Webinar
New flexibility resources: the role of hybrid pumped hydropower

Case study: pumped hybrid energy storage system for the provision of frequency control

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Energy Storage
Problem description

A fragile power system:

- Only two HVDC cables connect the island to the continent:
  - SAPEI (500kV x 1000MW)
  - SACOI (200kV x 300MW)
- Normal operating conditions:
  - ± 500mHz (100mHz for mainland)

More regulation needed in the future:

- Decommissioning of coal-fired power plants (2025)
- Increasing generation from non-programmable RES

Source: ENTSO-E www.entsoe.eu
Case study: pumped hybrid energy storage system for the provision of frequency control

Foxi Murdegu seawater Pumped Storage Hydro Power Plant (sPSHP)

- 1,200,000 m$^3$ upper reservoir,
- 345m to 367m a.s.l.
- 700m underground penstock
- 1x150MW variable speed pump-turbine

Model description

GRID \[\Delta f < 0 \text{ (underfrequency)}\] sPSHP

\[\Delta P > 0\]
Model description

GRID $\Delta f < 0$ (underfrequency) $\Delta P > 0$ sPSHP

Hydro Power Plant

Power setpoint

POWER CONTROL

$\Delta f$
Model description

GRID \[\Delta P > 0\]

GRIDS

Hydro Power Plant

\[\Delta P \text{ electric}\]

Doubly Fed Induction Generator

Power setpoint

\[\Delta f\]

POWER CONTROL

\[\Delta f < 0 \text{ (underfrequency)}\]

sPSHP
Model description

GRID

$\Delta f < 0$ (underfrequency)

$\Delta P > 0$

sPSHP

Hydro Power Plant

$\Delta P_{\text{electric}}$

Doubly Fed Induction Generator

PUMP-TURBINE

Power setpoint

$\Delta n$

POWER CONTROL

$\Delta f$

$\Delta n$

Case study: pumped hybrid energy storage system for the provision of frequency control
Model description

GRID \[\Delta f \leq 0 \text{ (underfrequency)}\] sPSHP

\[\Delta P > 0\]

Hydro Power Plant

Doubly Fed Induction Generator

POWER CONTROL

\[\Delta P \text{ electric}\]

\[\Delta f\]

\[\Delta P \text{ hydraulic}\]

PUMP-TURBINE

\[\Delta n\]
System behavior

Turbine

\[ \Delta f = 600 \text{mHz} \]

Intense frequency step perturbation

DFIG: decoupling of hydraulic power and electrical power

\[ \Delta P = 33 \text{ MW} \]

Rotational speed varies accordingly
System behavior

Fast response: pressure waves

Wear and tear of the wicket gate (WG) due to movements
System behavior: limitations

Upper reservoir: full (367m a.s.l.)

Max power → max rotspeed

Manufacturer’s rotspeed limit (472/577rpm) implies limit in power input/output.
Why hybridizing?

- Operate the Hydro Power Plant (HPP) at the best efficiency point
- Slow down the HPP’s response (reduce wear and tear)
- To achieve faster regulation responses
- Provide regulation services when the HPP is at its limit

**Candidate technologies**

Battery Energy Storage System (BESS)  
Flywheel Energy Storage System (FESS)

"UPS battery bank" by jon_gilbert is licensed under [CC BY-NC-SA 2.0](https://creativecommons.org/licenses/by-nc-sa/2.0/)

"File:Example of cylindrical flywheel rotor assembly.png" by Pirensburg is licensed under [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)
Candidate technologies

Battery Energy Storage System (BESS)

Equipped with own converter
Li-ion
Modeled by its own converter (fast electrochemical dynamics)

Flywheel Energy Storage System (FESS)

Equipped with own converter

The model has been kindly provided by Dr. Marcos Lafoz (CIEMAT)

Hybrid power plant

Hybrid Power Plant

GRID → Δf < 0 (underfrequency) → sPSHP

ΔP > 0

Hybrid Power Plant

CONTROL STRATEGY

POWER CONTROL

Power setpoint

Δf

HYDRO

BESS

FESS

psp H

psp B

psp F

ΔP electric
Control Strategy

1) Filter the power setpoint:
   - High frequencies → FESS
   - Low frequencies → BESS
   - Very low frequencies → HYDRO

2) Control the State of Charge (SOC) of BESS and FESS:

I_{1,2}: inner bounds
O_{1,2} = outer bounds

Hybrid power plant

20MW BESS, 10 MW FESS

Increased power output:
48MW vs 45MW vs 33MW

Flywheel: almost instantaneous

Slower Hydro and BESS action: less life consumption

Full activation within 30s is guaranteed.
Hybrid power plant

The challenges of an hybrid plant:

• **Purpose**: fastest response or minimum wear & tear (€)?
• **Design**: what are the best sizes of BESS and FESS (€€)?
• **Control**: optimal values of control parameters?
Example: continental Italy scenario

Continental Italy
21/01/2020, 4:50 – 5:50 AM

P_{BESS_1}, P_{BESS_2}, P_{FESS_1}, P_{FESS_2}, T_{hydro}, T_{bess}

SIMULATIONS

<table>
<thead>
<tr>
<th>Life consumption</th>
<th>Life consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>BESS</td>
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<td>...</td>
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Life consumption estimation

- HYDRO:
  - Wicket Gate: life consumption proportional to distance travelled and # of movements
  - Only in Turbine mode
- BESS:
  - Neglect calendar aging (depends on the simulation’s duration)
  - Ageing due to cycling: identify types of cycles (depth, amplitude, how many) with Rainflow Algorithm → maximum amount of cycles for each type → Miner’s rule for mechanical fatigue
## Equipment’s life consumption

<table>
<thead>
<tr>
<th></th>
<th>Th = 30s</th>
<th>Tb = 20s</th>
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<tr>
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<td><strong>Wicket gate</strong></td>
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<td>Distance (deg)</td>
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*Life consumption: if the expected life is 20 years, during this simulation it has lost N seconds of life*
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<td>H</td>
<td>32.48</td>
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| BESS        | Life Consumption* | – | 0.31 |

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*Life consumption lost N seconds*

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Conclusions

• Hybridizing a Pumped Storage Hydro Power Plant can be very convenient:
  • wear and tear reduction
  • faster responses
• The benefits are heavily dependant on the system’s design and control
  • Equipment’ size
  • Filters’ time constants, SOC control thresholds, …
• The identification of the best/optimal value of each parameter, given the context, must be automated, given the complexity of the system
Thank you!

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