Technical Session 2A (14:00 - 15:10)	**Short-term Hydropower Scheduling**	**Chair: Erlon Finard, UFSC**	
	A Two-Stage Model for Incorporating Wind Generation Uncertainties in the Short Term Power Generation Scheduling	Lucas Roberto Dagort	UFSC
	Recent improvements and computational challenges in the Brazilian Day-Ahead hydrothermal unit commitment solution strategy	Carlos Sabóia	CEPEL
	Hourly Granularity in Day-ahead Scheduling of the Brazilian system (DESSEM model): Implications for Hydro-Thermal Dispatch and Price Formation	Ronan Furtado	ELETROBRAS

A two-stage model to handle wind uncertainty in unit commitment models for hydrothermal systems

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In the context of the energy transition, in order to reduce greenhouse gas emissions, the international trend is to integrate renewable sources, such as wind and solar energy, on a large scale. In Brazil in particular, taking into account the increasing penetration of these sources in generation planning models represents a challenging problem, especially in the very short-term planning horizon (hours ahead). Advanced statistical tools are applied to forecast the generation from variable renewable sources (VRS) provided as input data to DESSEM, the official model for unit commitment [1] that determines the day-ahead dispatch and its remuneration, called PLD (from the Portuguese acronym for "difference settlement price"). However, these forecasts are estimates that may differ from the VRS realization in real time, the one that occurs during system operation. In such circumstances, to maintain the load-generation balance, the grid operator resorts to redispatching, which typically involves conventional energy sources, such as flexible hydroelectric and thermoelectric generators. Generators continue to be remunerated based on the PLD, which was calculated before any redispatching.

When real-time VRS generation deviates significantly from that used by DESSEM to determine a dispatch, the PLD may no longer represent an adequate price signal. To mitigate large deviations in this direction, we propose a two-stage stochastic programming model with a two-fold goal. First, to ensure flexible generation dispatch that can handle VRS forecast deviations, without compromising technological limitations or system-wide constraints. Second, to provide a price signal that is robust to such deviations and that represents an adequate remuneration for the flexibility and availability of conventional generators (in particular hydro-generators, which already provide these essential services to the system).

Among intermittent renewable sources, wind generation presents the highest level of uncertainty and variability in Brazil. In its first-stage problem, the proposed model minimizes dispatch costs for given wind power forecasts, like DESSEM. In the second-stage problems, corrective measures are taken to account for rescheduling costs incurred due to deviations from wind generation forecasts. The second-stage deviations are represented by equiprobable scenarios generated by a model calibrated on real data from the Brazilian interconnected system. The model is evaluated in a hydrothermal configuration with four submarkets that mimic the country's main operating features, but at a reduced scale. The proposed model determines a dispatch that is robust to different wind generation scenarios and satisfies the operational and import/export restrictions of each submarket.

[1] T. N. Santos, A. L. Diniz, C. H. Saboia, R. N. Cabral, and L. F. Cerqueira, “Hourly pricing and day-ahead dispatch setting in Brazil: The DESSEM model,” *Electric Power Systems Research*, vol. 189, p. 106709, Dec. 2020, Doi: 10.1016/j.epsr.2020.106709.

Recent improvements and computational challenges in the Brazilian Day-Ahead hydrothermal unit commitment solution strategy

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***Abstract*— Power generation planning and price setting in hydrothermal systems is a complex task, usually performed by a chain of optimization models, ranging from long to short-term time horizons. The latter is an optimization model, called DESSEM, which has been used by the Brazilian ISO and the Market Operator to determine the hourly dispatch and energy prices in the near future. This model considers a detailed set of thermal unit commitment (TUC) constraints, including a detailed approach for combined-cycle thermal plants, nonconvex security constraints for the electrical network and a very detailed operation of the hydropower plants, which includes - despite not in official use yet - the main aspects of hydraulic unit commitment (HUC). In this work we focus on the solution approach devised to tackle this problem including the recent advances by considering symmetry breaking and valid inequalities for TUC problem and the computational challenges to be overcome for the use of HUC in daily operation by ISO.**

***Index Terms*—Thermal and Hydraulic Unit commitment, Mixed-integer linear programming**

I. Introduction

Power generation planning and price setting in large-scale hydrothermal systems is a complex task, usually performed by a chain of optimization models, ranging from long to short-term time horizons. Several examples of such type of coordination can be found in the literature, especially for predominantly hydro systems, where water values need to be carefully evaluated along time to allow an optimization of thermal and hydro resources [1]. In this work we focus on the short-term optimization model, called DESSEM [2], which has been used by the Brazilian ISO and the Market Operator to determine the hourly dispatch and energy prices in the near future. In particular, we focus on the solution approach that has been used by ISO to solve this problem, including some recent strategies developed to reduce the computational burden as well as the computational challenges that have to be overcome for the adoption of hydro unit commitment (HUC) constraints in the day-ahead scheduling.

The current formulation of the DESSEM model, described in [2], includes a detailed consideration of: (i) thermal unit Commitment (TUC) constraints, including the operation of combined-cycle thermal power plants; (ii) a DC modeling of the power grid [3], including additional electrical security constraints [4]; (iii) a detailed representation of the physical characteristics of reservoirs and hydropower plants, such as the variation of efficiency with the head through a piecewise linear production function [5], modeling of water delay times through a propagation curve [6], linear modeling of evaporation, as well as several operational constraints. Additionally, it is also available but still in validation process the hydro unit commitment (HUC) modeling [7] that includes: (i) status (on/off) of each hydroelectric unit including idle mode operation; (ii) minimum and maximum limits of turbined outflow and generation of each unit; (iii) minimum up and down time constraints for each unit; (iv) start-up costs; (v) water consumption for the idle operation mode.

The core objective of optimal hydrothermal scheduling is to minimize the overall operation cost of the national interconnected system, considering all relevant constraints. System operation constraints encompass several essential aspects of the system, such as demand fulfillment per bus, power reserve to handle unforeseen demand peaks, and specific electrical constraints that represent limitations in the electrical network infrastructure. In the context of daily scheduling in interconnected hydrothermal systems, the DESSEM model discretizes the problem into intervals, sometimes up to half-hourly, with a horizon of up to two weeks. The objective function aims to minimize the sum of thermal generation costs and future cost based on the reservoir volume at the end of the week, determined through a Future Cost Function (FCF) provided by the mid-term model DECOMP [8]. The main constraints applied to this problem include: piecewise linear production function representing the hydroelectric power plants, accurately capturing the variation of efficiency with respect to the head, demand fulfillment, water balance with water delay times between reservoirs and water propagation curves, electrical security constraints, as well as additional hydro operational constraints for environmental purposes and other uses of water. The DESSEM model is thus formulated as a large scale mixed-integer program (MIP) using continuous variables to represent the hydrothermal operation and binary variables to for TUC/HUC [2,7].

II. SOLUTION APPROACH

The detailed solution approach is provided in [2] and makes use of two sequences of linear programs (relaxation of TUC/HUC) devoted to finding a set of violated network constraints, and one MIP to determine the optimal unit's status. In order to reduce the computational burden, in this work we consider enhancements in MIP phase by including a symmetry breaking strategy that imposes a lexicography start-up order for the units belong to the same thermal power plant [9] and deriving valid inequalities for TUC problem, similar to those found in [10]. As stated in [2] the solution strategy can be briefly summarized in the following chart:

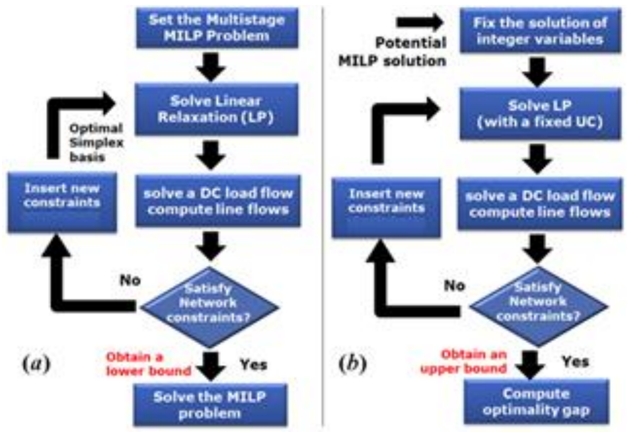

Figure 1. Iterative process to include violated network constraints (a) and to later find a high quality, near optimal, solution to the overall problem (b).

Briefly, in relation to valid inequalities for TUC we have derived cuts by combining minimum and maximum generation limits of the thermal power plant with the ramping polytope of each thermal unit. The procedure results in valid knapsack and set covering constraints for TUC that tighten the linear relaxation and leads to a faster convergence of the branch-and-cut algorithm.

III. COMPUTATIONAL RESULTS

As a first computational experiment, we present computational results for a set of 317 official day-ahead scheduling instances considered by the Brazilian ISO in the year of 2024, adopting the solver IBM/CPLEX for linear and integer programs. We provide a comparison with the original solution approach in order to show the effect of including symmetry breaking and valid inequalities in MIP in terms of reduction of CPU time. In the following table we can find the number of instances that were solved faster and slower than the original, moreover, we have considered that a difference of less than 10 minutes is not significant and thus there is no difference between instances:

No differences	Faster	Slower	Total
175	105	37	317
55,2%	33,1%	11,7%	100%

Table 1. Number of instances solved faster and slower with the introduction of symmetry and valid inequalities

Looking at the results, we can see the benefits of considering symmetry and valid inequalities in the instances since the number of faster instances overcame the slower ones in almost three times. Regarding the faster instances the overall time of the set was decreased by 43% with a greater decreased value in a specific instance of 3 hours. Regarding the slower instances the overall time was increased by 53% with a greater increased value in a specific instance of 2 hours.

IV. CHALLENGES AND FUTURE WORK

As a computational challenge we can mention the adoption of HUC in the official day-ahead scheduling problems since the dimensions of instances increase considerably. As an example, in the official instances with TUC there are 100.000 binary variables, 500.000 continuous variables and 500.000 constraints, and the same problem with HUC the dimensions reach 250.000 binary variables, 1 million continuous variables and 1 million constraints. In a future work we intend to present results to those instances considering the HUC problem with and without a symmetry breaking strategy for hydro units as well as comparing the efficiency of IBM/CPLEX and GUROBI solvers.

V. REFERENCES

[1] M.E.P. Maceira, L.A. Terry, F.S. Costa, J.M. Damazio, A.C.G. Melo, "Chain of optimization models for setting the energy dispatch and spot price in the Brazilian system", Proceedings of the Power System Computation Conference - PSCC, Sevilla, Spain, June 2002.

[2] T.N. Santos, A.L. Diniz, C.H. Sabóia, R.N. Cabral, L.F. Cerqueira, "Hourly pricing and day-ahead dispatch setting in Brazil: The dessem model", Electric Power Systems Research, v.189, December 2020.

[3] T.N. Santos, A.L. Diniz, "A dynamic piecewise linear model for DC transmission losses in optimal scheduling problems", IEEE Transactions on Power Systems, 26, 508-519 (2010).

[4] T.N. Santos, A.L. Diniz, R.N. Cabral, L.F. Cerqueira, "Inclusion of electrical network security constraints in the DESSEM model". CEPEL Technical Report 6691 (2019).

[5] A.L. Diniz, M.E.P. Maceira, "Four-dimensional model of hydro generation for the short-term hydrothermal dispatch problem considering head and turbining effects", IEEE Transactions on Power Systems, 23, 1298-1308 (2008).

[6] A.L. Diniz, T.N. Santos, "Short-term hydrothermal dispatch with river-level and routing constraints", IEEE Transactions on Power Systems,29, 2427-2435 (2014).

[7] L.F. Cerqueira, C.H. Sabóia, A.L. Diniz, "Consideração da Modelagem do Unit Commitment Hidráulico na Programação Diária da Operação", XXVII SNPTEE - Seminário Nacional de Produção e Transmissão de Energia Elétrica, 2023, Brasília.

[8] A.L. Diniz, F.S. Costa, M.E.P. Maceira, T.N. Santos, R.N. Cabral, "Short/mid-term hydrothermal dispatch and spot pricing for large-scale systems-the case of Brazil", 2018 Power Systems Computation Conference (PSCC), pp. 1-7 (2018).

[9] J. Alemany, F. Magnago, D. Moitre, H. Pinto, "Symmetry issues in mixed integer programming-based Unit Commitment", Electrical Power and Energy Systems, 2013.

[10] Kai Pan, Yongpei Guan, "A Polyhedral Study of the Integrated Minimum-Up/-Down Time and Ramping Polytope", arXiv:1604.02184, 2016.

Hourly Granularity in Day-ahead Scheduling of the Brazilian system (DESSEM model): Implications for Hydro-Thermal Dispatch and Price Formation

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(1) Objective

The DESSEM model, employed by Brazil's Independente Electrical System Operator (ONS) for day ahead scheduling (PDO) and by the Market operator (CCEE) for determining the energy spot price (PLD), solves a mixed-integer linear programming (MILP) problem to optimize hydro-thermal-wind generation dispatch under physical, operational, and electrical network constraints.

Given the computational complexity of the MILP problem for a large-scale system like Brazil's, this work considers a modification in the time discretization to accelerate the model solution process for the cases that present a large CPU time. The proposal involves adopting an hourly time step for the first day – instead of a half-hourly discretization set by official regulation effectively reducing the number of periods and decision variables for that day. Several considerations favor this choice: some unit commitment data are already specified on an hourly basis; the published PLD price on a hourly basis; some operational constraints are set or end at the beginning of a full hour; electrical network data often remain relatively stable within each hour.

(2) Methodology

To quantify the effects of temporal aggregation, the study employs representative case data from 2023 to 2024 under varied hydrological and load conditions. In a baseline scenario, DESSEM is configured with half-hourly intervals for the first day, capturing the standard practice in current operations.

The first modified scenario replaces half-hourly intervals with hourly intervals for the initial day of the horizon. While the second up to seventh days may retain daily or hourly discretization depending on standard practice, the focus is on the immediate 24-hour period where the most complex constraints tend to accumulate. We note that, in some cases, adjustments and flexibilization of constraints originally defined in half-hour intervals will be necessary to ensure feasibility and consistency within the revised temporal resolution.

Reservoir trajectories are examined closely in upstream-downstream chains to detect any notable shifts in water management strategies, and wind profiles are aggregated to match the hourly step, allowing an assessment of how intra-hour smoothing might reduce or delay curtailment.

(3) (Expected) Results

Preliminary simulations show that hourly discretization can substantially decrease solver run times in DESSEM, thereby improving the feasibility of solving detailed MILP problems within operationally required deadlines. Although small changes in reservoir trajectories can be observed when switching to hourly steps, these do not appear to cause major disruptions to upstream-downstream coordination, and net storage outcomes can remain aligned with the baseline. Wind curtailment may decline in certain intervals if wind peaks are averaged over an entire hour, though the significance of this effect seems to depend on regional wind penetration. Moreover, thermal unit commitment decisions, which typically hinge on hourly rather than half-hourly data, tend to align closely with the resulting price signals. While precision losses may occur, the operational benefits—particularly during time-sensitive or critical grid conditions—could justify this trade-off.

This work underscores the trade-offs between computational efficiency and operational accuracy. While hourly resolution accelerates solutions, it reduces precision in modeling sub-hourly dynamics of hydropower and renewable generation. Future research could explore adaptive temporal discretization, refining granularity only during critical operational windows, to balance computational tractability with accuracy in dispatch and price formation.