International Forum on Pumped Storage Hydropower

Innovative PSH configurations & uses

Pumped Storage Hydropower preliminary site selection and engineering design based on power system requirements

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Technology brief

Current discussions around pumped storage hydropower tend to be centred on PSH as a proven technology (which it is), and its sustainability. But the question should not be focused solely on whether PSH is sustainable, but whether and how it can be integrated into electrical power systems so that those systems are affordable, reliable and lead to net zero emissions.

PSR is currently working on a R&D project on Pumped-Storage Hydro addressing these issues with the Brazilian subsidiaries of EDF (EDF Norte Fluminense), Brookfield (Itiquira Energética S.A) and China Three Gorges (Rio Paranapanema Energia S.A) and the power utility of Rio de Janeiro (Light). The project is supported by ANEEL, the electricity regulatory authority.

The proposed methodology is quite general and can be applied in any country or jurisdiction provided sufficient data is available for the IRP model.

The proposed methodology of this project has two main intertwined components.

Top-down perspective

This is an iterative process, which starts with a preliminary query about what the power system needs in the next several years. This query should be defined in the context of a country's plans to meet NDC's with respect to emission reductions and climate change targets. The initial investigation into system needs will give us hypotheses about what's needed to provide stability, reliability, clean, low cost, and resilient power. This will give us initial assumptions about how much energy storage will be needed where and of what type: short-term, rapid response for system stability (an hour or less, micro-second response times)? Mid-term response to balance supply and demand, load following and peaking (1 to 12 hours, a few seconds in response time)? Long-term or seasonal storage to address sufficiency of supply over a few weeks or longer? Combinations of these? What are the existing bottle necks in transmission system, and are there energy storage options for addressing these?

These hypothesized needs will then inform an Integrated Resource Planning – IRP - model based on mathematical programming[1] to define a set of general candidate technologies or known proposed projects of

[1] http://www.psr-inc.com/softwares-en/?current=p4040

generation, transmission, and storage of electricity to fulfil power system requirements of energy consumption, peak demand, reserves, as well as attributes such as resilience and reliability of supply. The process minimizes total costs (investment + O&M) along the planning period.

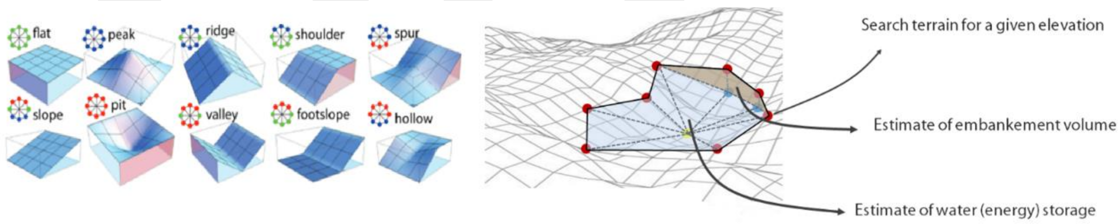
There is a fair amount of effort involved in preparing these general candidates, including a detailed modelling of their actual operation, possible constraints, and investment costs (both present and expected in the future (forward cost curves, given that the cost of some new technologies is decreasing). In the case of renewable projects, the process includes project site selection (based on primary resources, such as wind velocity and solar radiation) and the preparation of power production scenarios from recorded "real-life" project production and reanalysis data (MERRA2 or ERA5).

PSH can be of interest to the power system if it costs are smaller than the benefits to provide services such are simulated by the IRP such as: flexibility of supply to mitigate variability of wind power and solar power or meet the system demand (in particular, the peak demand), supply reliability, reserves and system resilience against plausible, yet improbable scenarios (e.g. extreme weather scenarios, perhaps related to climate change).

Bottom-up perspective

The objective is to develop a methodology to identify promising sites for pumped-storage hydro plants (PSH) based on a computational model that automates the screening process and produces preliminary engineering designs and estimates of project costs. The methodology consists of a two-pronged analysis, first screening the terrain and then simulating the construction of potential projects.

The screening involves geoprocessing techniques applied on a Digital Elevation Model – DEM, using *geomorphons* (see below[2]), to investigate possible locations and using optimization techniques for the selection of most adequate reservoirs[3]. It then uses an automated engineering model for the analysis of design, costs, and performance.



The automated engineering model is a continuation of a project between PSR and EDF from 2015 to 2019 that resulted in the development of computational model HERA[4] that plans hydropower to maximize economic value while minimize socioeconomic impacts. A specialized module for PSH screening and modelling is now

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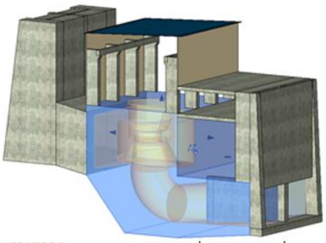
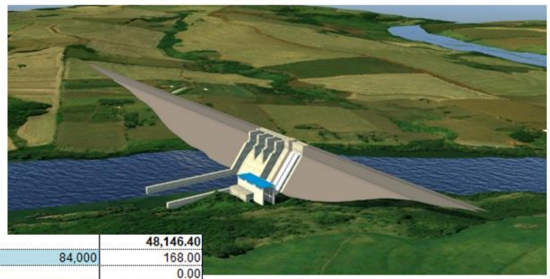
[2] Adapted from Jasiewicz & Stepinski, 2013
[3] https://arxiv.org/abs/2007.16036
[4] https://www.psr-inc.com/softwares-en/hera

being added to HERA. The level of detail is equivalent to pre-feasibility planning studies executed by project developers and energy planning agencies.





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Turbines	un	2	7,180,000	14,360.00
Generators	un	2	12,580,000	25,160.00
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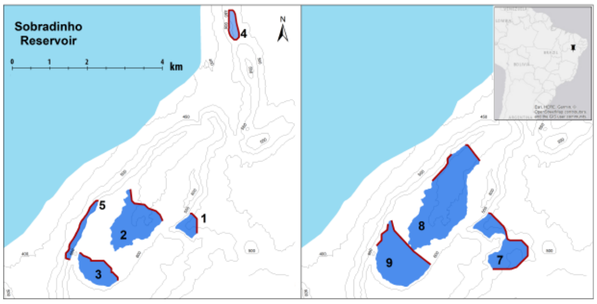
The objective function of this engineering model includes cost components of the dam, hydraulic circuit, electromechanical equipment, access road, grid connection and costs related to socio-environmental impacts. This step can be performed for different regional DEMs, and the best local solutions can be selected to meet requirements of the power systems.

The screening of possible projects considers social environmental and other risks. Whatever existing information available can be used, such as conservation blueprint, protected areas, Indigenous territories, special habitat areas, and others. The process can be used and benefits from existing tools available, such as IHA's ESG tool. This would lead to a first set list of candidate projects.

The result of this more refined search is illustrated by the alternatives of the upper reservoir 1 to 9 in a case study of a PSH in the vicinity of UHE Sobradinho, Brazil in which the lower reservoir of the PSH would be the existing reservoir. For each alternative identified below, the red line indicates where a dam or embankment would be built based on the DEM. These possible dams or embankments were then designed, and costs evaluated by the engineering model. At least some of these candidates are economical for the grid, around $800/kW[5].



Interface of top-down with bottom-up

This "bottom up" approach of screening the terrain and then simulating the construction of PSH projects to estimate investment costs is used in conjunction with the "top-down" approach that identifies those that are

[5] https://hal.archives-ouvertes.fr/hal-02147740

of interest – are "needed" by -- the power system. If PSH projects - identified from the described bottom-up approach - can competitively meet those needs, they will be selected by the IRP model as part of the optimization. Initial results of this approach show that when PSH candidate projects are available for system expansion, they increase the amount of variable renewable sources (solar PV and wind). They can also displace gas-fired plants that were selected in a reference case (without PSH projects) mainly to provide firm capacity to supply peak demand and for reserves.

IRP optimization also provides economic signals that can be used to validate PSH project feasibility in the bottom-up approach. For instance, if too expensive, PSH candidate projects are not selected at all. In this case the IRP model provides insights on what combination of resources (e.g. open cycle gas plants, other technologies of energy storage, demand response, etc.) is selected instead to meet the system requirements. If viable, the IRP will suggest the type of projects that are more appealing to the power system in terms of location, configuration ("more energy, less power" x "less energy, more power") and ability to provide ancillary services.