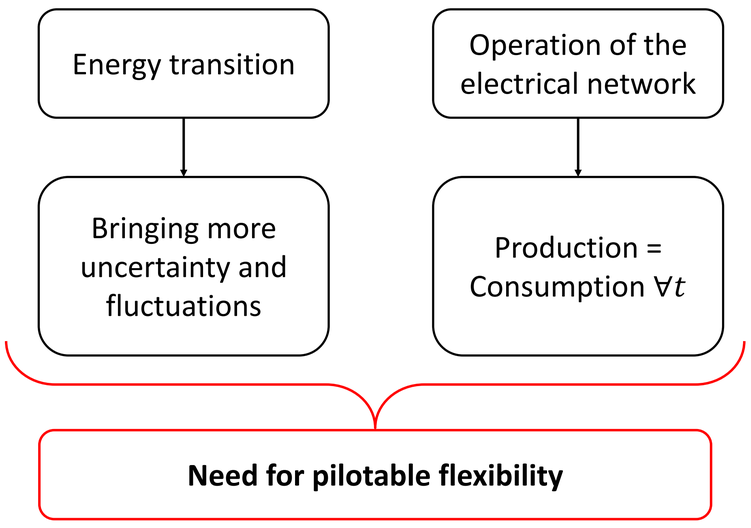
Machine Learning Informed Optimisation: Application to Pumped-Hydro Energy Storage

Context

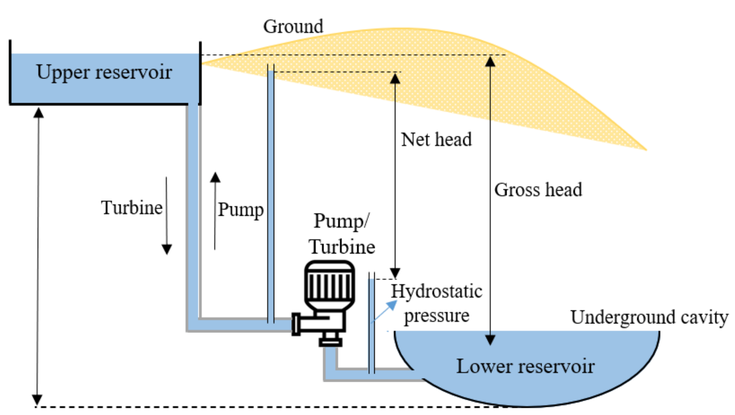
The increased contribution of uncertain and fluctuating renewable generation impacts the operation of power systems since the electricity production and consumption must be equal at all times.



Pumped Hydro Energy Storage (PHES)

Storage brings flexibility since it can store energy when there is an excess of generation/a lack of consumtpion and, conversely, release electricity on the network when there is a lack of generation/an excess of consumption.

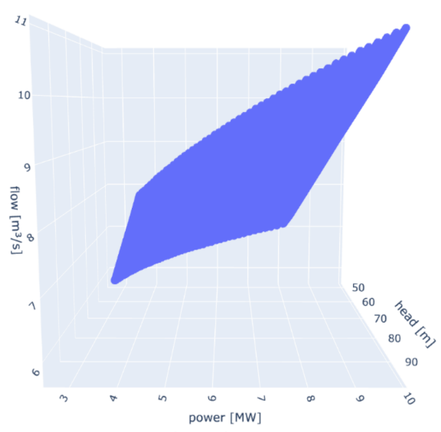
PHES uses water as a medium to store energy by pumping it to higher altitudes. **Nowadays, 95% of storage is PHES**.



Sketch of underground PHES

Work objectives

In order to decide which operations a PHES plant must perform, operators use models formulated as optimization problems. Ideally, those models must be linear, or piecewise linear. However, the Unit Performance Curves (UPCs) of the turbines in PHES plants are non-linear.

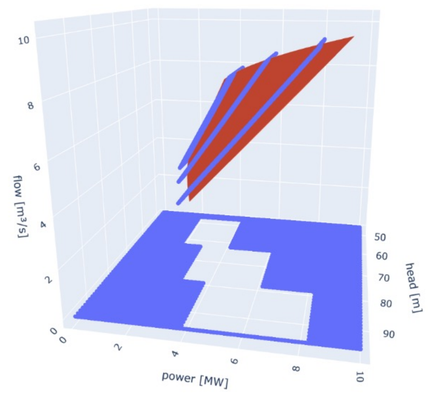


Original turbine UPC

Therefore, **this work aims at proposing a new new data-driven paradigm to encode the operating curves of PHES systems.**

Piecewise Linear

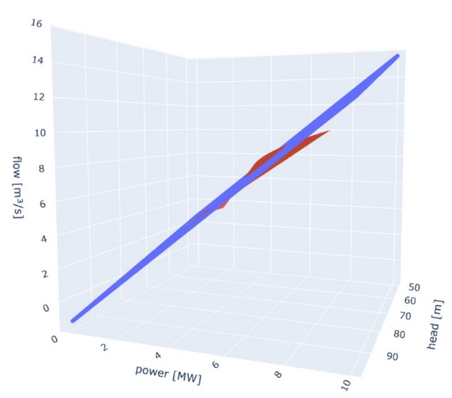
The state-of-the-art uses a non-smart piecewise linear approximation of the curves. The head and power spaces are discretized arbitrarily and planes are used to fit the curves on each of the newly defined regions.



Original turbine UPC (red) and piecewise approx. (blue)

Linear Regression

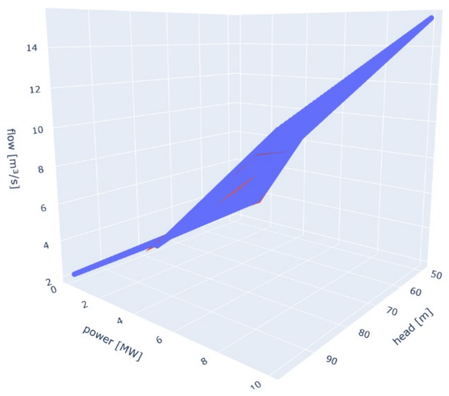
Multiple Linear Regression (LR) is studied due to its modelling simplicity but, by imposing a simple linear form, this approach suffers from a limited explanatory power.



Original turbine UPC (red) and LR approx. (blue)

Neural Networks

Neural Networks (NNs) are more versatile than linear regression. **The complexity of the fit (and its quality) can very easily be tailored by adjusting the number of neurons and layers.** It is also possible to change the activation function.

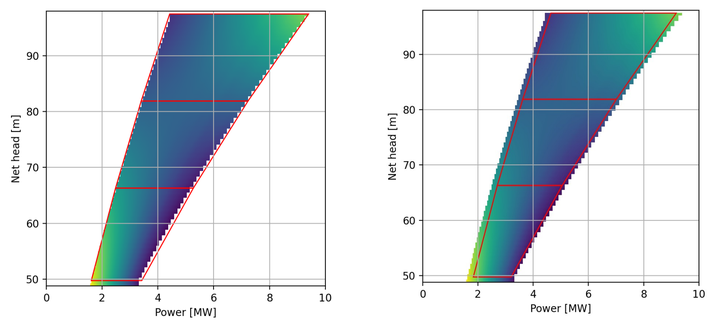


Original turbine UPC (red) and NN (one hidden layer with two ReLU neurons) approx. (blue)

Any NNs with only (Leaky) ReLU activation functions can be reformulated as a set of piecewise linear equations. This set is then embedded into the intial optimzation problem of the PHES plant.

Domain Approximation

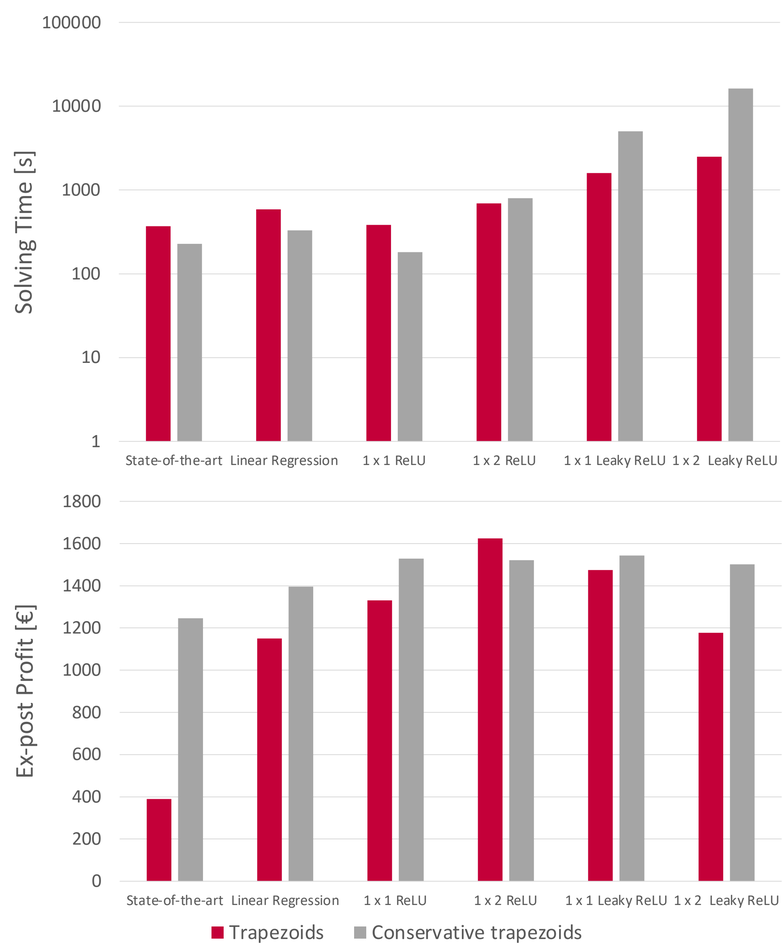
Not only is the curve non-linear, but also its domain . In this work, a conservative piecewise approach is benchmarked against a classical piecewise approach.



Bound approximation for three head subintervals: piecewise (left) and conservative piecewise (right)

Results

The different dispatch performances are compared over a typical day. The economic performances are assessed thanks to a simulation of the market penalties imposed on the deviations.



Solving time (up) and ex-post profit (down) for different approximations

Ccl & perspectives

- **NNs are a very versatile tool to model non-linear curves and can be reformulated into a MILP problem.**
- The solving time increases quickly but sparsity allows to reduce it.
- The tuning of the hyperparameters (architecture, type of activation functions etc.) is challenging.
- Work with higher non-linear curves
- Look into other reformulations of the activation functions
- Apply the NN approximation to the bounds

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