Università degli Studi di Padova
Dipartimento di Ingegneria Industriale

Webinar
New flexibility resources: the role of hybrid pumped hydropower

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

Eng. Stefano Casarin

PhD candidate
Turbomachinery & Energy System Research Group

Supervisor: Prof. Giovanna Cavazzini
University of Padua
Co-supervisor: Prof. Juan Ignacio Pérez Díaz
Politechnical University of Madrid

EERA European Energy Research Alliance
Energy Storage
Politécnica Universidad Politécnica de Madrid
RSE Ricerca Sistema Energetico

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)

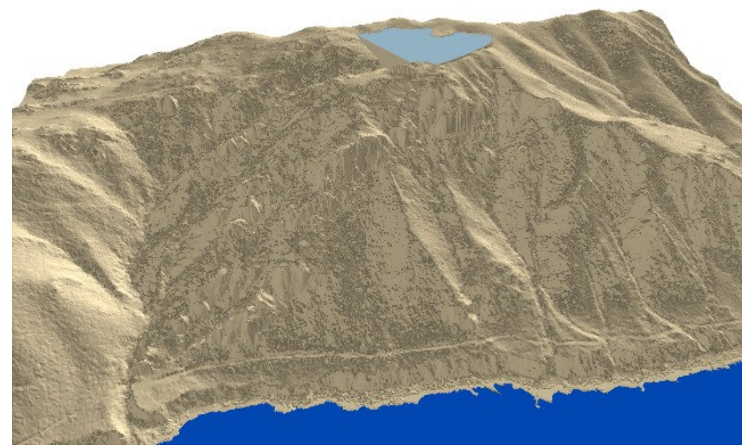
Source: ENTSO-E www.entsoe.eu

More regulation needed in the future:

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

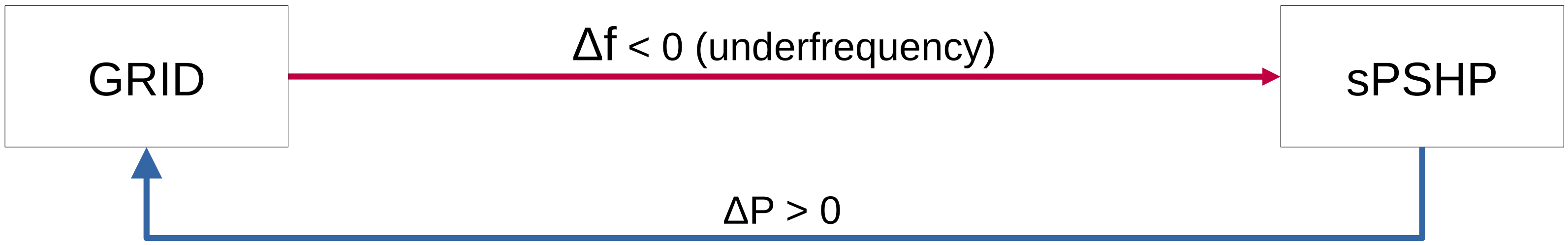
Foxi Murdegu seawater Pumped Storage Hydro Power Plant (sPSHP)

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

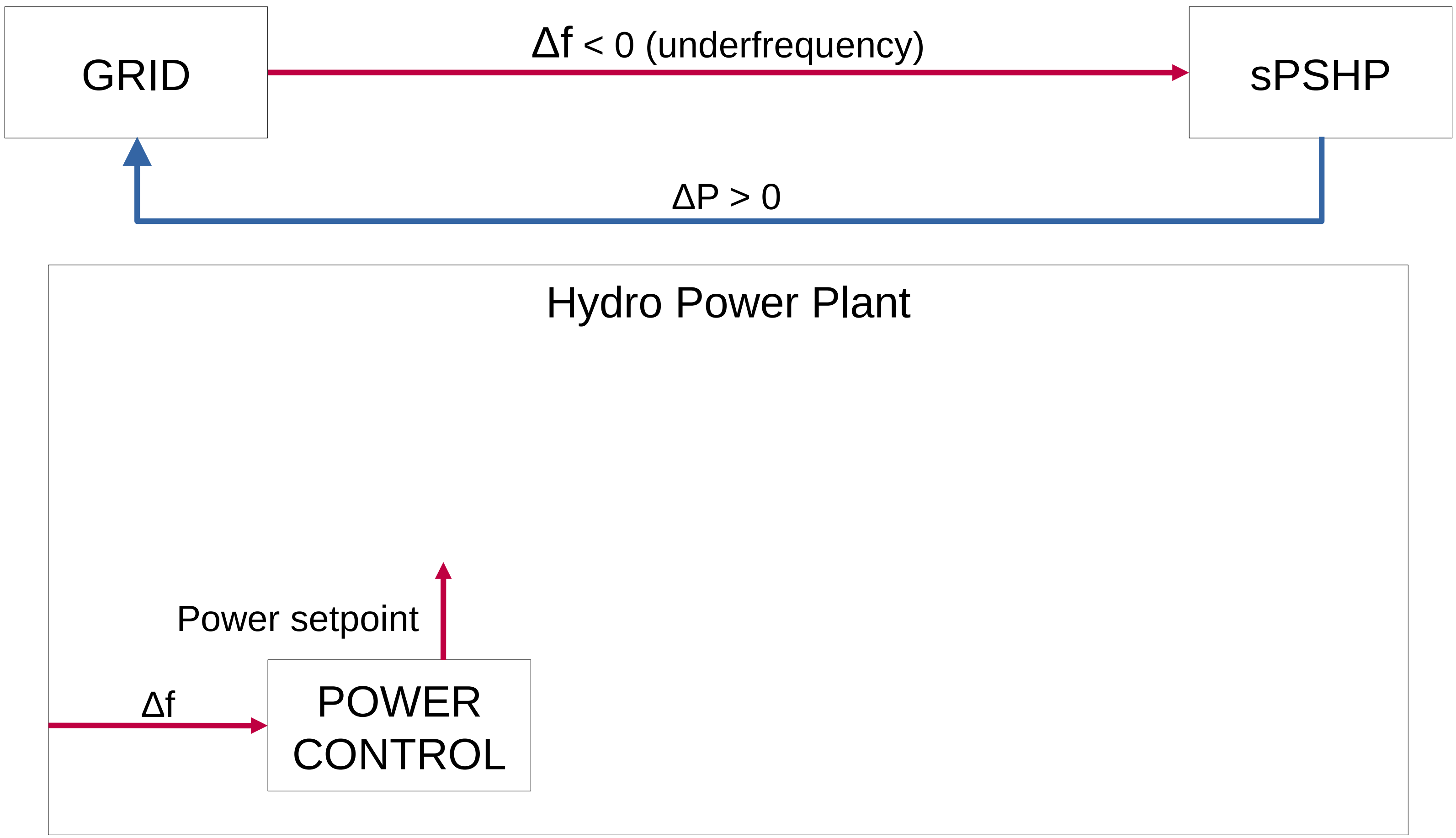


M. Meghella, J. Alterach, E. Gobbi, G. Gardini, and R. Marazzi, "Studi e analisi di pre-fattibilità per l'integrazione ottimale in rete dell'energia prodotta da fonti rinnovabili mediante sistemi di pompaggio marino," Ricerca sul Sistema Energetico, Jan. 2013.

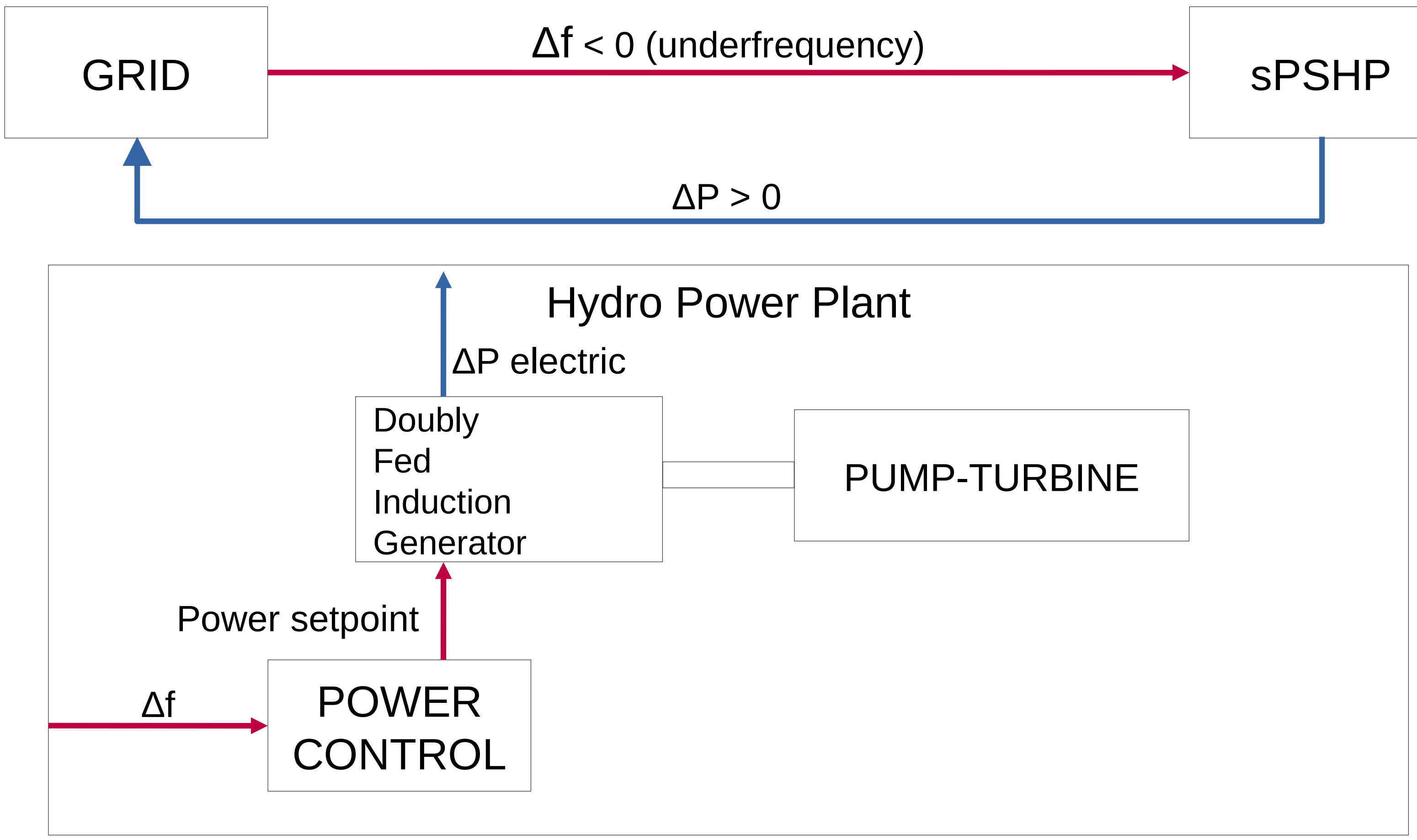
Model description



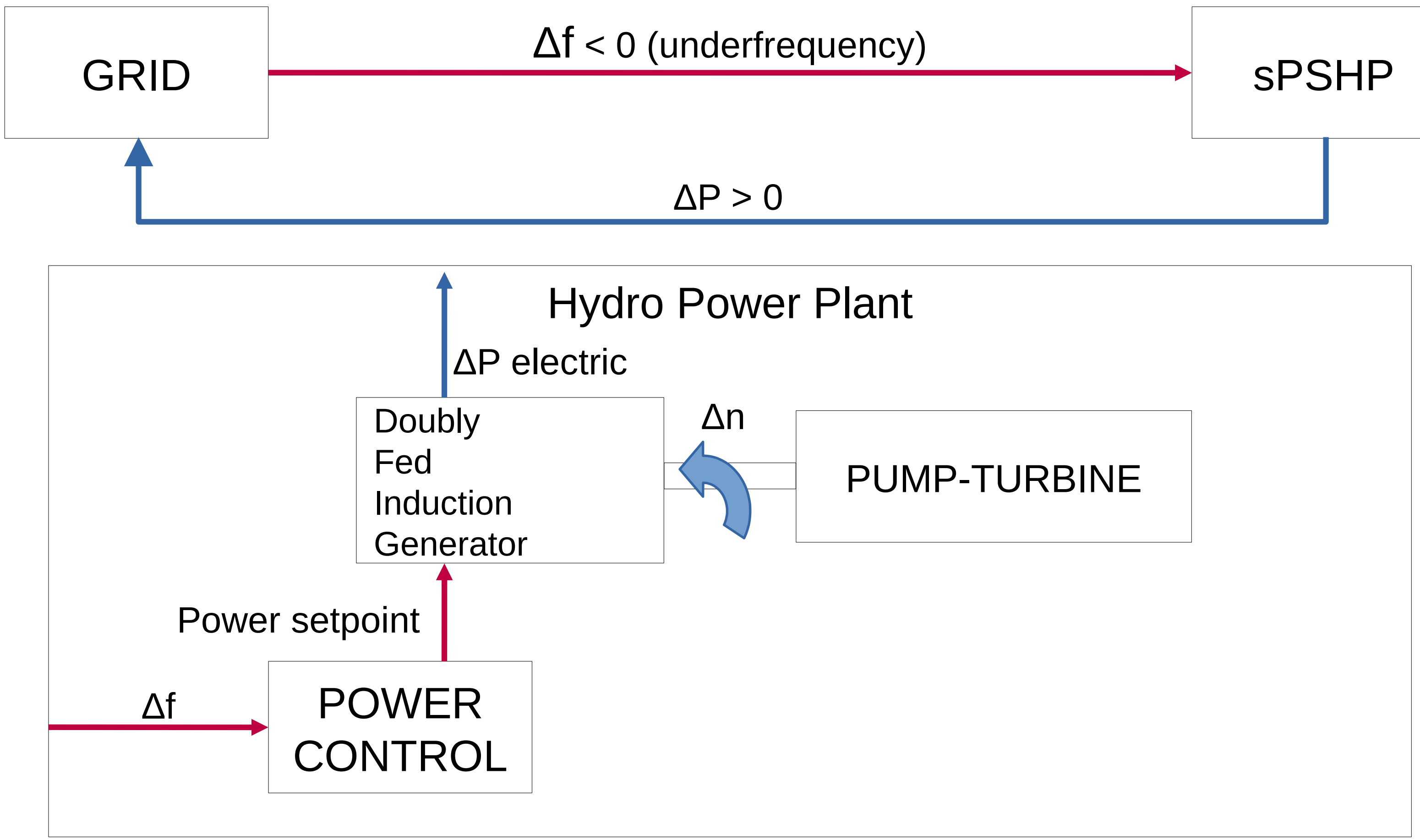
Model description



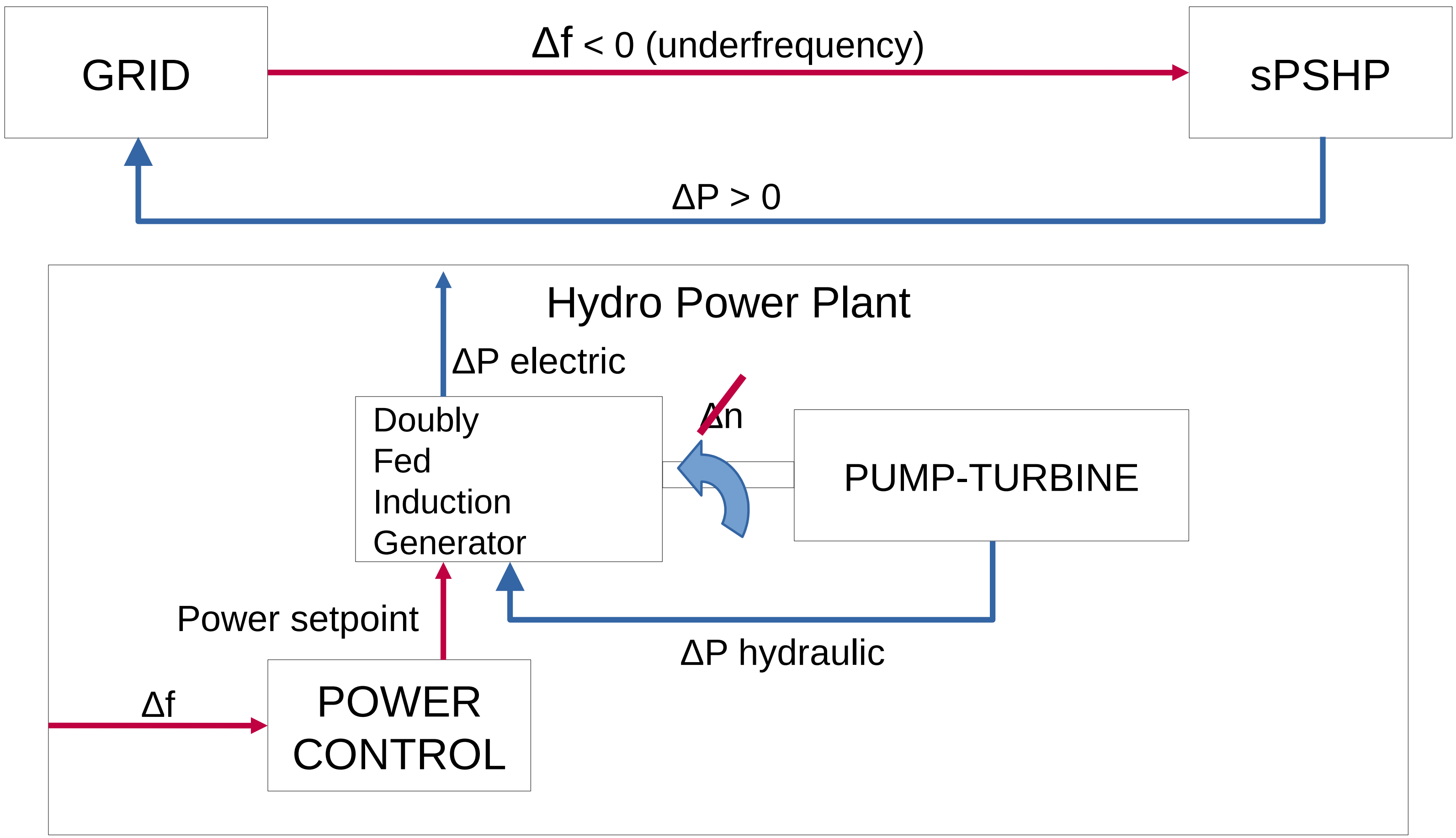
Model description



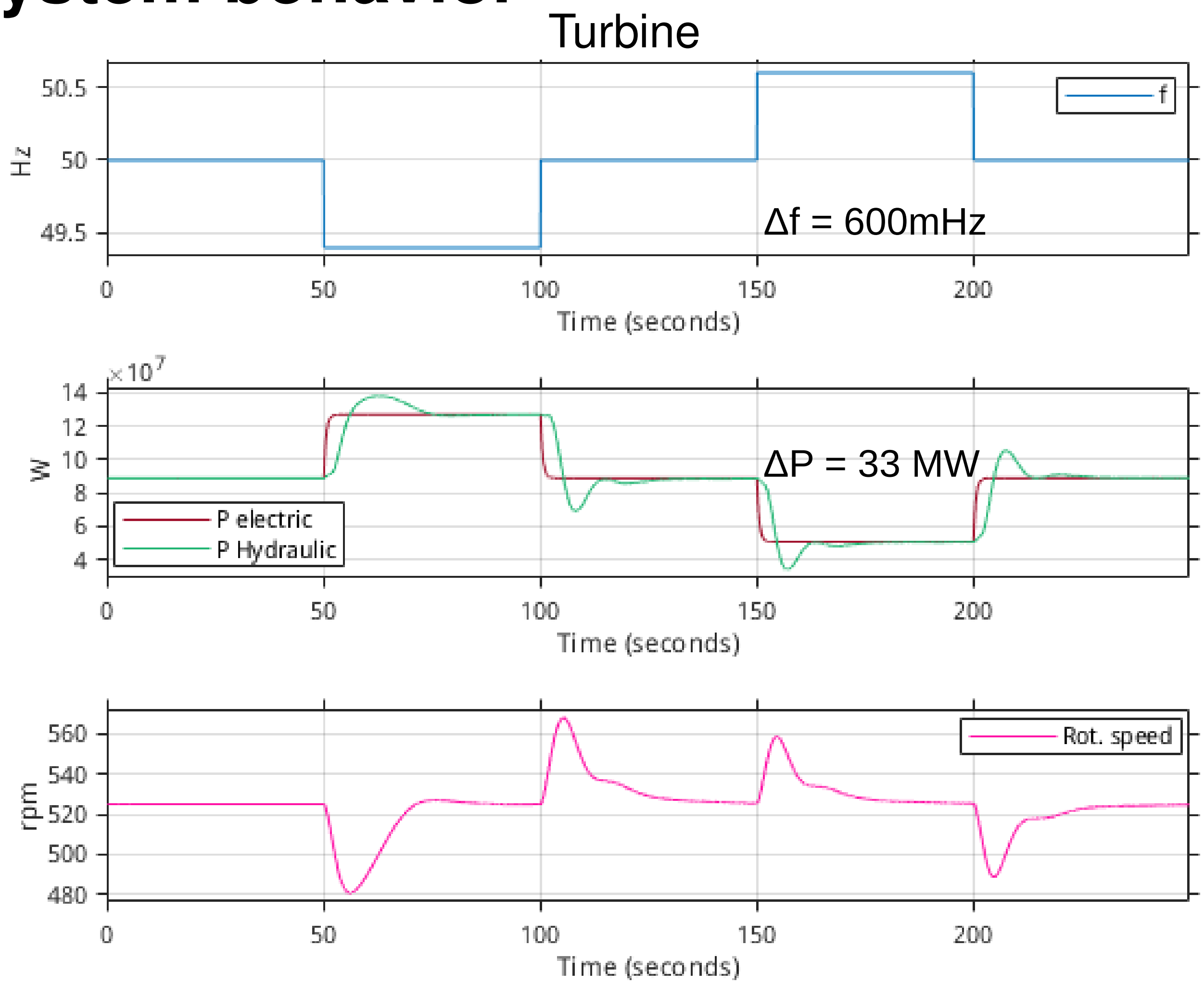
Model description



Model description



System behavior

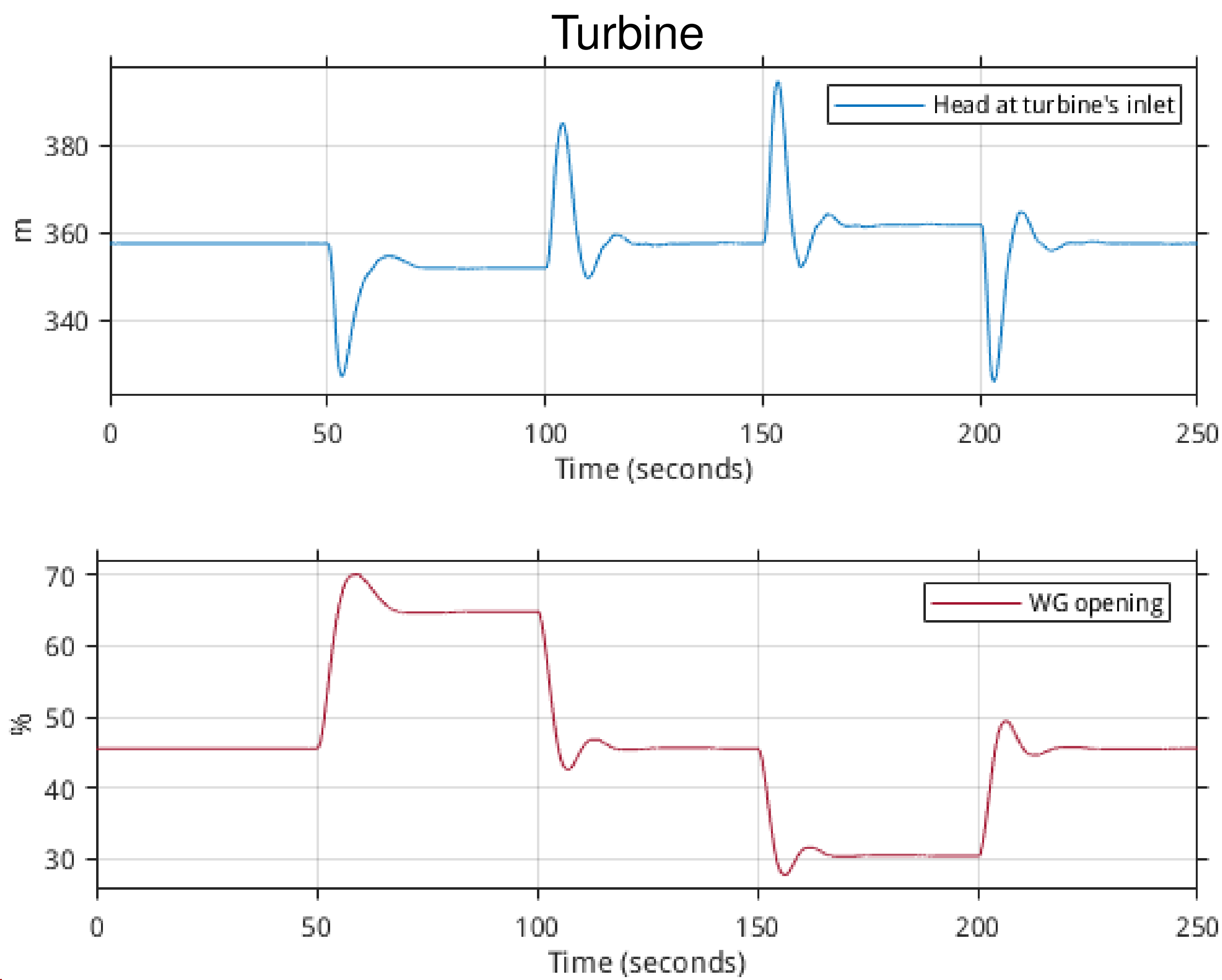


Intense frequency step perturbation

DFIG: decoupling of hydraulic power and electrical power

Rotational speed varies accordingly

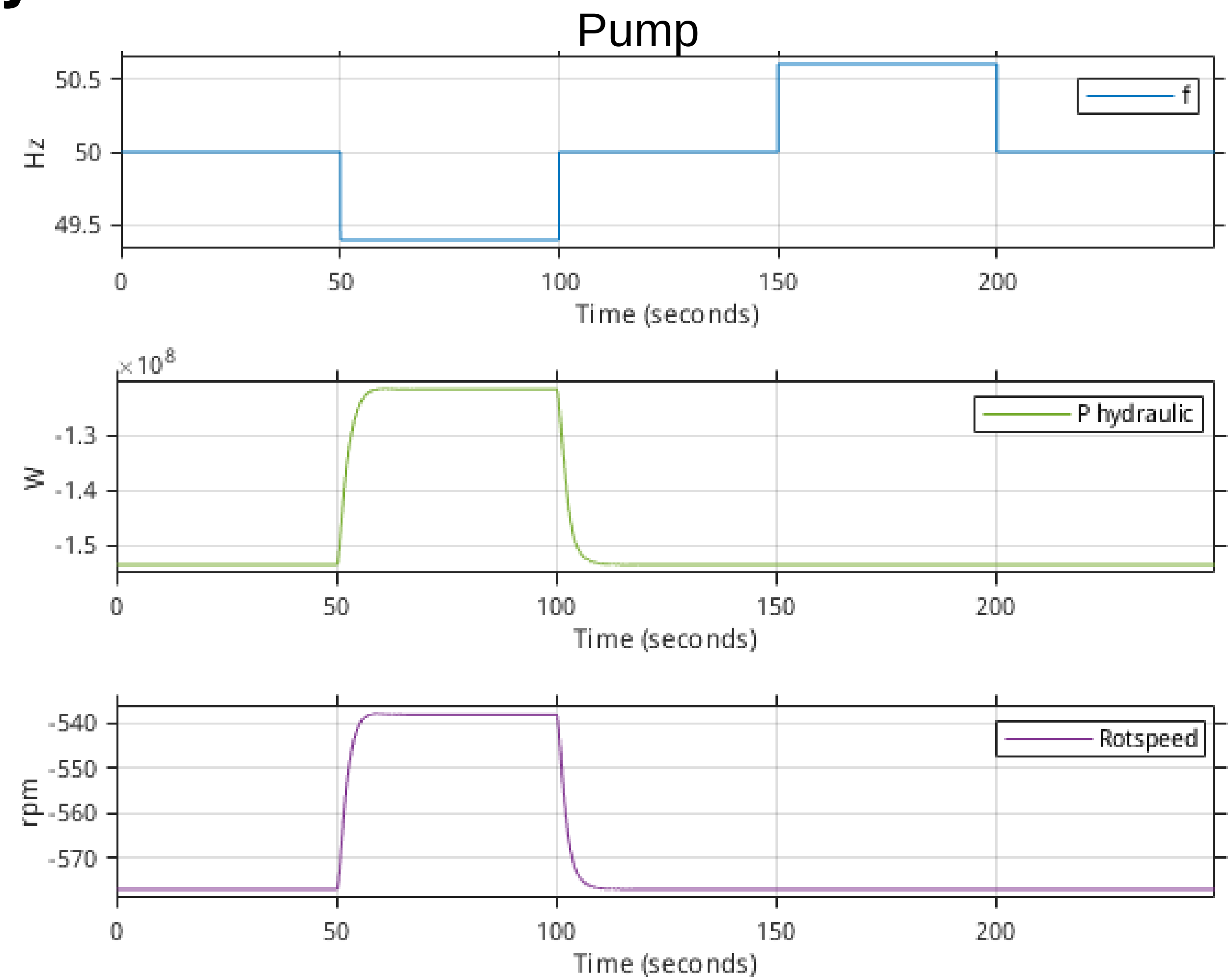
System behavior



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?

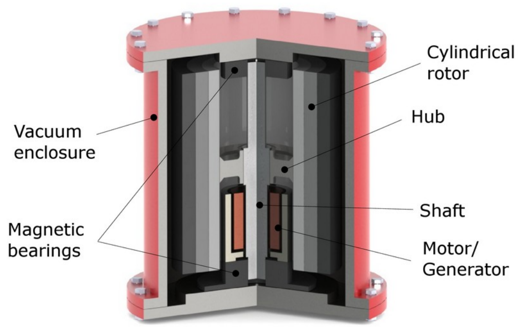
- Operate the Hydro Power Plant (HPP) at the best efficiency point
- Slow down the HPP's response (reduce wear and tear)
- To achieve faster regulation responses
- Provide regulation services when the HPP is at its limit

Candidate technologies

Battery Energy Storage System (BESS)

"UPS battery bank" by jon_gilbert is licensed under CC BY-NC-SA 2.0

Flywheel Energy Storage System (FESS)



"File:Example of cylindrical flywheel rotor assembly.png" by Pjrensburg is licensed under CC BY-SA 3.0

Candidate technologies

Battery Energy Storage System (BESS)

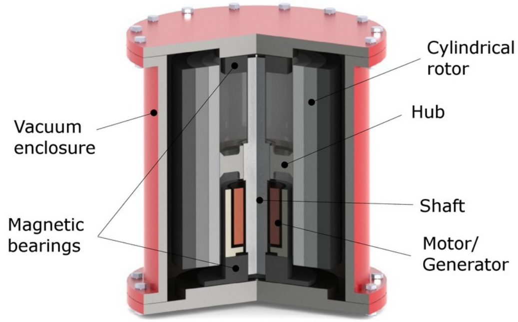
"UPS battery bank" by jon_gilbert is licensed under CC BY-NC-SA 2.0

Equipped with own converter

Li-ion

Modeled by its own converter (fast electrochemical dynamics)

Flywheel Energy Storage System (FESS)



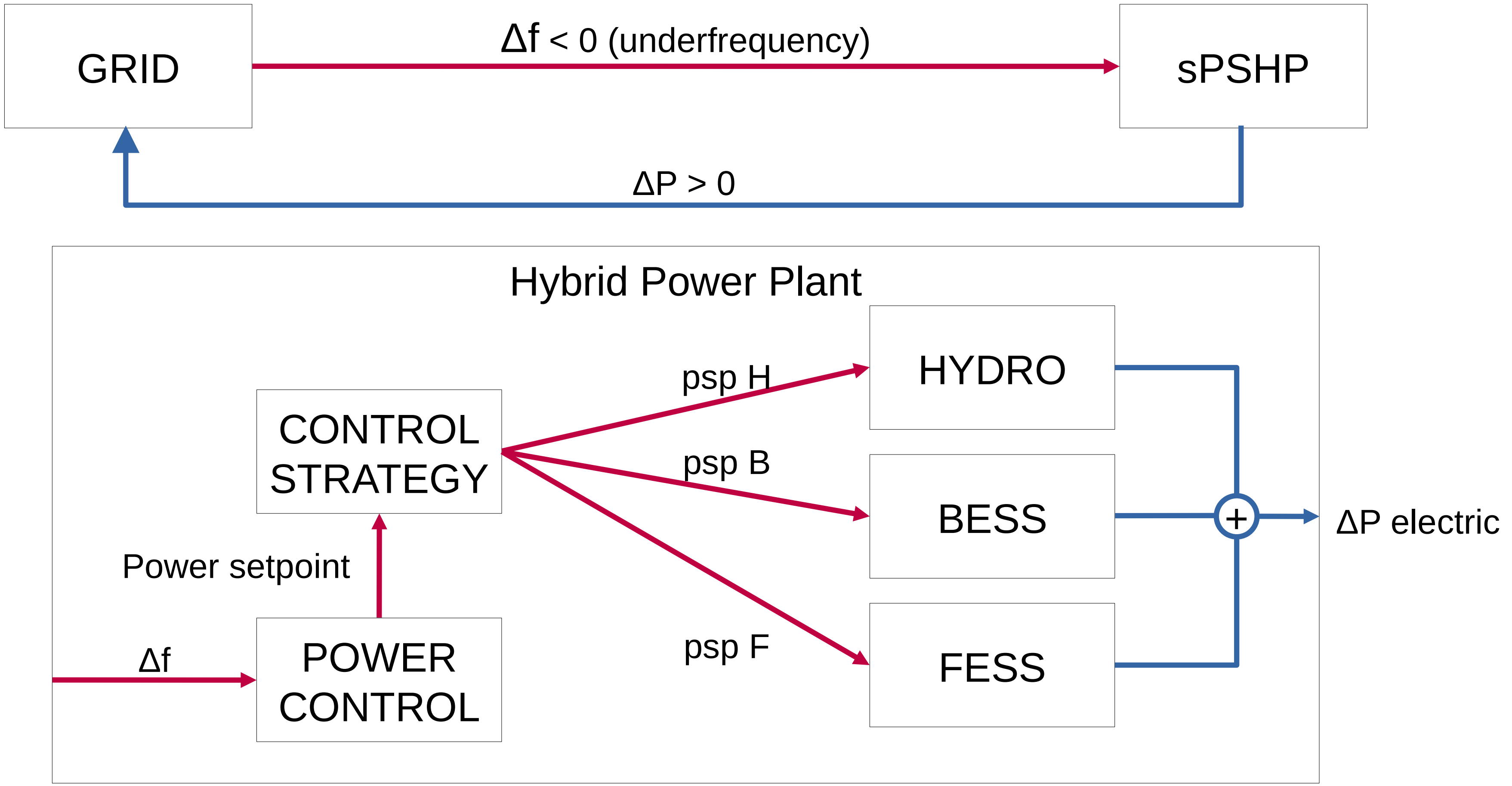
"File:Example of cylindrical flywheel rotor assembly.png" by Pjrensburg is licensed under CC BY-SA 3.0

Equipped with own converter

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

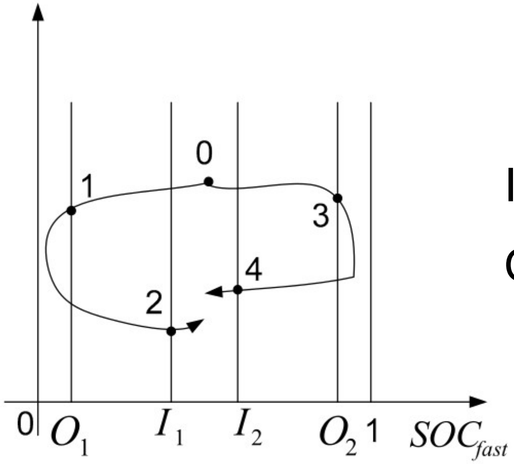
J. Torres, G. Navarro, M. Blanco, M. González-de-Soto, L. García-Tabares, and M. Lafoz, "Efficiency Map to Evaluate the Performance of Kinetic Energy Storage Systems Used with Renewable Generation," in 2018 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe), 2018, p. P-1.

Hybrid power plant



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:



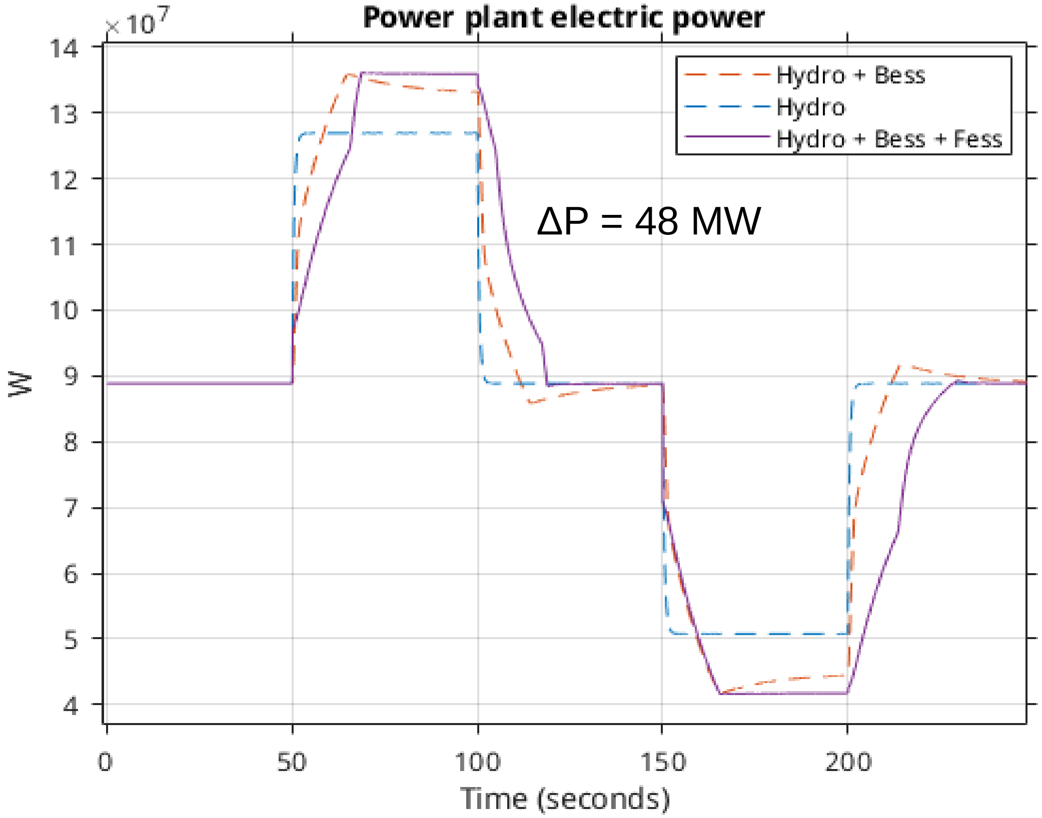
$I_{1,2}$: inner bounds

$O_{1,2}$ = outer bounds

C. Jin, N. Lu, S. Lu, Y. Makarov, and R. A. Dougal, “Coordinated control algorithm for hybrid energy storage systems,” IEEE Power and Energy Society General Meeting, pp. 1–7, 2011.

Hybrid power plant

Turbine



20MW BESS, 10 MW FESS

Increased power output:

48MW vs 45MW vs 33MW

Flywheel: almost instantaneous

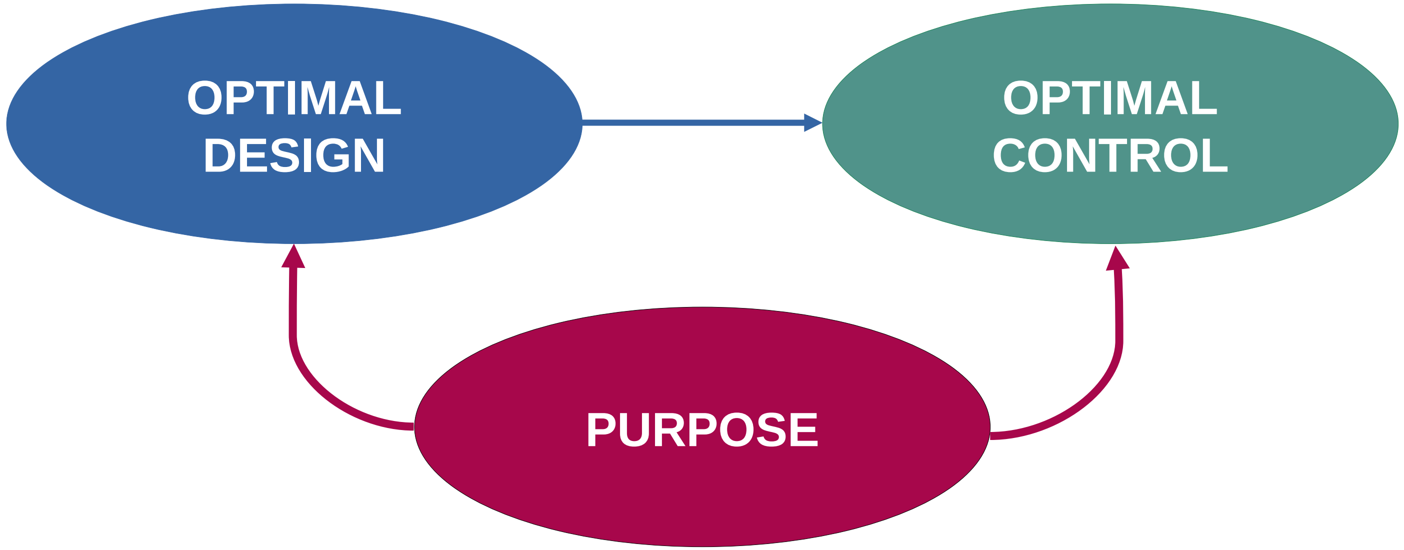
Slower Hydro and BESS action: less life consumption

Full activation whithin 30s is guaranteed.

Hybrid power plant

The challenges of an hybrid plant:

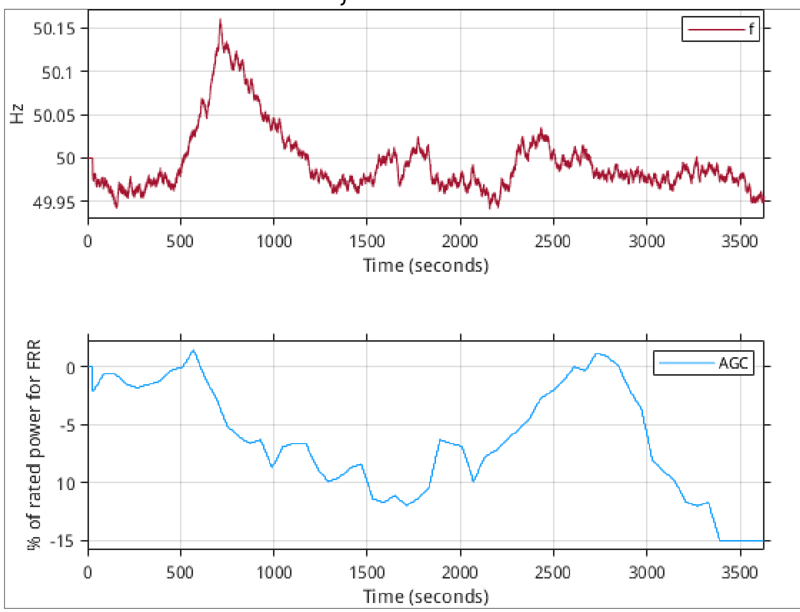
- **Purpose:** fastest response or minimum wear & tear (€)?
- **Desgin:** what are the best sizes of BESS and FESS (€€)?
- **Control:** optimal values of control parameters?



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

Life consumption Hydro	Life consumption BESS
...	...

Life consumtpion 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

10MW BESS – 5MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48			
	# movements	146			
BESS	Life Consumption*	–			

*Life consumption: if the expected life is 20 years, during this simulation it has lost N seconds of life

Equipment's life consumption

10MW BESS – 5MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48	16.26		
	# movements	146	29		
BESS	Life Consumption*	–	0.31		

*Life consumption: if the expected life is 20 years, during this simulation it has lost N seconds of life

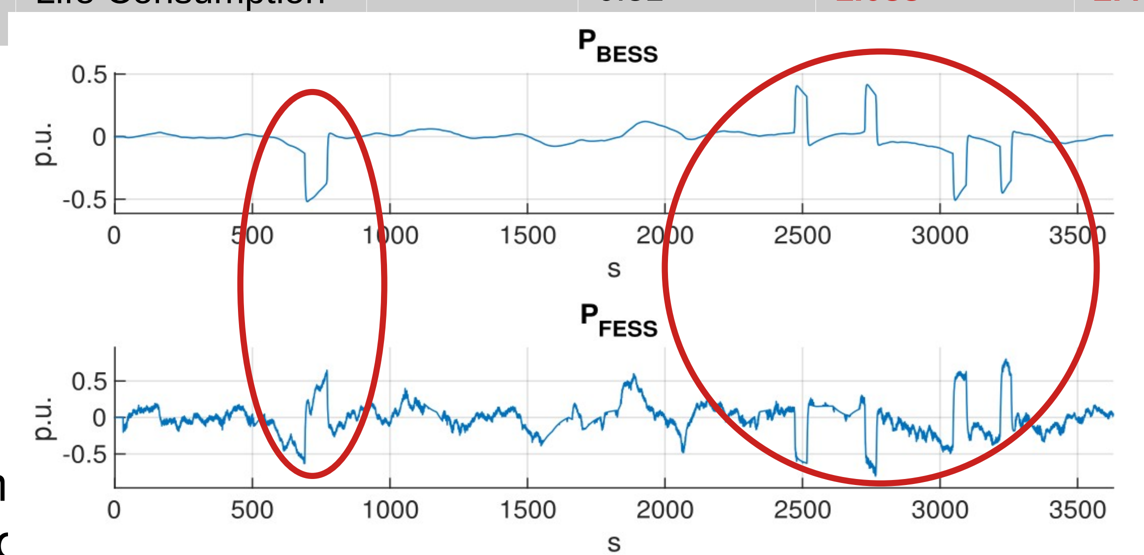
Equipment's life consumption

10MW BESS – 5MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48	16.26	13.25	11.23
	# movements	146	29	17	15
BESS	Life Consumption*	–	**0.31**	**1.033**	**2.45**

*Life consumption: if the expected life is 20 years, during this simulation it has lost N seconds of life

Equipment's life consumption

10MW BESS – 5MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48	16.26	13.25	11.23
	# movements	146	29	17	15
BESS	Life Consumption*	–	0.31	**1.033**	**2.45**



*Life consum … tion it has lost N secon…

Equipment's life consumption

10MW BESS – 5MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48	16.26	13.25	11.23
	# movements	146	29	17	15
BESS	Life Consumption*	–	**0.31**	**1.033**	**2.45**

20MW BESS – 10MW FESS					
			Th = 30s	Tb = 20s Th = 60s	Tb = 50s Th = 100s
		H	HB	HBF	HBF
Wicket gate	Distance (deg)	32.48	17.43	14.20	11.93
	# movements	146	31	16	15
BESS	Life Consumption*	–	**0.09**	**0.298**	**0.705**

*Lif as
lost N seconds of life

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

Università degli Studi di Padova

Dipartimento di Ingegneria Industriale

Thank you!

Eng. Stefano Casarin

PhD Candidate
Turbomachinery & Energy System Research Group

Supervisor: Prof. Giovanna Cavazzini
University of Padua

Co-supervisor: Prof. Juan Ignacio Pérez Díaz
Politechnical University of Madrid

This work has been financed by the Research Fund for the Italian Electrical System in compliance with the Decree of the Minister of Economic Development April 16, 2018.

EERA European Energy Research Alliance Energy Storage

POLITÉCNICA UNIVERSIDAD POLITÉCNICA DE MADRID

RSE Ricerca Sistema Energetico