A CRITICAL ANALYSIS OF THE ASYMETRY IN THE OPERATION PLANNER DILEMMA

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ABSTRACT

In large hydro-dominated electrical power systems, such as the Brazilian interconnected system, with centralized operation the decision-making process during operation planning is usually referred as "operation planning dilemma". In this case, the dilemma resides in the management of the hydroelectric power plant dams along the time with the focus on the minimal operation cost along the planning horizon. In the typical optimal timeline of the decision-making process, spillage and droughts are plotted with symmetrical undesired impacts, however, as it has been observed in recent years, the consequences are very asymmetric. This paper will present the dilemma of the planner and discuss the impacts of its real asymmetries based on insights from simulations and supported by data from the operation and fluctuations in costs of the Brazilian system. Observations from the discussion are aimed to contribute to call the attention of decision makers and provide guidance to improve reliability and security of the electricity supply.

Keywords: operation planning, energy, polices, hydroelectric, energy costs.

Introduction

In spite of the recent grow and popularization of new renewable energy sources (RES) and diversification of the electricity mix, Brazilian electric power system remains one of the largest hydro-dominated electrical power system in the world. In 2022, 61,9% of the electricity consumed in Brazil was produced in the hydroelectric plants [1]. In addition to that, Brazilian system is very unique, the origin and stochasticity of the water flow regimes, the complexity of the large cascades of spatially connected power plants (owned by different private agents), and the centralized operation are characteristics that demands a distinct approach by the system planner.

In the operation planning of such system, the decision-making process is also coupled in time, i.e., the decisions taking at a time will have consequences in all subsequent decisions [2]. Therefore, in the optimization of the hydroelectric production, there is a dilemma between the depletion of the reservoirs (use of the water for electricity production) or the preservation of the reservoirs' volumes (use of thermal power plants, burning fuel) during the current period. Because of the uncertain consequences it will have due to the stochasticity of the affluences of the rivers that feed the reservoirs.

For example, if there is a decision of depleting reservoirs in one moment before an unexpected drier season, there may be insufficient hydro energy to overcome the dry period and large amounts of thermal energy will be necessary, eventually in excess of the installed capacity, leading to shortages or blackouts. On the contrary, if there is a decision to keep the reservoirs full through the additional use of thermal generation in an instant before a period of high precipitation, it will be necessary to spill the excess water. It also represents an energy spill, with costly consequences, once the available water could not be stored and the additional thermal energy was used unnecessarily. This dilemma is typically illustrated with an adaptation of the Figure 1 [2-6], with certain symmetry of the consequences.

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Despite the models used to precify or penalize the non-desired scenarios, the illustration and discussions along the decision-making does not emphasize enough the difference between the bad and the ruin, between the costly and the catastrophic. Thus, this paper further discusses the dilemma and presents the recent development of the Brazilian case with conclusions of recent researches. Although hydro dominated systems from other countries are not presented or discussed in this paper, conclusions may also be applicable to them.

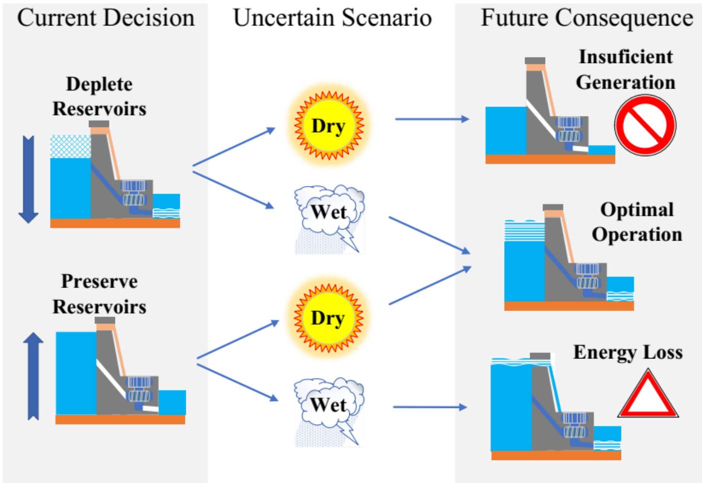

Figure 1: Illustration of operation the planner dilemma

Historical operation

Recently, the information of the operation has been made available online by the Brazilian System Operator (ONS) and it is possible to review the past operation (in this case the Stored Energy – ARM – is used to represent the operation or the "water volume in hydroelectric power plants' reservoirs") and compare with the spot price of energy (PLD) applicable in the same period. It is also important to mention that the PLD is regulated with a minimum and maximum value regulated, therefore it is possible to note some caps in the top and bottom of the PLD curve of Figure 2.

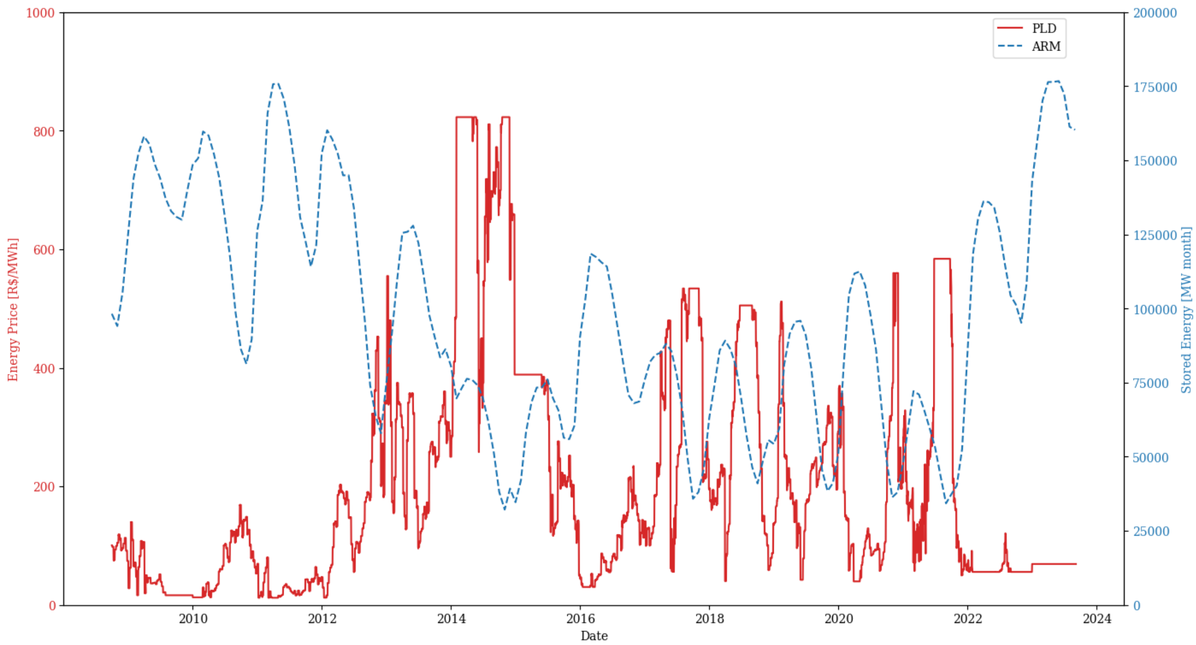

Figure 2: Energy price and stored energy in Brazil from October 2008 to September 2023 with data from [7,8]

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The decade from 2013 to 2022 has demonstrated to be abnormal, in spite of the fact most of the people perceives it as the regular situation. Energy price has fluctuated from a week to another almost from the celling to the floor every year. Such situation has been shown very critical for the economy, creating difficulties not only to the energy industry, but to every economic sector that demands electricity.

It has been very different in 2023 as one can observe in Figure 1. The price has been stable and low during the year so far (September of 2023) while the reservoirs are maintained above a certain level. Before further evaluate the chart, it is important to mention that the energy offer has been growing, mainly due to RES expansion projects and that the demand has not growth as expected. Therefore, it is possible to observe an excess of supply, in terms of energy, not necessarily in terms of power. Those facts certainly operate in favor of the current scenario; however, it is noticeable that the model that regulates the price does not explicitly consider such effects in future price. Even though, the prices have been sustainably low despite of any future expectation on the stochastic affluences.

The recent work [9], has also pointed out the influence of the stored energy (ARM) in the stabilization of the costs (PLD). A systematic investigation of the price model has not been concluded yet, but as the past operation suggests (Figure 2), energy security brought by the elevated levels of reservoirs support the stabilization of the prices. With reservoirs kept above about 50% of the capacity, the price fluctuation is drastically reduced.

Insights from the deterministic planning

In [6], the operation of hydrothermal systems has been discussed with several simulations that clarify different models and operations. Details of the mathematical models are available in the same reference[1]. In simulations, a cascade of three Hydroelectric Power Plants (HPPs) with reservoirs from the actual Brazilian system were used to illustrate the variations of scenarios and collect insights.

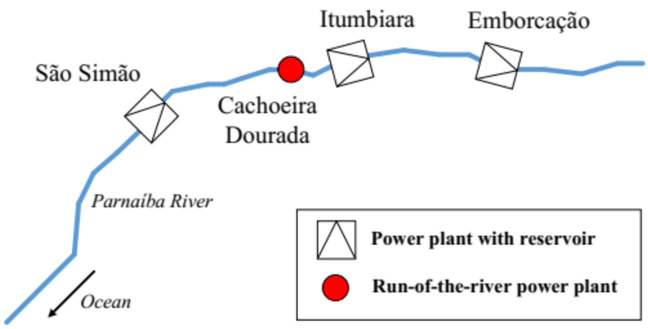

Fig. 3: Relative location of the power plants of the test system

Figure 4 presents the results of a deterministic optimization considering that the planning horizon of 24 months starts on May (end of the wet season). The affluences used were derived from the long term mean of natural inflows (MLT). In this case, the series from the first year were repeated in the second. Therefore, repeated yearly results are expected due to its condition. It is noticeable that each HPP was independently optimized systematically together with the others and the optimal result is different for each of them.

It is valuable to mention that in such optimized conditions, flow regulation is made by the HPPs upstream, which may sound contradictory. Because one may think that it is better so have the water stored upstream in order to take benefits of its flow in the whole cascade. However, the apparent contradiction is a reliable result of practical systems. In practical systems, downstream HPPs are larger than the ones upstream, therefore, their efficiency assumes greater importance. Thus, optimization

[1] Reference available for download: http://biblioteca.ufabc.edu.br/index.php?codigo_sophia=111304

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signals that it is better to keep higher volumes at those downstream HPPs (for example, São Simão does not reduce volume along the planning cycle – see Fig. 4) in order to benefit of their best productibility, i.e., best efficiency per m^3/s of water flow.

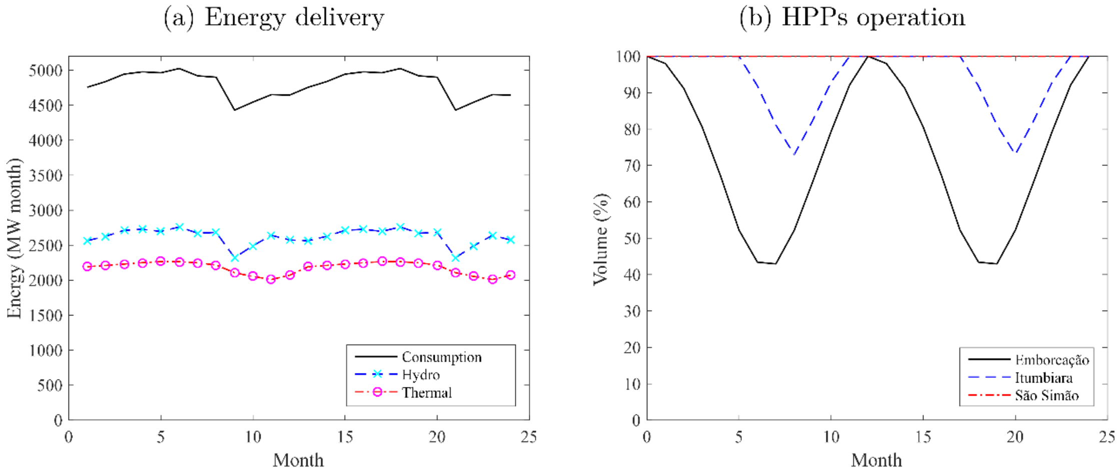

Fig. 4: Result of the optimized operation of the HPPs (benchmark reference)

This increase in productibility is not neglectable. In order to further emphasize its importance, [6] has added two more simulations. In those simulations, the cascade was operated like run-of-river HPPs, i.e., the volume of the reservoir was kept constant during the whole planning horizon in two different extreme scenarios, with full and empty reservoirs. Due to the lack of optimization according to the consumption curve, both alternatives are more costly in spite of the fact that 1.45% more energy was produced by the HPPs in the full-reservoirs scenario, comparing to the benchmark. On the contrary, with the empty-reservoir's scenario, the production has declined above 21% and the costs skyrocket to about 200% of the benchmark [6]. In such small system of three HPPs with reservoirs, these 21% may represents more than 6.000 MW month per year.

Another relevant insight from [6] has been observed when the system was optimized with a significantly reduction of the affluences, in this case, a reduction of 40%. The simulation presented in [6] was also useful to verify the conditions of the reservoirs in the beginning and end of the cycle. In the results presented in Figure 5, operation was considered cyclical. i.e., the same reservoir volume was referred in the beginning and at the end of the planning horizon.

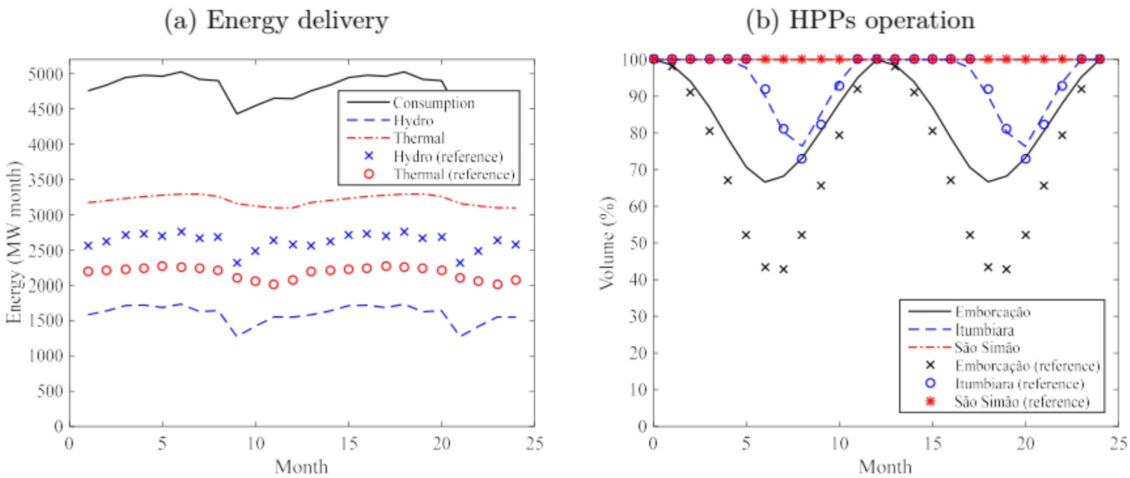

Fig. 4: Result of the optimized operation of the HPPs with 40% lower affluence and its comparison with the benchmark

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As a result, it is possible to observe that in both scenarios (reference – dots - and with reduced affluences - lines), all reservoirs have their volume restituted to the maximal level at the end of the wet cycles (after 12 and 24 months). Moreover, it is evident that optimization requires the system to preserve the use of water in the case of drought (lines are above the dotted lines, i.e., higher volumes are observed in the drier scenarios). Thus, low reservoir levels shall not be attributed to low affluences. It is another important insight that contradicts the results of the operation observed in the atypical decade of 2013-2022.

Additional discussions

The impact of the correct adjust of the productibility according to the reservoir's volume is a key for multiple points presented in this paper. However, it is known that an average of 65% of the volume is used to estimate the mean producibility in the reference software used by the Brazilian system planner. This was a good choice outside the window of 2013-2022, but it was never true during this decade. Once the contracts of private owners (their expected production and revenue) were based on optimistic calculations relying on such considerations, the lower reservoirs volumes (and below than expected productibility) contributed to the maintenance of the low reservoirs' levels for almost a decade.

Conclusions

This paper raised attention to the mindset of the operation planner which is derived from a symmetric illustration of the dilemma. In spite of the coherence of this illustration and adoption by multiple authors describing the operation planning process, its simplicity may lead to a false interpretation of equality of the consequences. Recent historical data of the Brazilian system has been used to present the differences and the situation of the year 2023, so far (September 2023). It reveals new lessons which shall be welcomed by the system planners. Mainly, due to price stabilization at lower levels, that can be a booster to the overall Brazilian economy. Low and stable energy price is possible.

In additional to simulations this paper has questioned the current optimization models used as well as the premises from the dilemma regarding the dispatch of hydroelectric energy. While in scarcity, the optimal solution requires storage of water, therefore it makes planning decision more important. Except in a scenario with abundance of affluence, reservoirs should not be consciously depleted. It is beneficial to take advantages of the higher productibility, due to the higher pressure-head, and the effects on energy price caused by the security of supply due to higher volumes of the hydroelectric reservoirs.

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