CALIBRATION OF THE PENALTIES OF THE OPERATING RESTRICTIONS OF CASCADE HYDROELECTRIC PLANTS IN URUGUAY AND THEIR CONSEQUENCES ON THE COST OF SUPPLYING NATIONAL DEMAND

Hernán Rodrigo, UTE, +598 23237771, hrodrigo@ute.com.uy
Milena Gurin, UTE, +598 23237771, mgurin@ute.com.uy
Felipe Palacio, ADME, fpalacio@adme.com.uy
Pablo Soubes, ADME, psoubes@adme.com.uy
Vanina Camacho , ADME, vcamacho@adme.com.uy
Ruben Chaer, IIE-FING y ADME rchaer@adme.com.uy

Overview

The operation of hydroelectric plants with an associated reservoir usually has operating restrictions. Regarding the upper level of the lake, there is usually a safety level of the dam from which the opening of the spillways is mandatory, in addition to restrictions at the maximum level associated with effects of flooding on the lakes' shores. For the lower level of the lake, there is usually a lower operating limit associated with issues of operational safety or system safety (for example, for a black start after a generalized black-out) or levels imposed by the intake of water for other uses. In addition to the need to control the maximum and minimum levels of the lake, there is the need to ensure a minimum flow in the river associated with maintaining an ecological flow, navigability conditions and/or minimum level downstream of the plant to ensure levels imposed by water intakes for other uses. Added to the above, in some cases, is the need to use the reservoir to cushion the floods downstream of the plant due to the effects on riverside populations, which translates into trying to control that the flow delivered does not exceed established maximum values.

The four conditions mentioned, maximum level, minimum level, minimum delivered flow and maximum delivered flow, are restrictions that may or may not be met depending on the incoming flows.

The optimal operation of the system is carried out by stochastic dynamic programming procedures in which the objective function of the optimization problem is to minimize the expected value of the future supply cost. In this cost function, explicit costs such as fuel consumption and costs associated with energy imports are represented, and operation restrictions are represented by imposing costs (or penalties) for not being able to comply with the restrictions. As an example, failure to supply demand is penalized with failure costs. Similarly, the four conditions for the operation of hydroelectric plants are introduced into the cost function through penalties for non-compliance. Unlike electric power rationing, in which the cost of non-compliance is the failure values that are set (in Uruguay) by the executive branch, there are no official values for non-compliance with the operating restrictions of hydroelectric plants and it would be very difficult to have values that take into account the costs of other sectors due to the effects associated with not being able to comply. In practice, what is done is to calibrate the set of penalties to reduce the probability of non-compliance.

In this work, the case of the calibration of the set of penalties of the plants that are located in a chain on the Negro River in the Uruguayan system is presented.

In recent years, Uruguay's electricity generation system has incorporated a significant amount of Variable Renewable Energies, with the composition of the expected annual generation being 44% hydroelectric, 35% wind, 5% solar and 16% in thermal power plants. Wind and solar energy present variability on a daily scale but are relatively stable on a monthly scale, a characteristic that clearly differentiates them from hydroelectric energy, which presents great variability on an annual scale. The new generation matrix imposes a different use of the lake system of the hydroelectric plants that begin to operate on daily and weekly scales as filters for the variability of wind and solar energy.

This use more frequently brings the level of the lakes to their upper levels, which is why greater care must be taken in their operation due to the effects caused by flooding in the event of unexpected rain events. In addition to having to take care of the upper limit of the lakes' operation, there are safety criteria such as the need for a black start in the face of a general black-out that requires leaving a minimum reserve in the lakes. And in addition to having to control the upper and lower elevation of the lake, minimum delivery restrictions must be respected at the plants to ensure the ecological flow of the rivers, navigability conditions, etc.

The work done to carry out the procedure for calibrating the minimum delivery penalty in Bonete and the work that was subsequently done on the stability of the Bonete level control (minimum level penalty) is presented.

Methods

The restrictions on the flow delivered are related to those on level control. Ensuring a minimum flow delivered downstream necessarily implies leaving a reserve in the lake to be able to comply. This goes in the same sense of maintaining a minimum level. We could say that these two restrictions help each other and therefore the calibration of their penalties are linked. In the same sense, not exceeding a maximum delivered flow implies leaving free space in the lake to be able to cushion possible contributions caused by intense rains in its basin; It is helpful to limit operations at high levels of the lake. In addition to this coupling between the restrictions of the same hydroelectric plant, in the case of chained plants, the coupling also occurs between the restrictions of the different plants.

The methodology followed consists of finding the set of penalty values θ that lower the probability of non-compliance with each restriction, minimizing the consequences on the expected value of the future operating cost. For the simulations, the daily step model used by the Administration of the Electricity Market (ADME) of Uruguay for the programming of the operation corresponding to the November 2023 Seasonal Programming [1] was used.

The model is a daily simulation step and in a dynamic way, the simulation is carried out by rearranging the hours of the time step in four blocks from highest to lowest power requirement of the Net Demand (Demand less Wind and Solar) of 1, 4, 13 and 6 hours long.

For calibration, the horizon of the simulations was extended to 1 year and the operation policy was concatenated with the longterm policy provided together with the same model. For the optimization and simulation of the operation, the SimSEE[2] platform was used and the function of chained years in the elevation of the reservoirs was used and all forecast information (El Niño, flows, radiation, wind speed and temperature) to make the results independent of the initial condition.

To do this, an optimization problem is posed with the objective function:

$$J = \langle CAD \rangle + R_{Bon} + R_{Pal} \quad , \qquad (1)$$

where $\langle CAD \rangle$ is the expected value of the supply cost (without considering the penalties associated with hydroelectric plants) and the R_{Bon} and R_{Pal} components represent costs associated with failing to comply with the restrictions of each plant conditioned to a risk greater than 5% and can be expressed as:

$$R_x = f(h_x - h_{x_{max}}) + f(h_{x_{min}} - h_x) + f(Q_{x_{max}} - Q_x) + f(Q_{x_{min}} - Q_x) \quad , \qquad (2)$$

where the function $f(x)$ has the expression:

$$f(x) = CVaR(x^+, 0.0, 0.95) \quad , \qquad (3)$$

and represents the expected value, in the set of chronicles and simulated time steps, of. 95% of the lowest x^+ values. In this way, the search for parameters is intended to lead to a risk of non-compliance of 5%.

Each evaluation of the cost function involves performing simulations of at least 100 realizations of the stochastic processes, which takes approximately 2 hours on 48-core servers. The high randomness component imposed by the variables with uncertainty added to the time of each evaluation, configures a problem of the type for which the OddFace[3] optimizer was designed. OddFace, specially designed for the evaluation of High Cost Evaluation Functions (hence FACE for the acronym in Spanish) and its evaluation is based on Monte Carlo simulations.

Results

As an example, Table 1 shows the sensitivity of the maximum Bonete level to the penalty and additional cost for the electrical system. As can be seen, observing the 5% probability of exceedance column, the operation cost skyrockets for penalty values greater than 1 MUS$/(m.day) without significant reductions in the possibility of controlling the upper limit of the lake.

Tabla 1: Sensitivity of the maximum the Bonete's lake level to the penalty and extra cost for the electrical system

	COSTO NETO ANUAL (MUSD) (restando penalizaciones por transgresión de cotas)		Cota BON (m) con PE5%, PE1% y máximo en 1000 crónicas		
	COSTO V.E.	SOBRECOSTO RESPECTO A BASE	PE5%	PE1%	Max
BASE (PES_Nov_2021 + ISMES)	753	0	80.8	82.1	89.8
PES_Nov_2021	756	3	80.4	81.8	89.8
Vertedero en 79m	761	8	80.2	81.7	88.8
Penalidad cota max 0.1 MUSD/m.día	756	3	80.4	80.9	88.4
Penalidad cota max 1 MUSD/m.día	767	14	79.9	80.8	88.4
Penalidad cota max 10 MUSD/m.día	839	86	79.8	80.7	88.4
Penalidad cota max 100 MUSD/m.día	1482	729	79.7	80.7	88.4

*Valores en MUSD de 2021
*Incluye costos fijos (contratos) + costos variables

Conclusions

The results show that it is possible to comply with the set of restrictions with a risk of 5% of non-compliance, with an extra cost for the electricity sector of the order of 10 MUS$/year.

It can also be concluded that the sensitivity of compliance with respect to penalties saturates quickly for values above those obtained, evidencing that the penalties only operate on the possible operation of the system and not on the influent hydraulic energy.

References

[1] Programación Estacional Noviembre 2023 - Abril 2024 (https://adme.com.uy/informes/progest.php)
[2] SimSEE. Software platform for Simulation of Systems of Electrical Energy. (https://simsee.org/index_en.html)
[3] D. Vallejo, E. Cornalino and R. Chaer, "Genetic algorithm applied to the specialization of neural networks for the forecast of wind and solar generation," 2018 IEEE 9th Power, Instrumentation and Measurement Meeting (EPIM), Salto, Uruguay, 2018, pp. 1-4, doi: 10.1109/EPIM.2018.8756397. keywords: {neural networks;wind and solar power midterm generation forecast;genetic algorithm}

Disclaimer