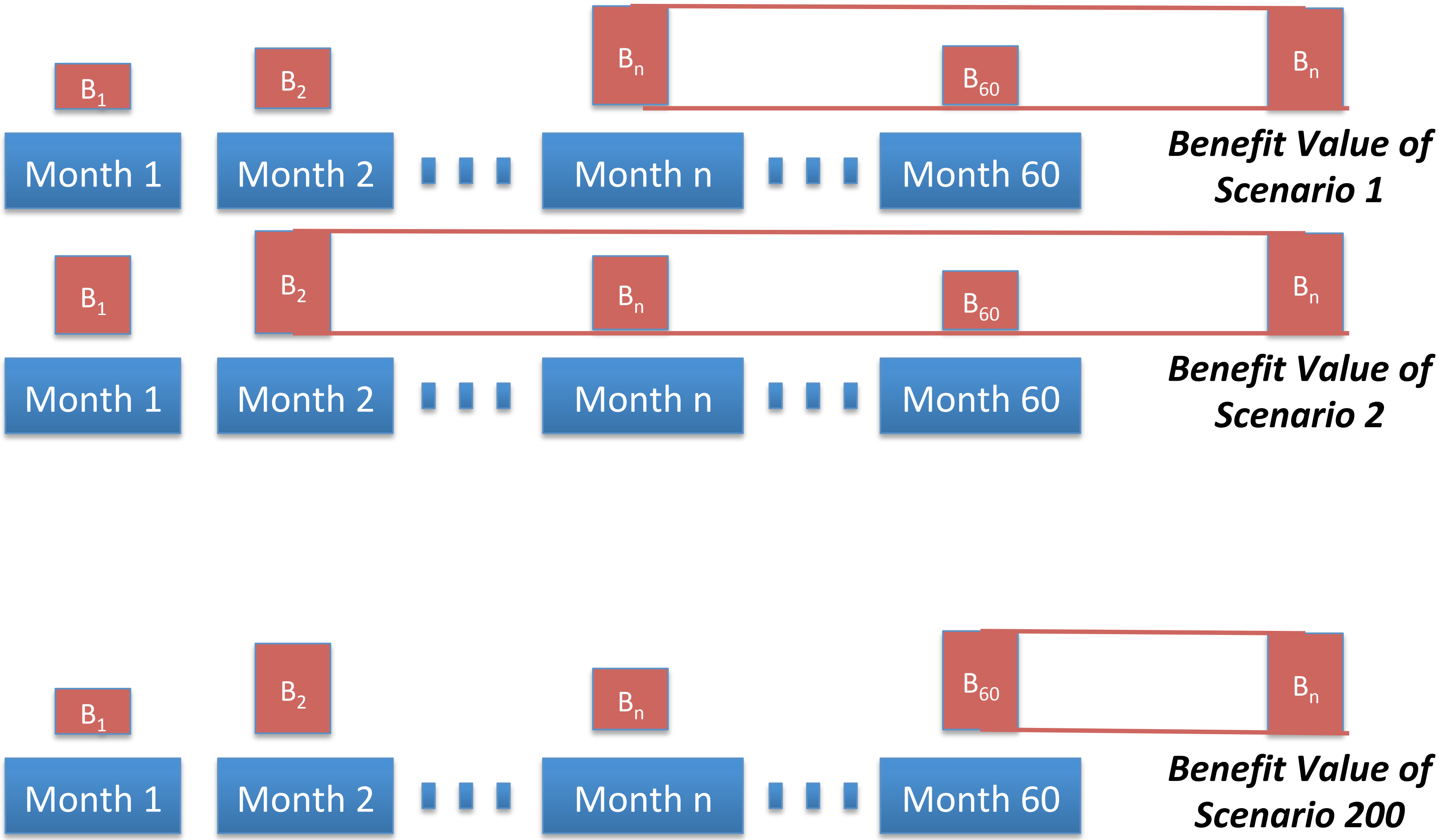
Didactic Illustration



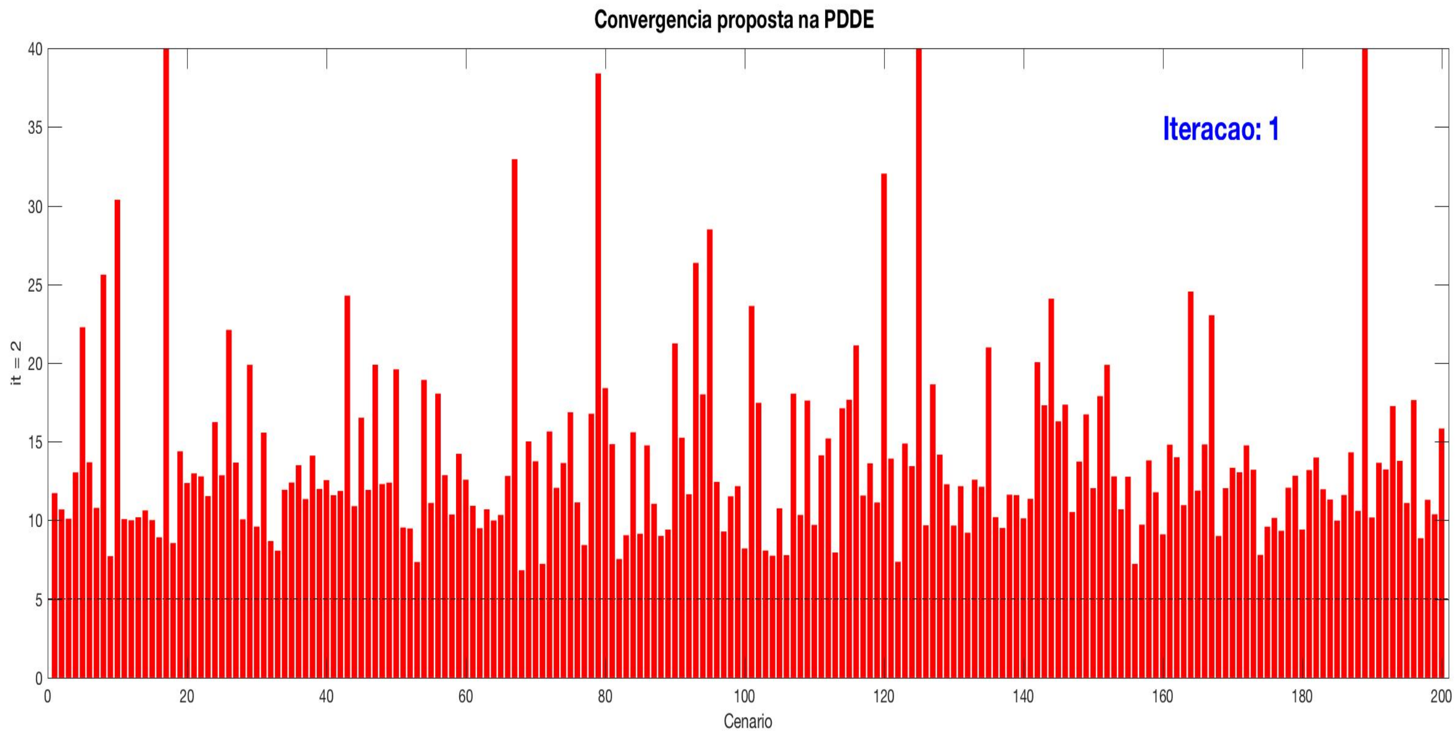
Didactic Illustration



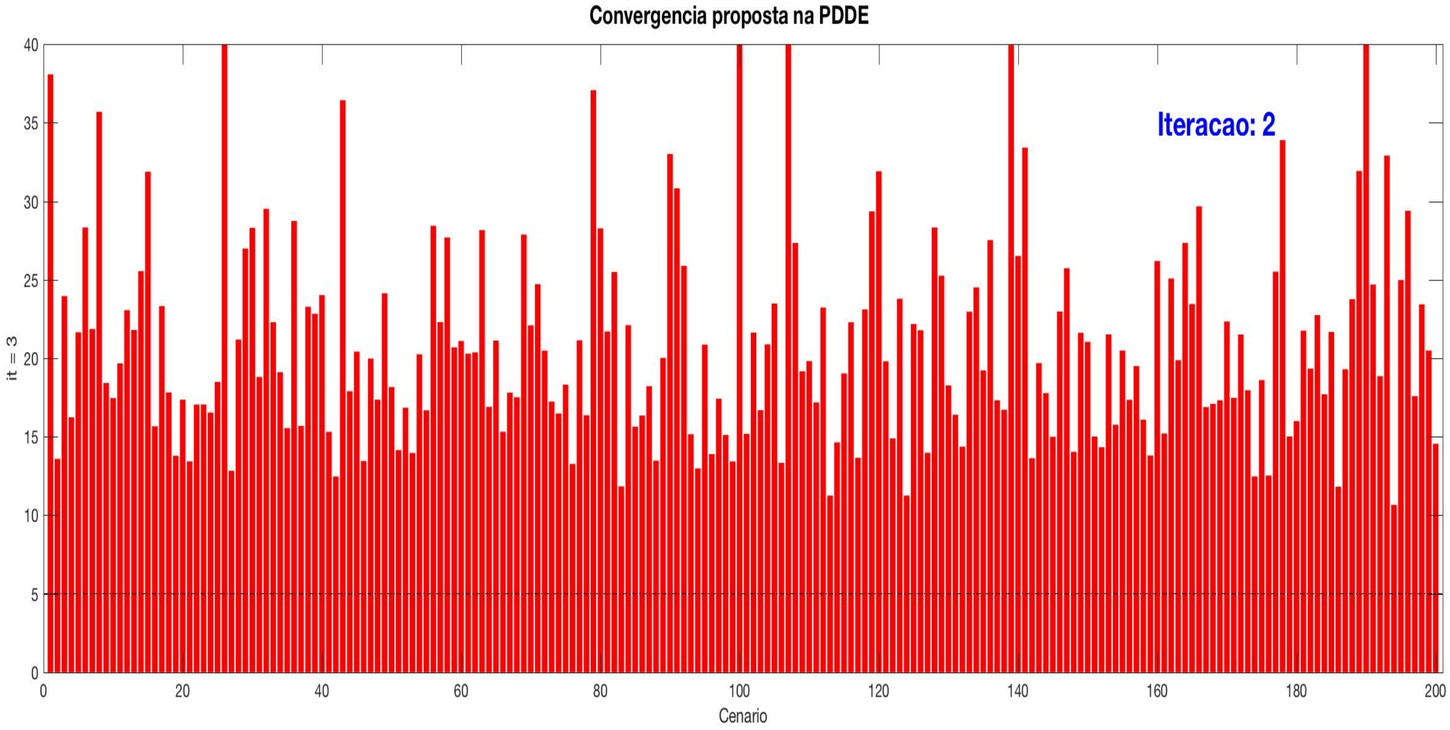
Didactic Illustration (Usual SDDP Algorithm)



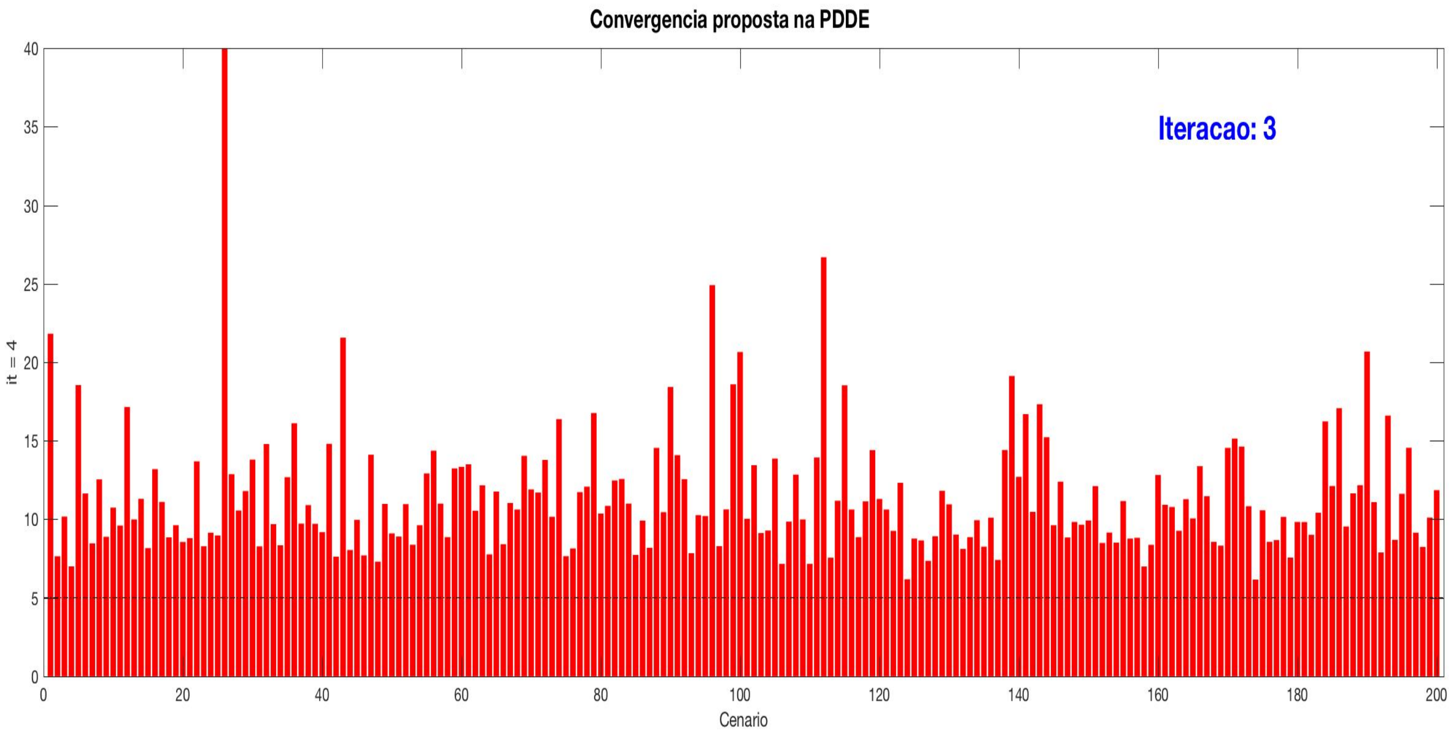
Looking for The Benefit Values



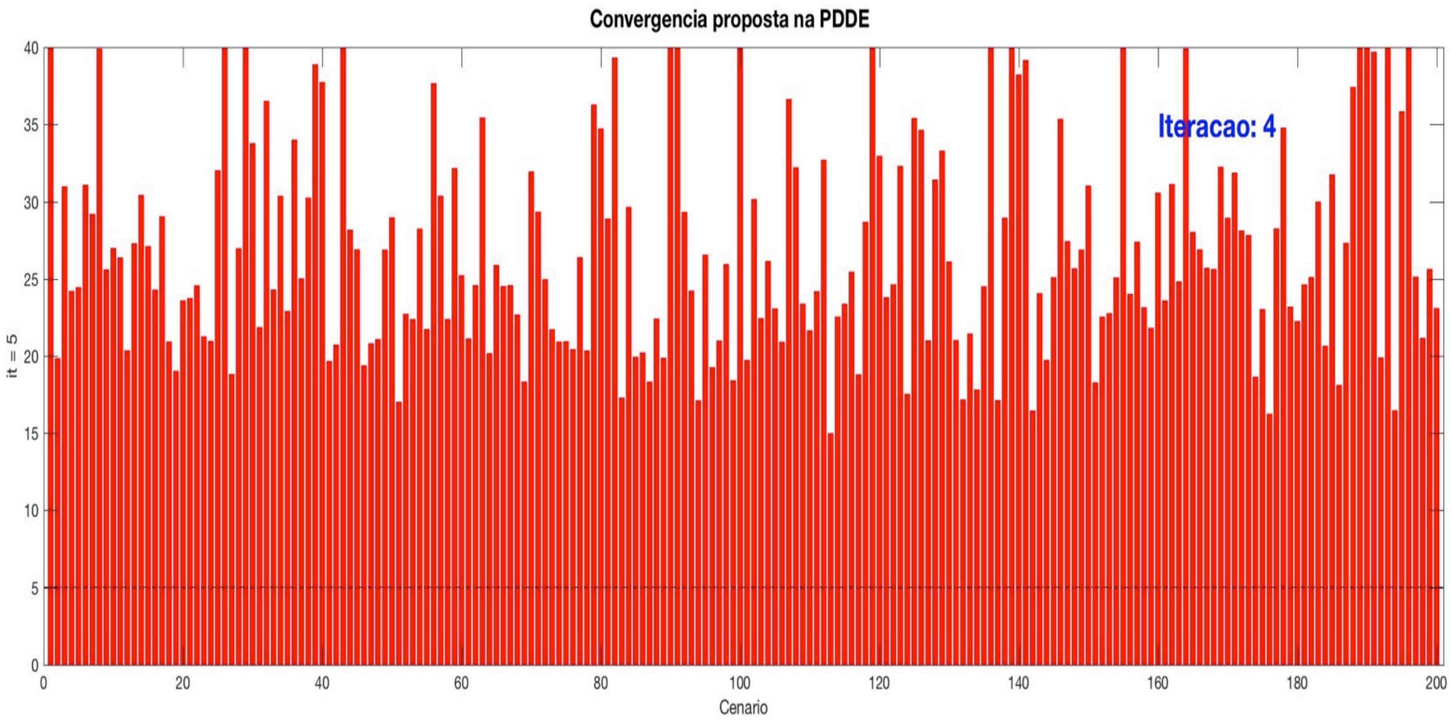
Looking for The Benefit Values



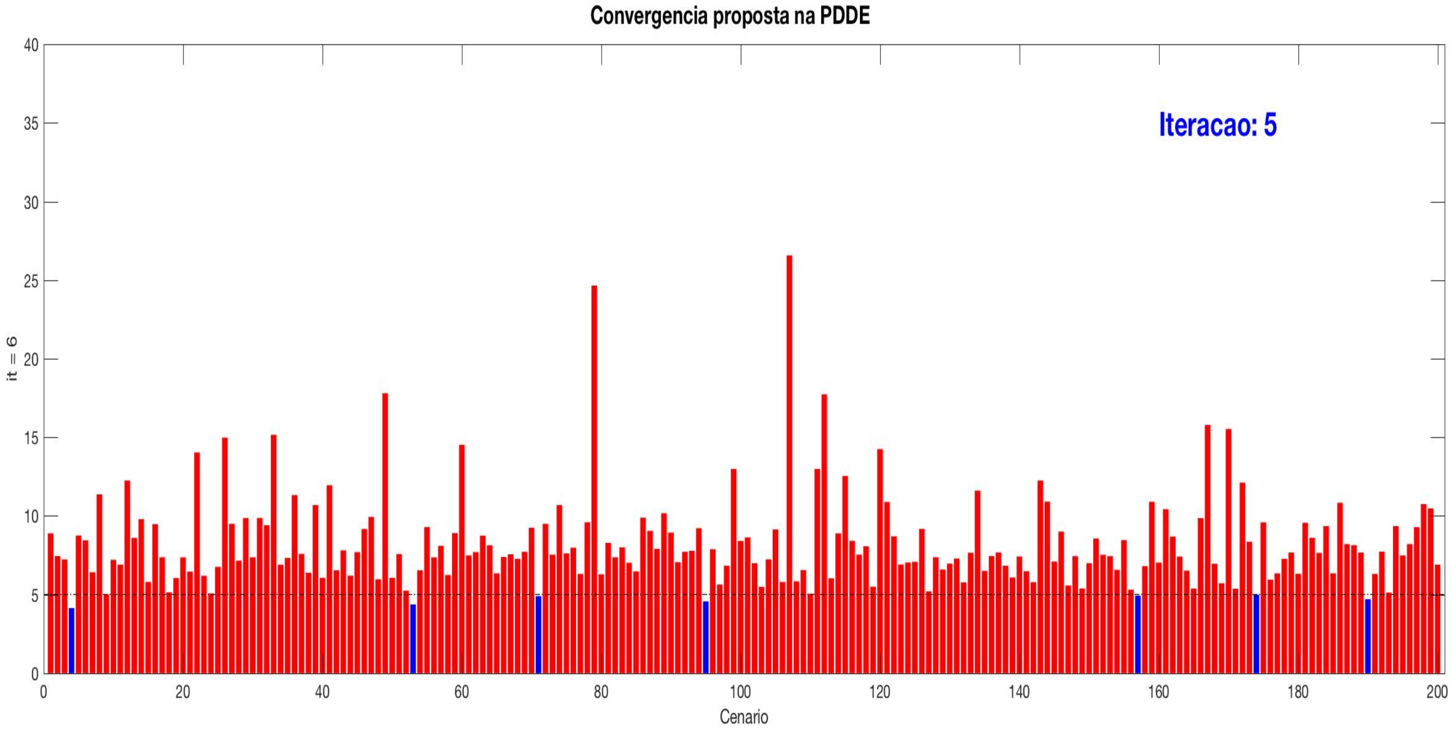
Looking for The Benefit Values



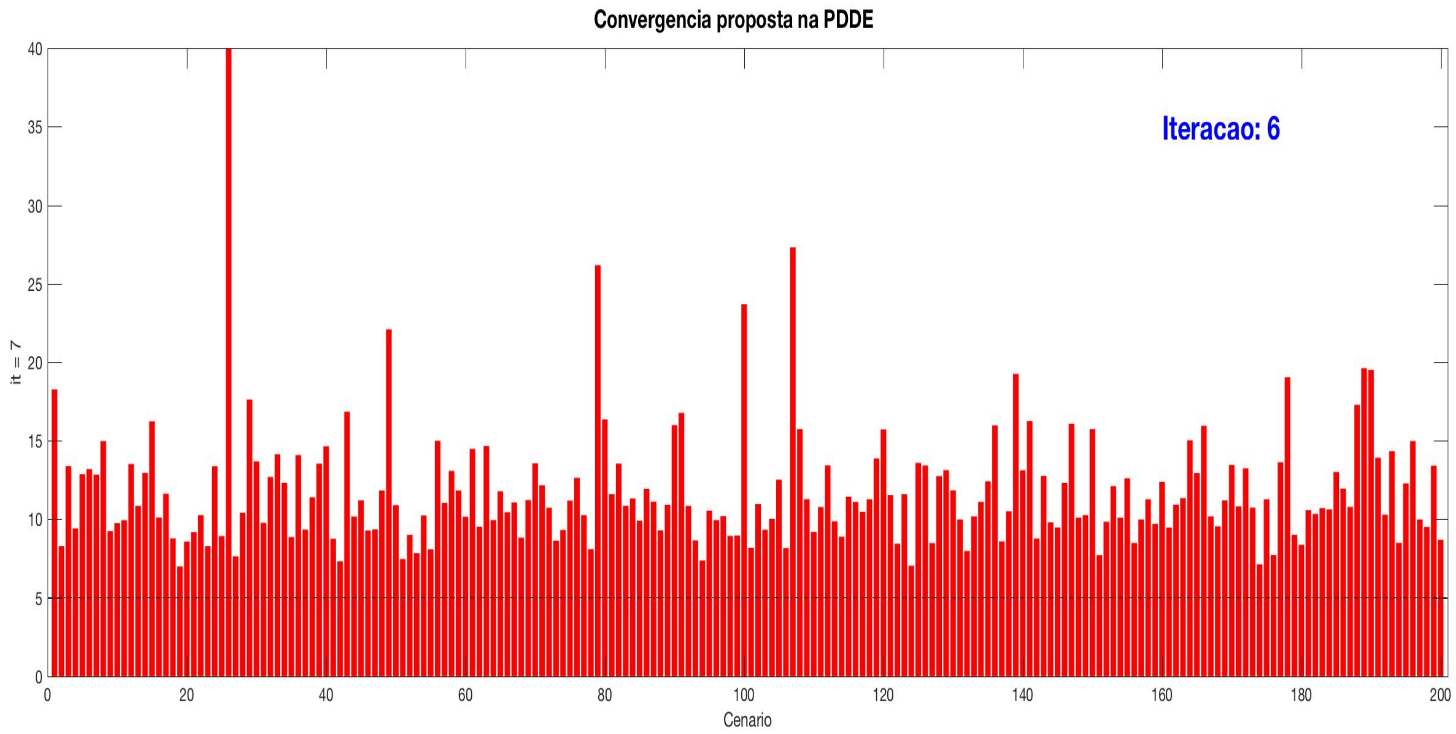
Looking for The Benefit Values



Looking for The Benefit Values

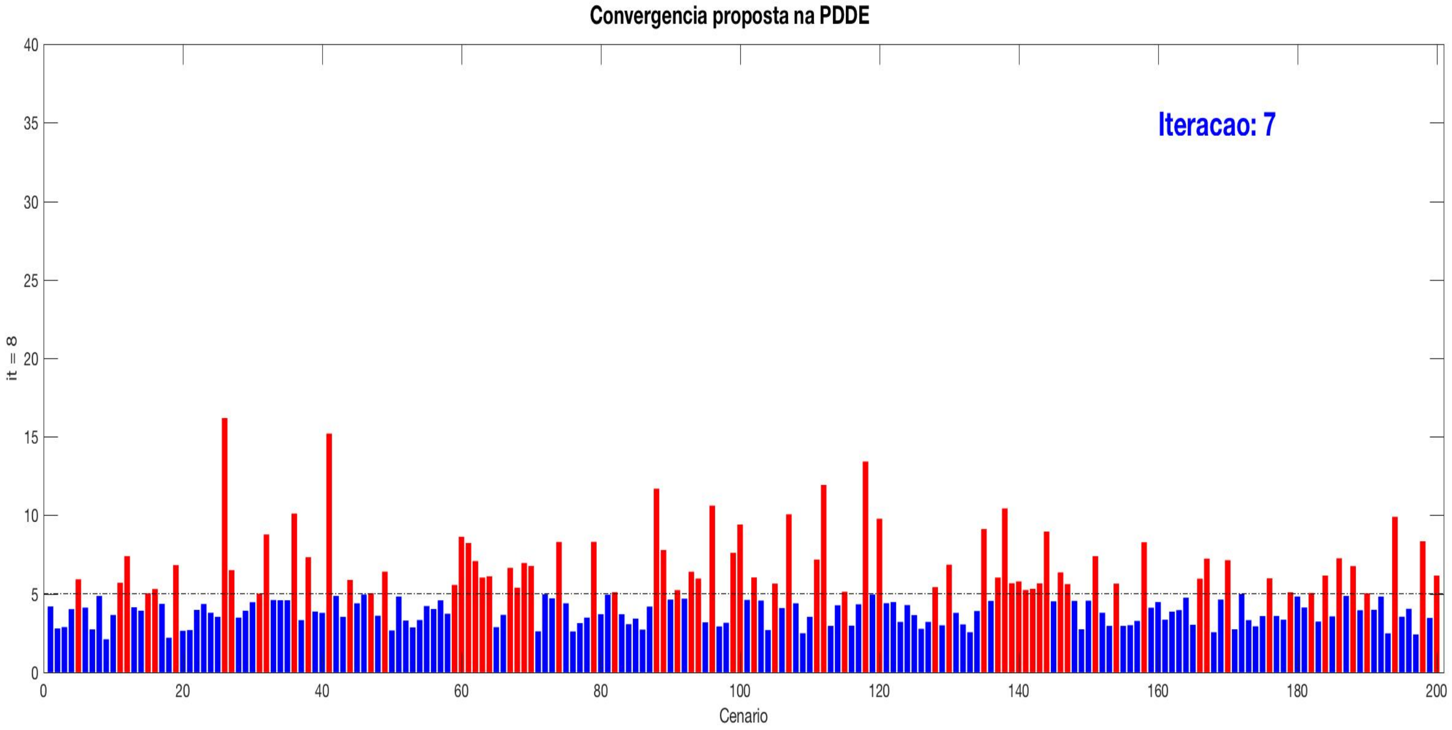


Looking for The Benefit Values

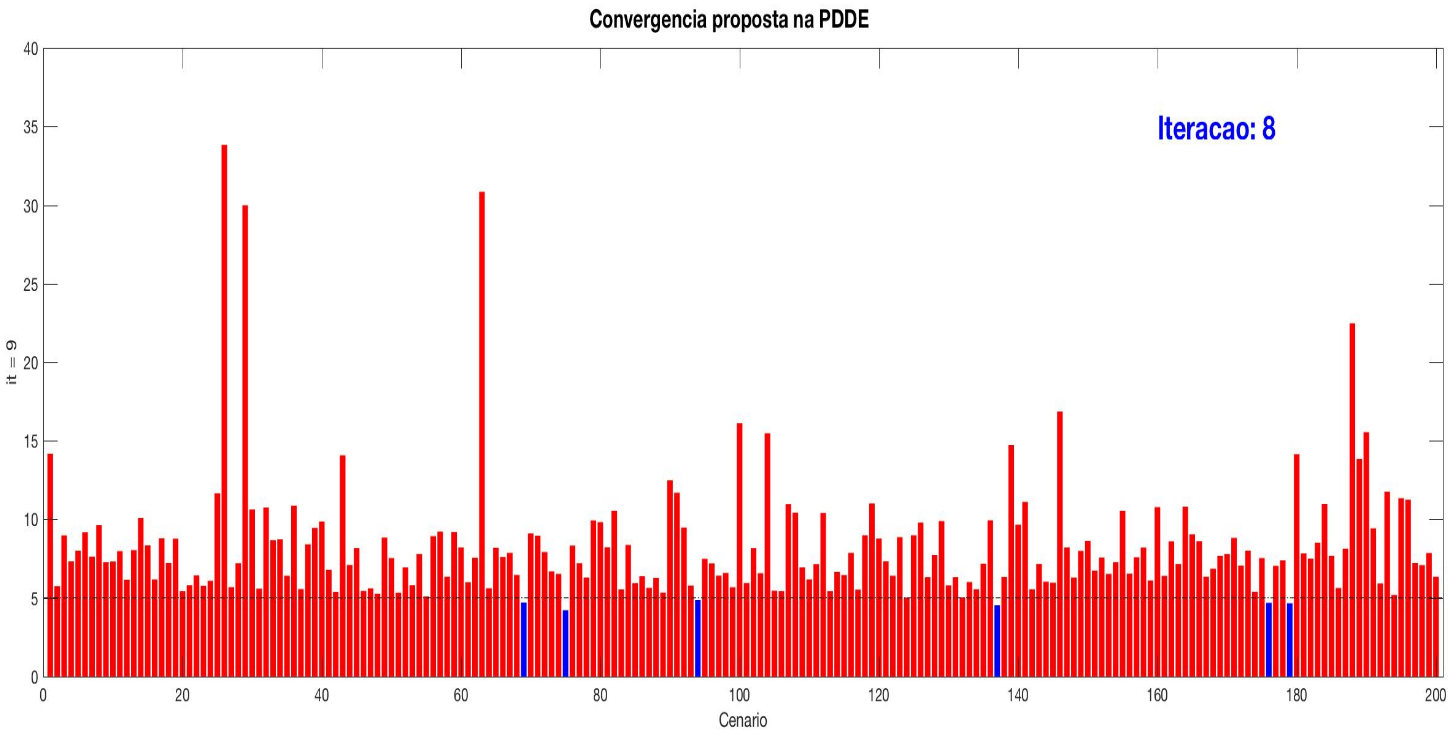


Universidade Federal de Juiz de Fora

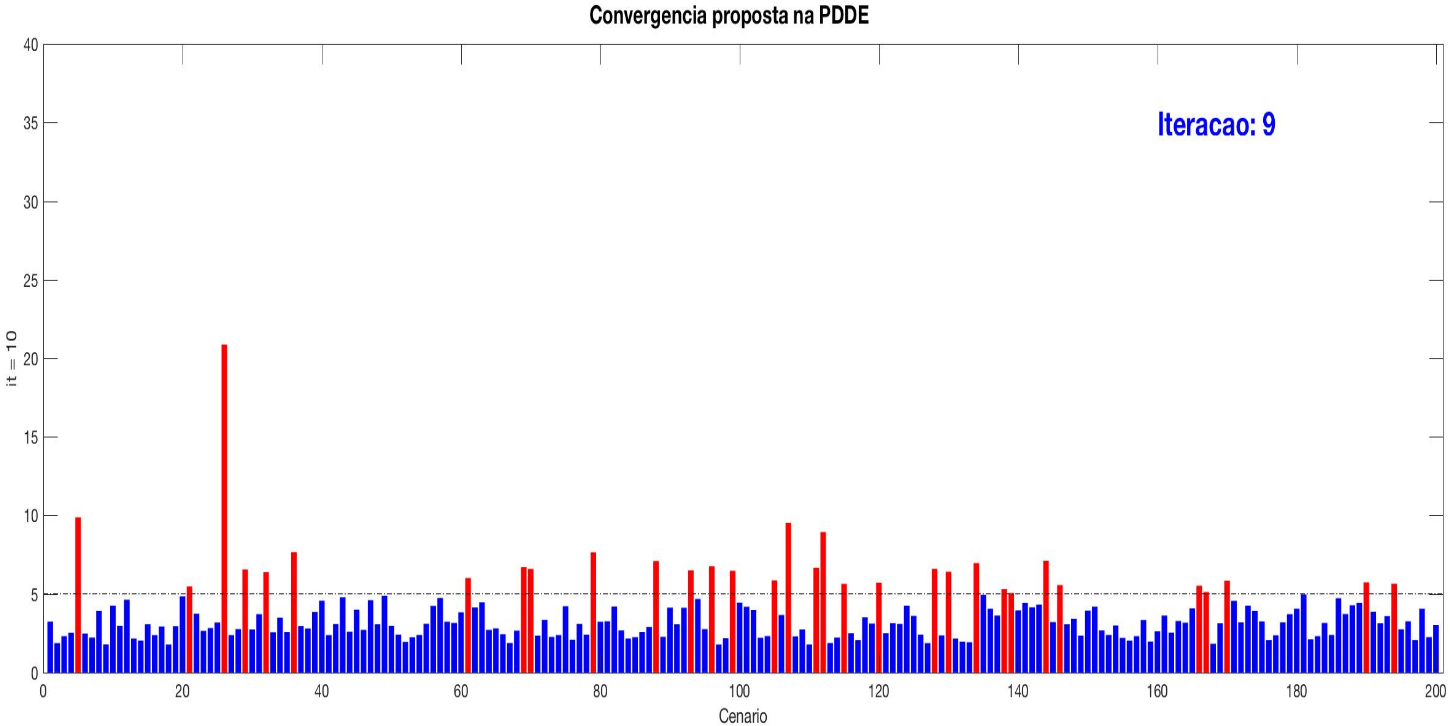
Looking for The Benefit Values



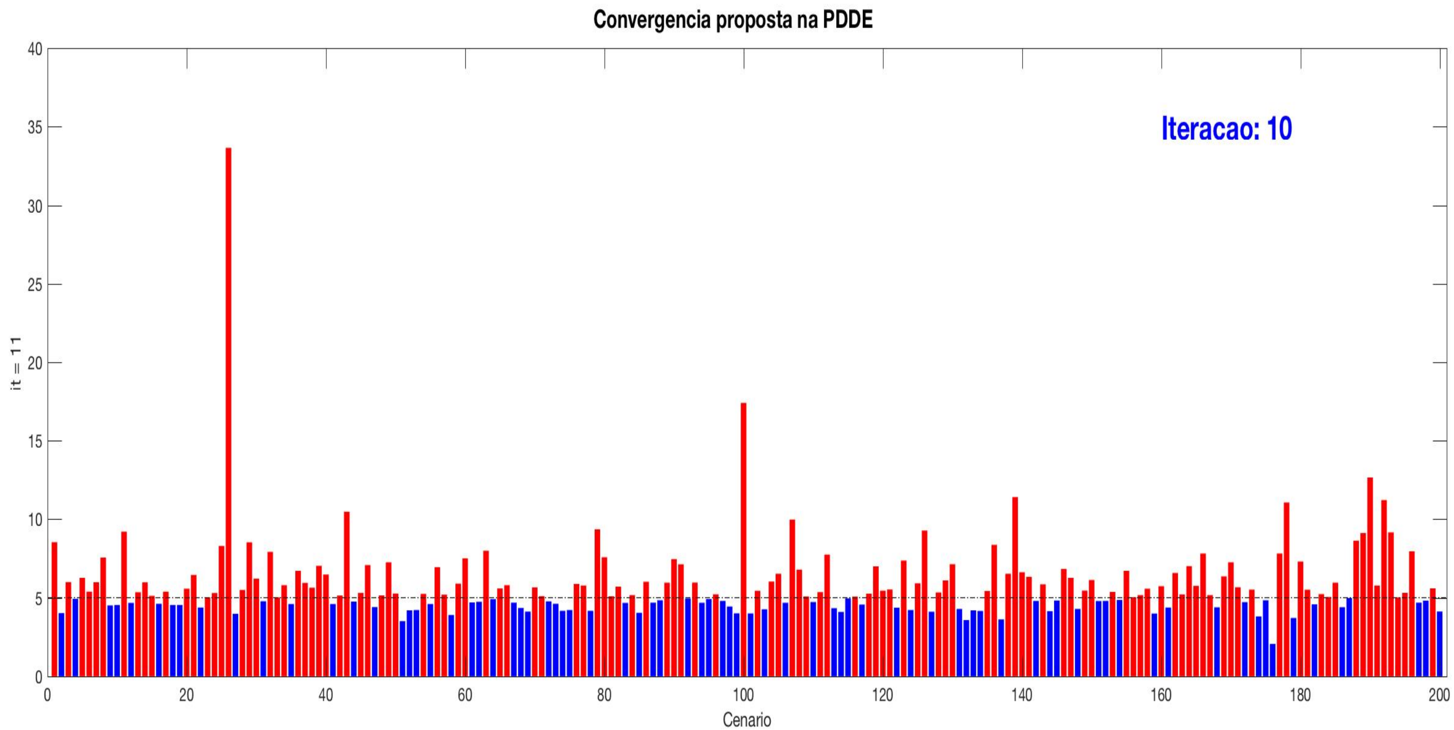
Looking for The Benefit Values



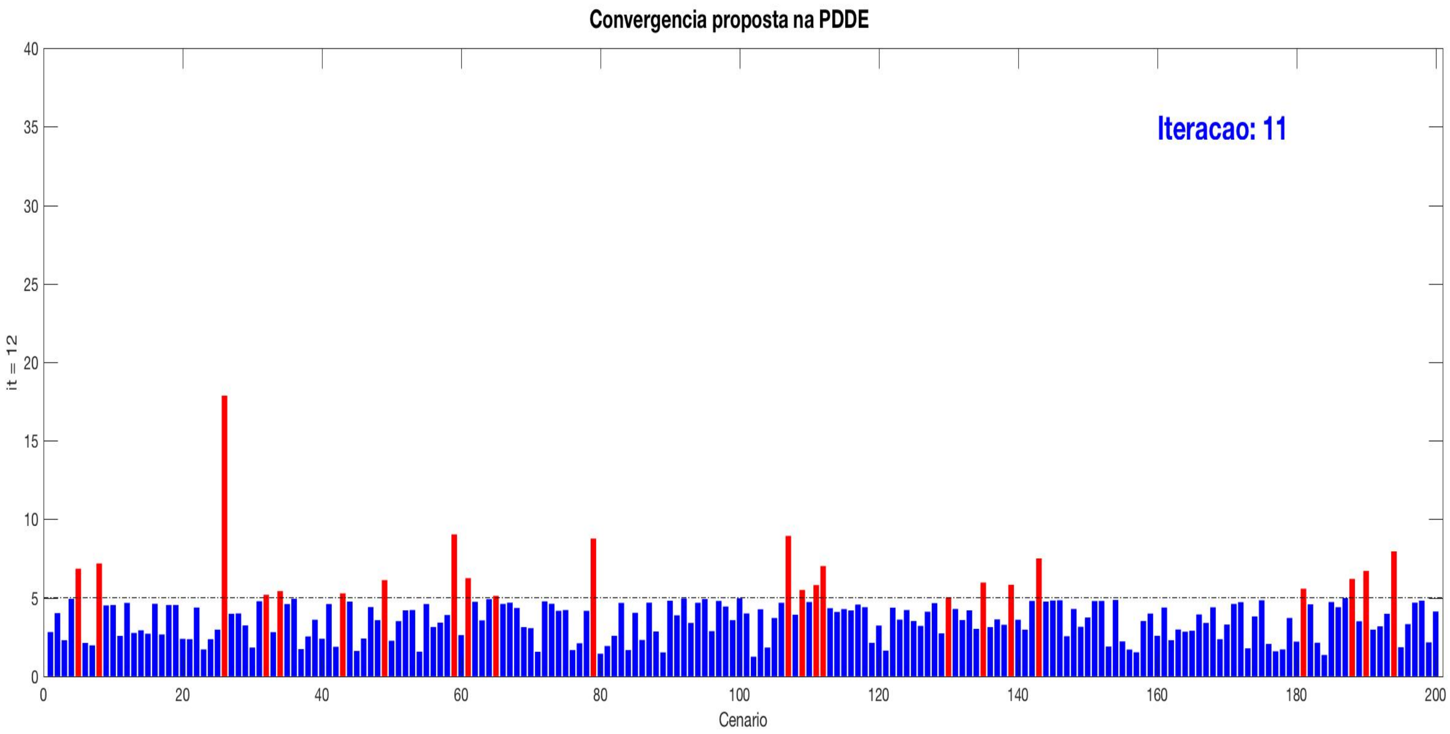
Looking for The Benefit Values



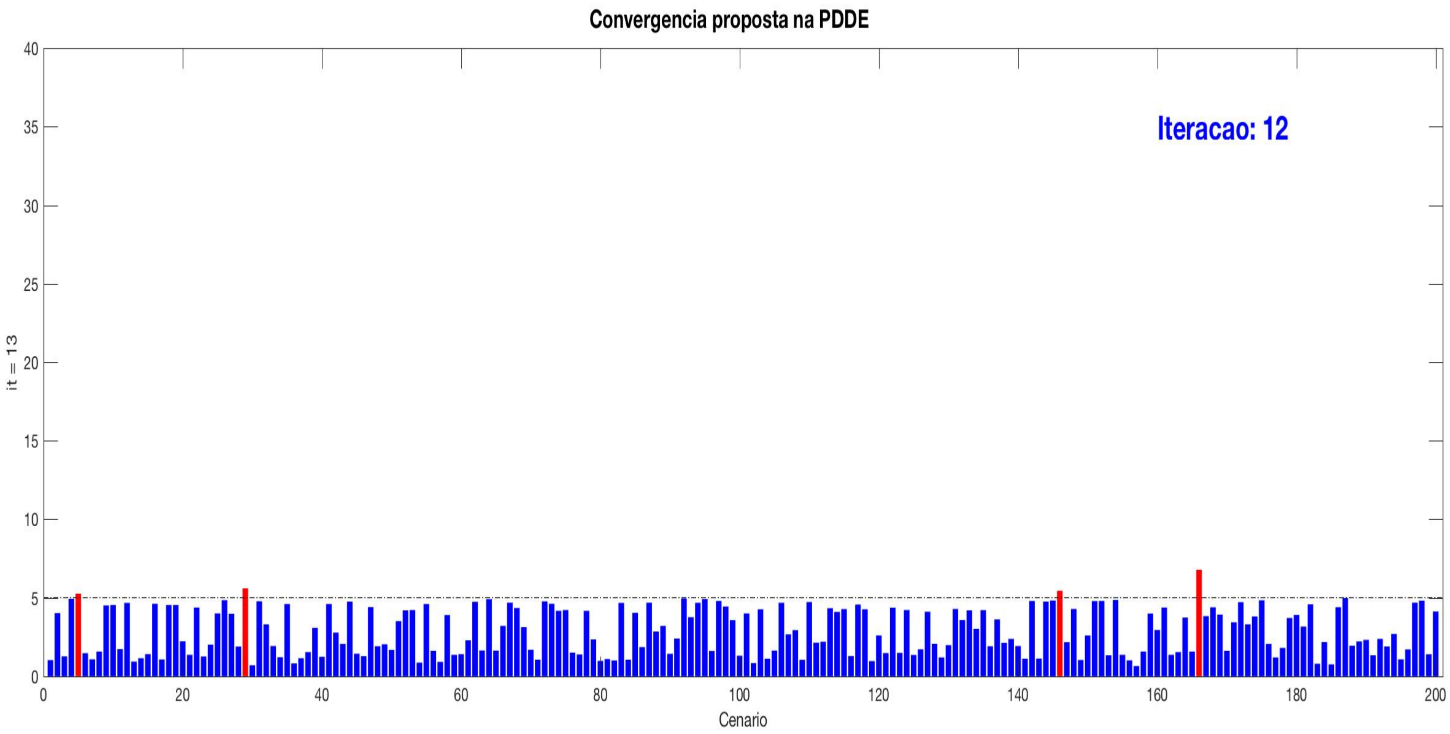
Looking for The Benefit Values



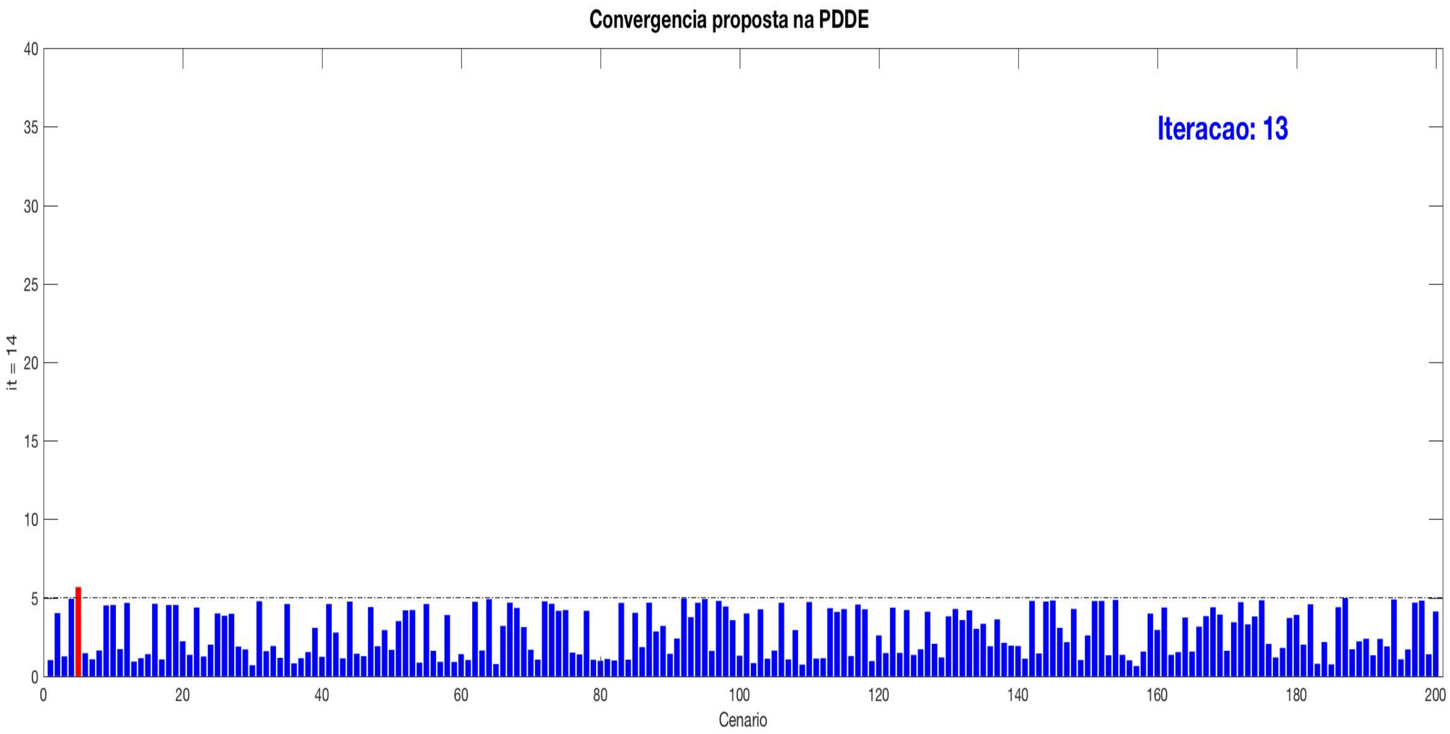
Looking for The Benefit Values



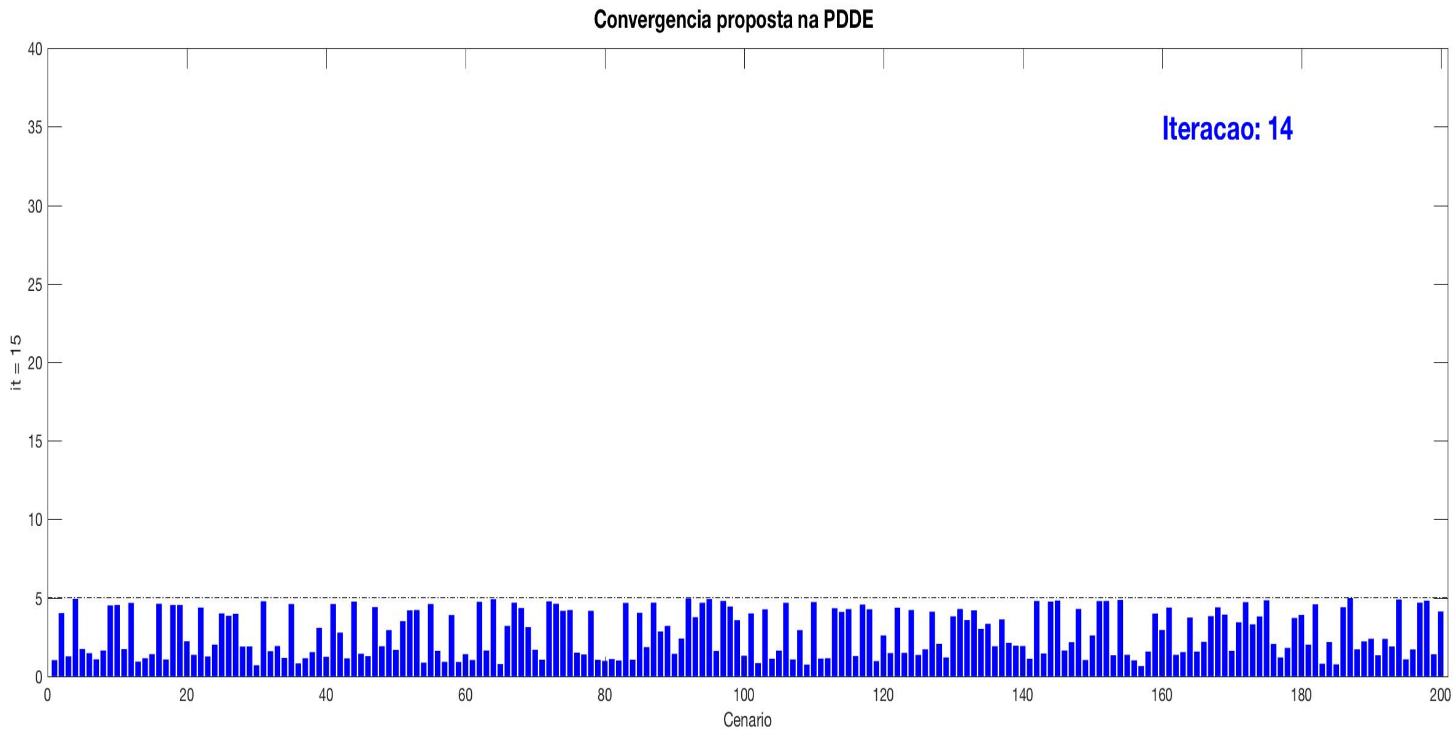
Looking for The Benefit Values



Looking for The Benefit Values

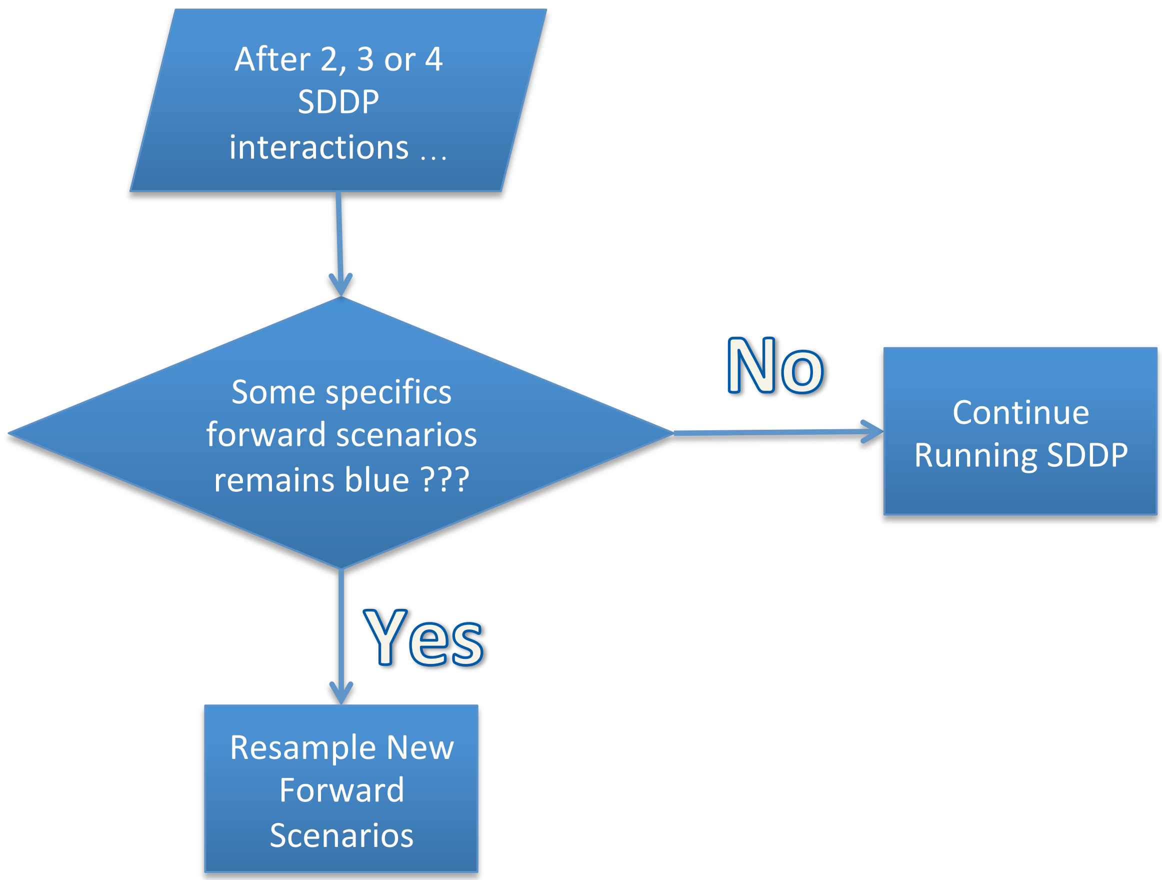


Looking for The Benefit Values



R. B. S. Brandi, A. L. M. Marcato, B. H. Dias, T. P. Ramos and I. C. d. S. Junior, "A Convergence Criterion for Stochastic Dual Dynamic Programming: Application to the Long-Term Operation Planning Problem," in *IEEE Transactions on Power Systems*, vol. 33, no. 4, pp. 3678-3690, July 2018, doi: 10.1109/TPWRS.2017.2787462

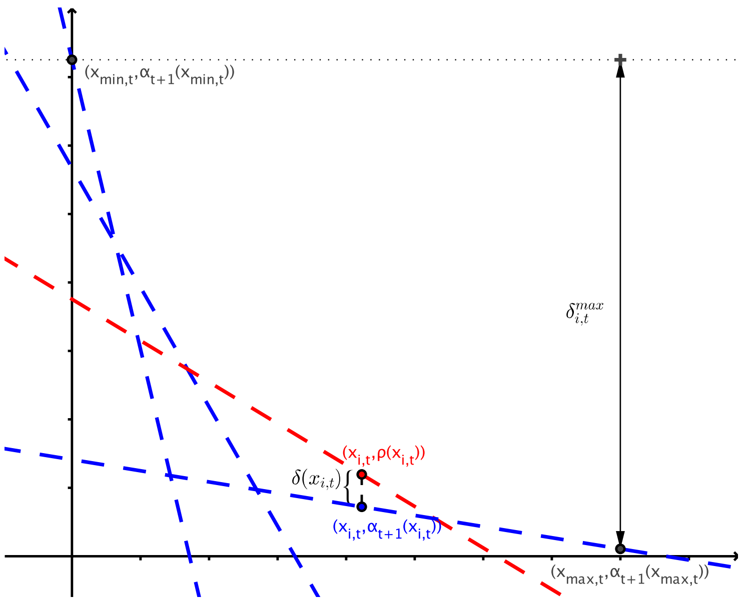
Work in Progress: Smart Resampling

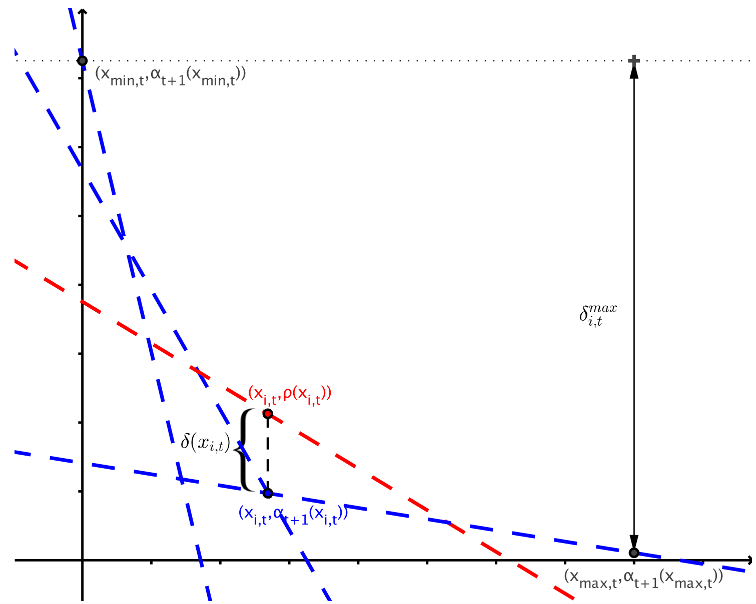


Work in Progress: Optimal Benefit Value

- **Currently**, the benefit is evaluated on the state (storage and past inflows)

- **Work in Progress**: To solve another Linear Optmization Problem. What's the maximum benefit of the new cut?





Work in Progress: Optimal Benefit Value

$$\mathfrak{B}_{i,t}^{k} = \frac{\delta_k}{\delta max_{k,i,t}}$$

$$\delta_k = max \left\{ \alpha_{t+1}^{new} - \alpha_{t+1}^{current} \right\}$$

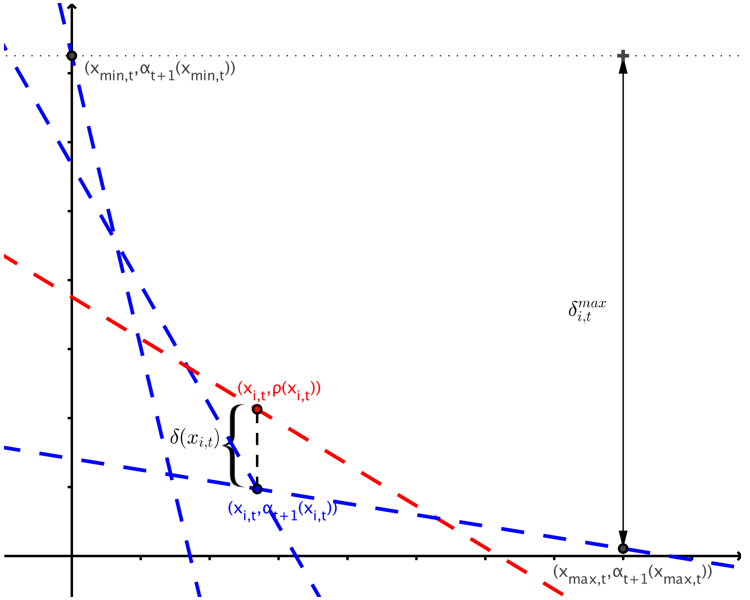
sa

$$\alpha_{t+1}^{current} \geq \sum_{i=1}^{nuhe} \lambda_{i,t+1}^{jcut} v f_i + b_{t+1}^{jcut}$$

One inequality for each current cut.

$$\alpha_{t+1}^{new} = \sum_{i=1}^{nuhe} \lambda_{i,t+1}^{jnew} v f_i + b_{t+1}^{jnew}$$

Only for new cut.



A. L. Castro *et al.*, "A new criteria for convergence of multistage deterministic dynamic programming applied to multiobjective functions: A Brazilian hydro-thermal dispatch case," *2017 IEEE Manchester PowerTech*, Manchester, 2017, pp. 1-6.
doi: 10.1109/PTC.2017.7981119

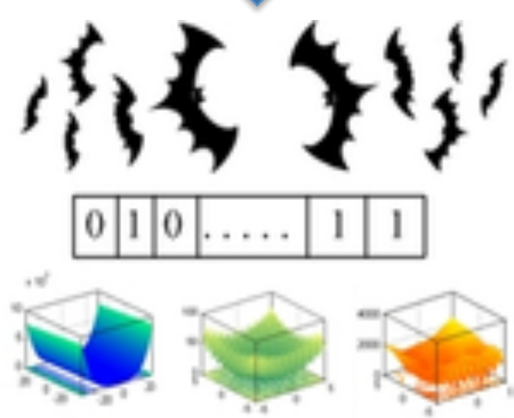
Universidade Federal de Juiz de Fora

Additive x Multiplicative PAR(p)

The stochastic behavior of historical inflows must appear in synthetic scenarios:

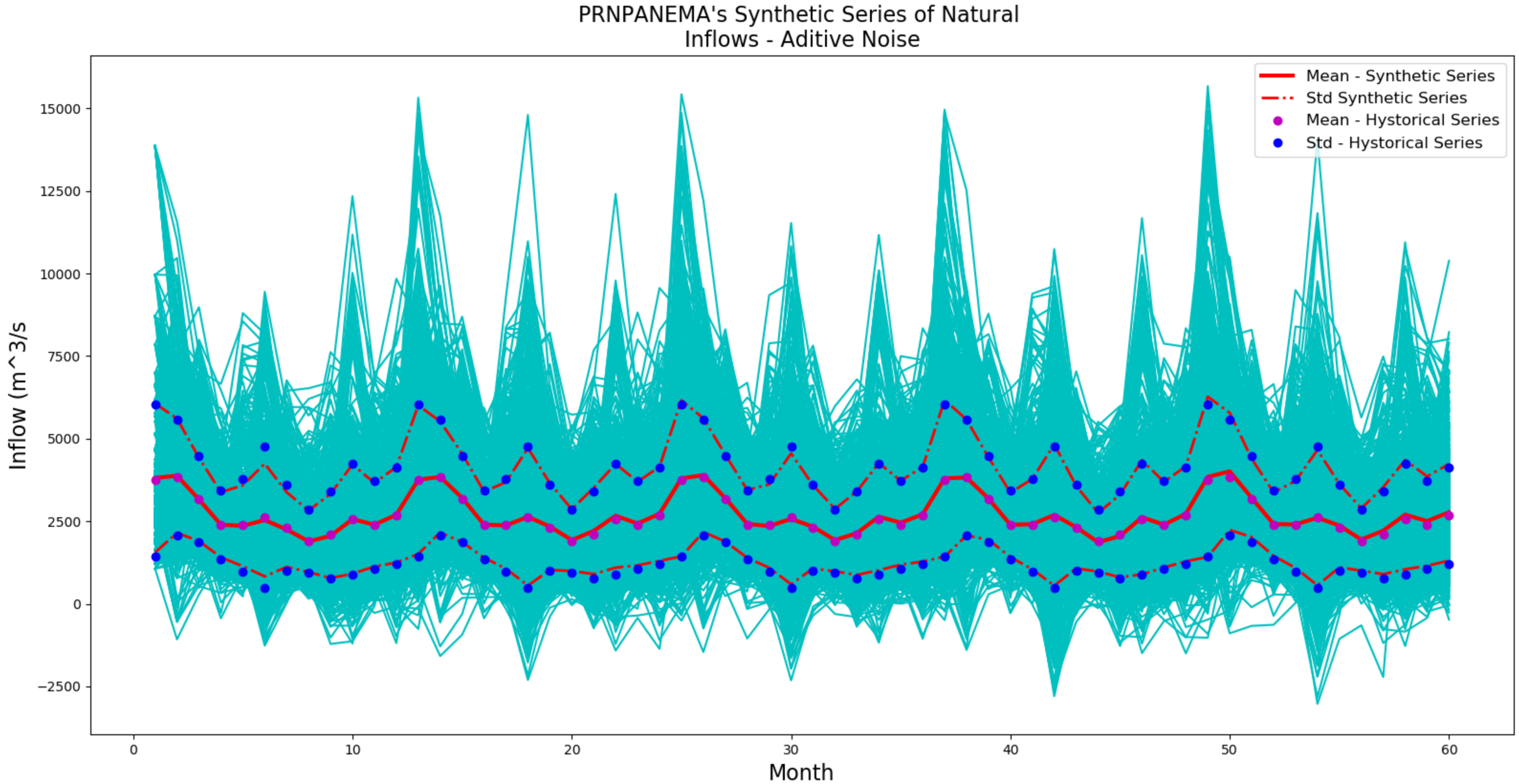
- Mean, standart deviation, seasonality, negative/positive sequences, skewness

Computational Intelligence



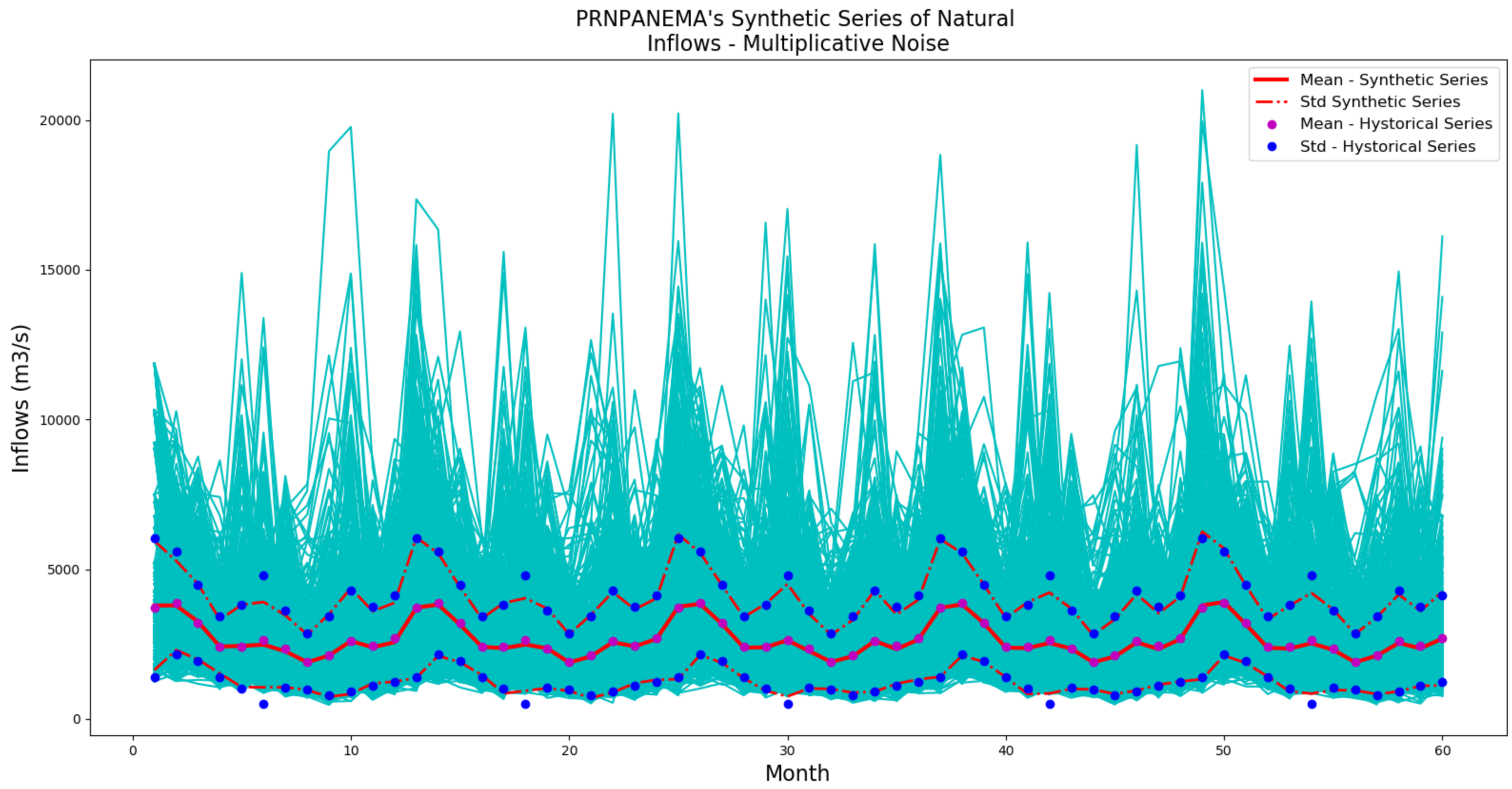
Bat Search Algorithm

Additive PAR(p)



$$Z_t = \Phi_1 Z_{t-1} + \Phi_2 Z_{t-2} + \ldots + \Phi_n Z_{t-n} + \varepsilon$$

Multiplicative PAR(p)



$$Z_t = (\zeta + \Phi_1 Z_{t-1} + \Phi_2 Z_{t-2} + \dots + \Phi_n Z_{t-n}).\varepsilon$$

Main Conclusions

Improvements in SDDP algorithm to tackle convergence problems

- Benefit Values to establish the convergence
- Resample
- LP to evaluate Benefit Values

Generating Synthetic Scenarios

- Monthly Multiplicative Auto-Regressive Model
- Intelligence Computational Techniques

Acknowledgments

Thank You !

andre.marcato@ufjf.edu.br

Sponsors:

CTG Brasil

CAPES

INERGE
Instituto Nacional de Ciência e Tecnologia em Energia Elétrica

CNPq