Università degli Studi di Padova

Dipartimento di Ingegneria Industriale

Webinar

New flexibility resources: the role of hybrid pumped hydropower

Challenges for pumped hydropower plants in the future grid scenario

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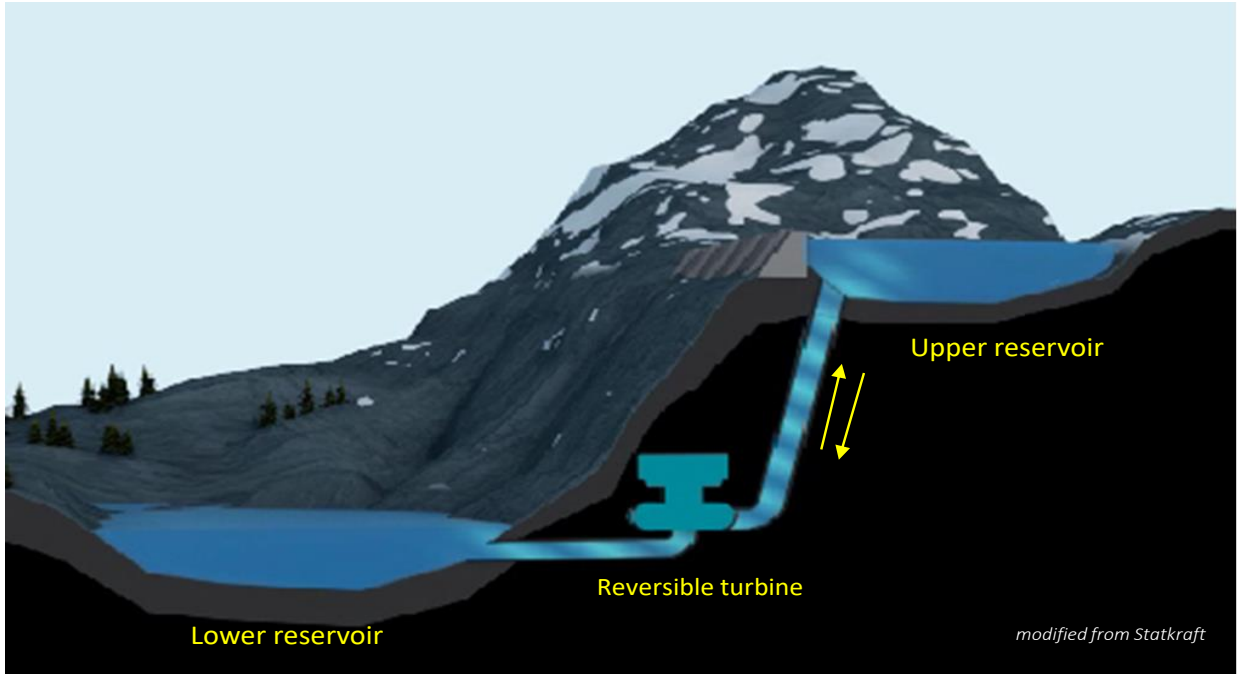
Turbomachinery & Energy System Research Group

EERA European Energy Research Alliance

Energy Storage

RSE Ricerca Sistema Energetico

The Principle



General performance

Typical Power: 200 to 350 MW

Head range: 100 -1500m

Cycle efficiency: 75-85%

Energy capacity: 10 GWh

Discharge time: > 8 hrs

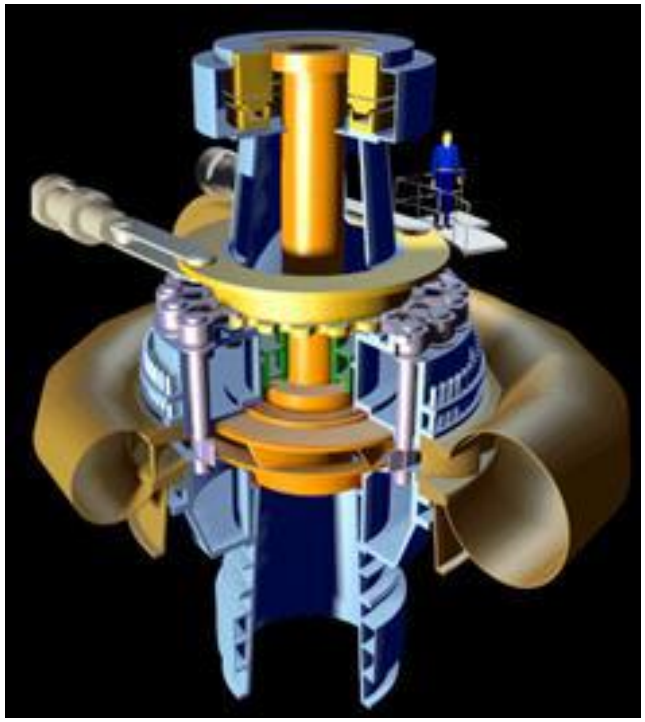
Technical lifetime: 40-80 years

CO2 emissions: -

Generating mode: the water is released through the turbines to a lower reservoir

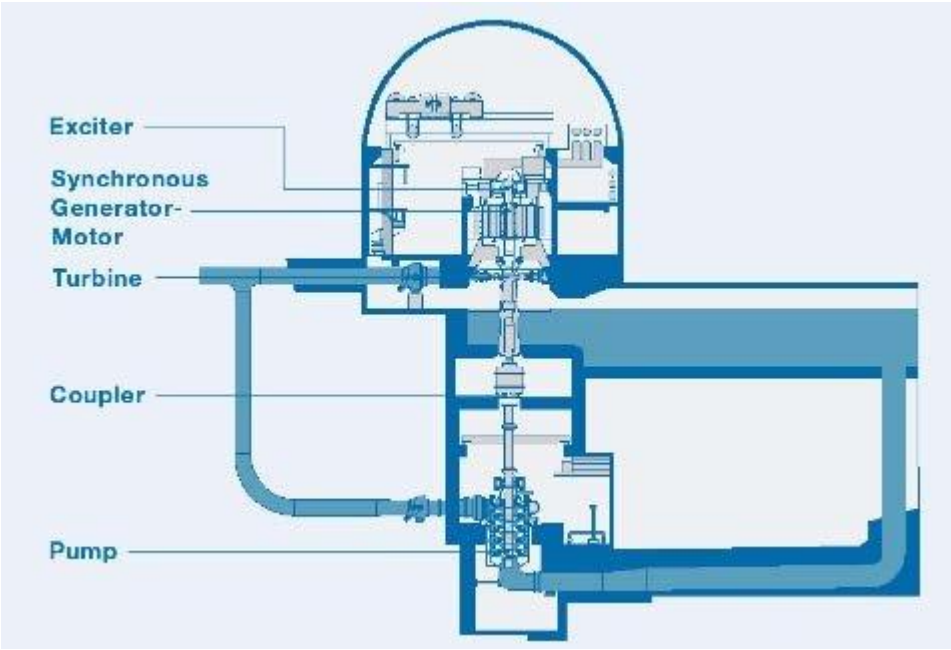
Pumping mode: the water is pumped back from the lower reservoir and stored in the upper reservoir

Configurations



Binary set

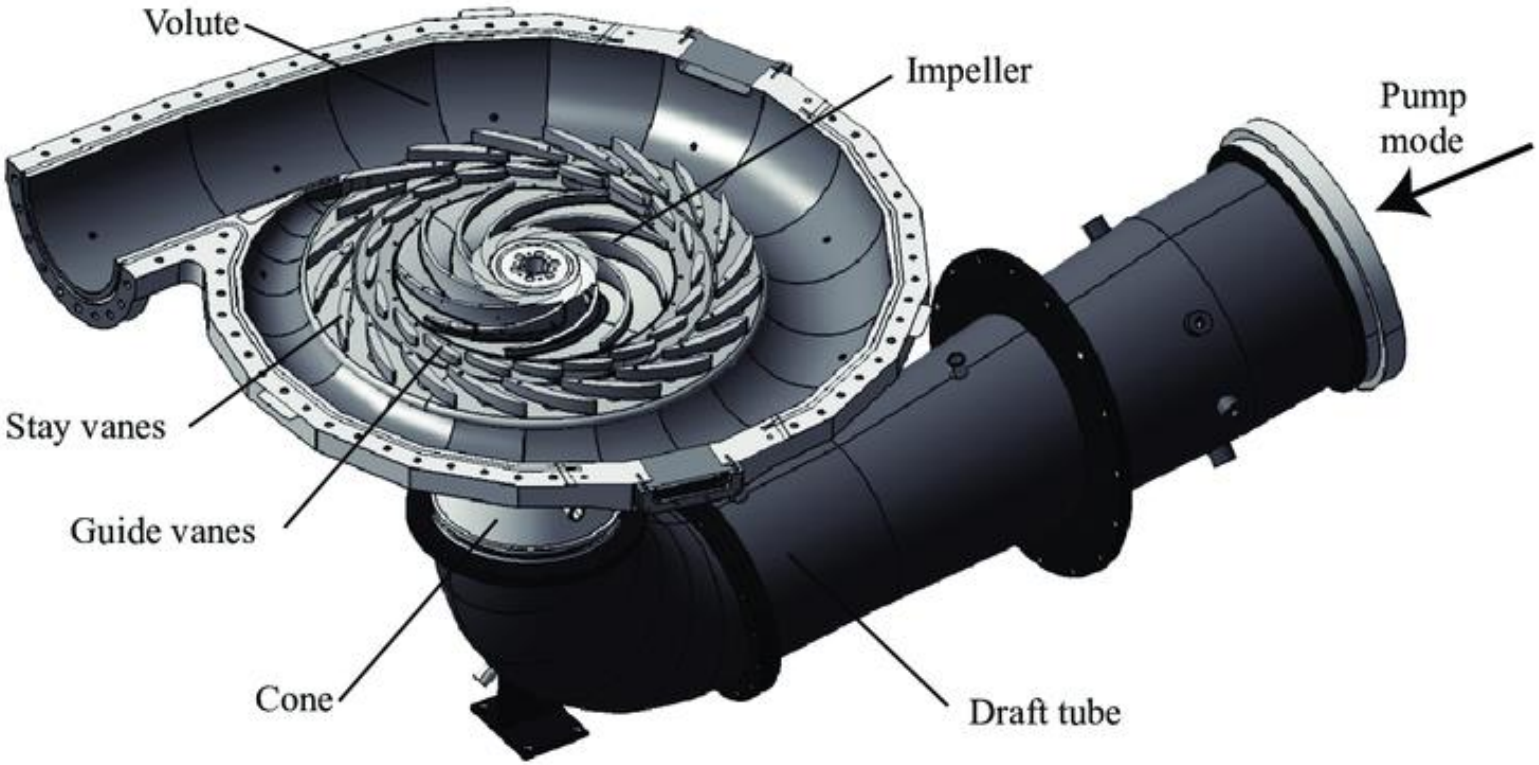
- pump-turbine
- electrical machine (motor/generator)



Ternary set

- pump
- turbine
- electrical machine (motor/generator)

Pump-turbine

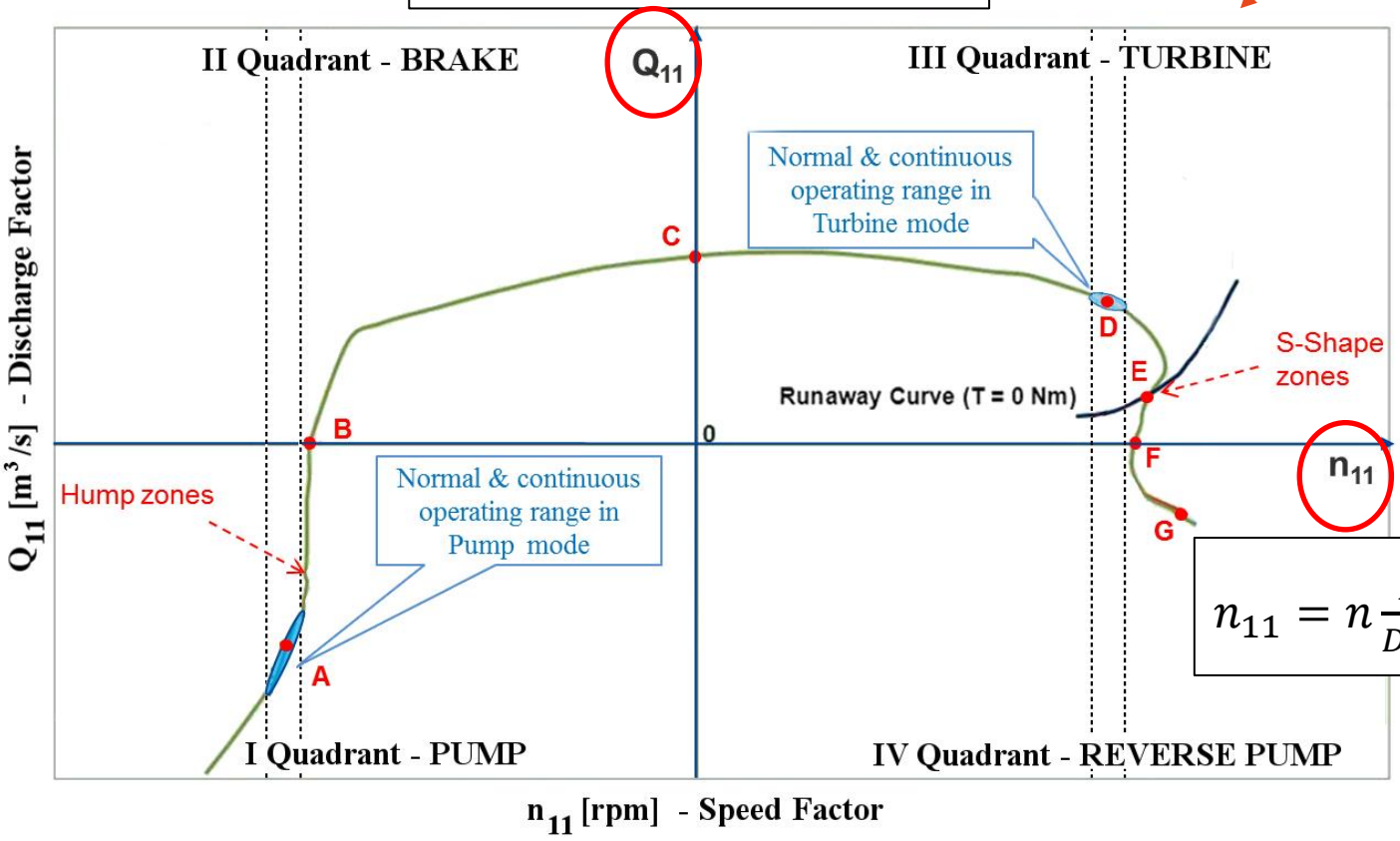


The forth-quadrant characteristic

$\alpha = cost$

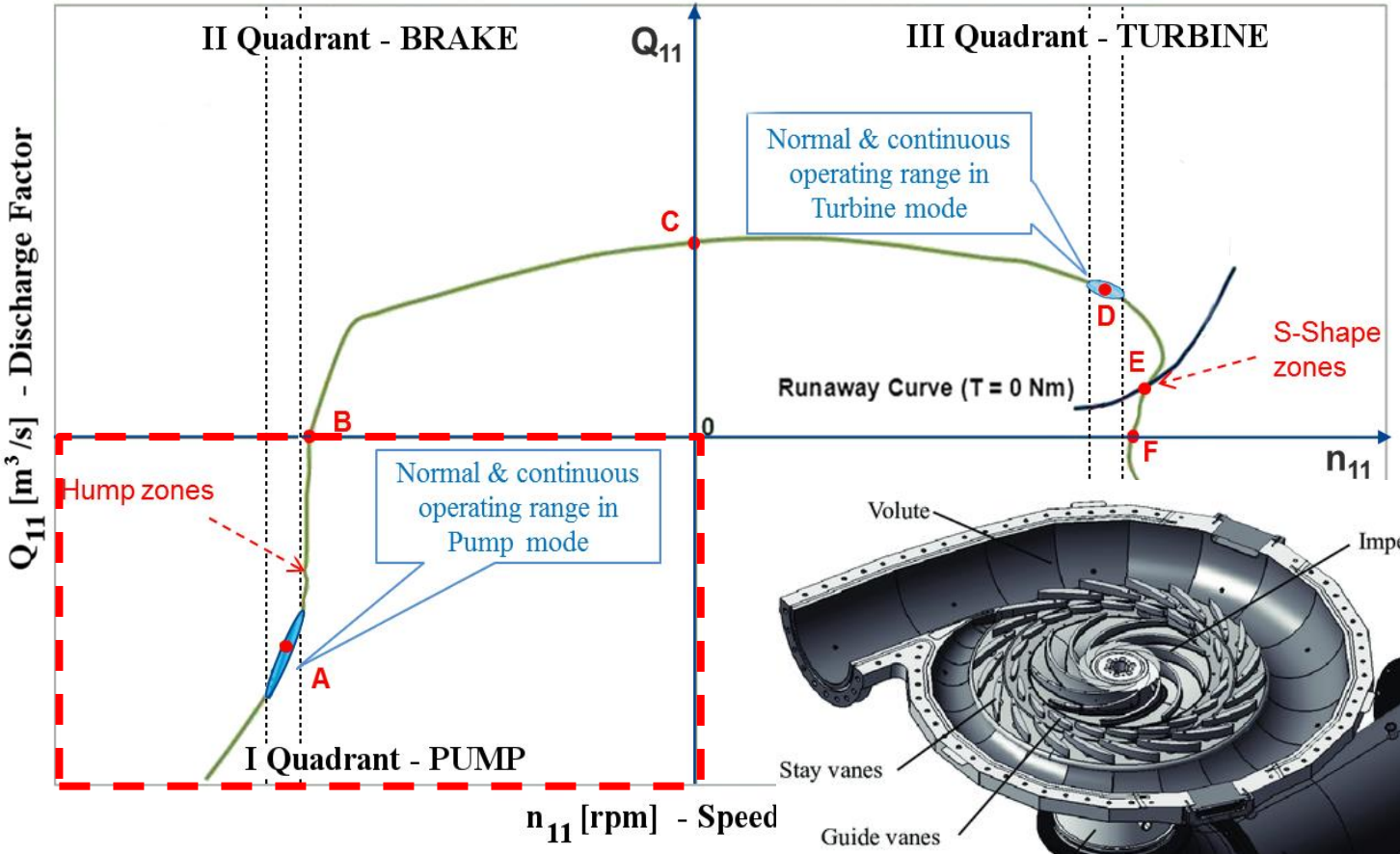
$$Q_{11} = Q\left(\frac{D_{11}}{D}\right)^2 \sqrt{\frac{H_{11}}{H}} \ [\mathrm{m^3/s}]$$

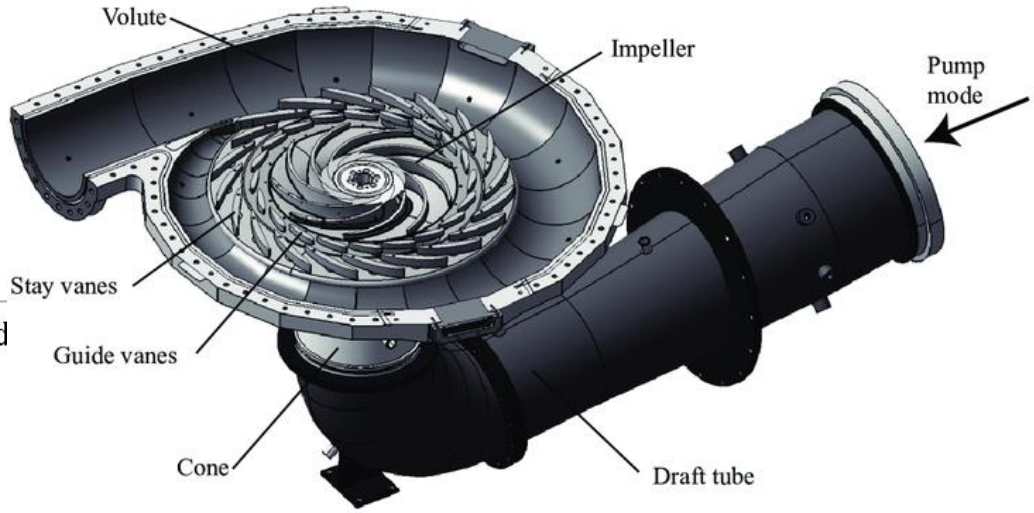
Q>0
n>0



$$n_{11} = n\frac{D}{D_{11}}\sqrt{\frac{H_{11}}{H}} \ [\mathrm{rpm}]$$

*Houdeline et al. (2012) Start-up , Start-up improvement in turbine mode for high head PSP machine. Proceedings of the IOP Conf Ser. Earth Environ. Sci., 15: 42022.

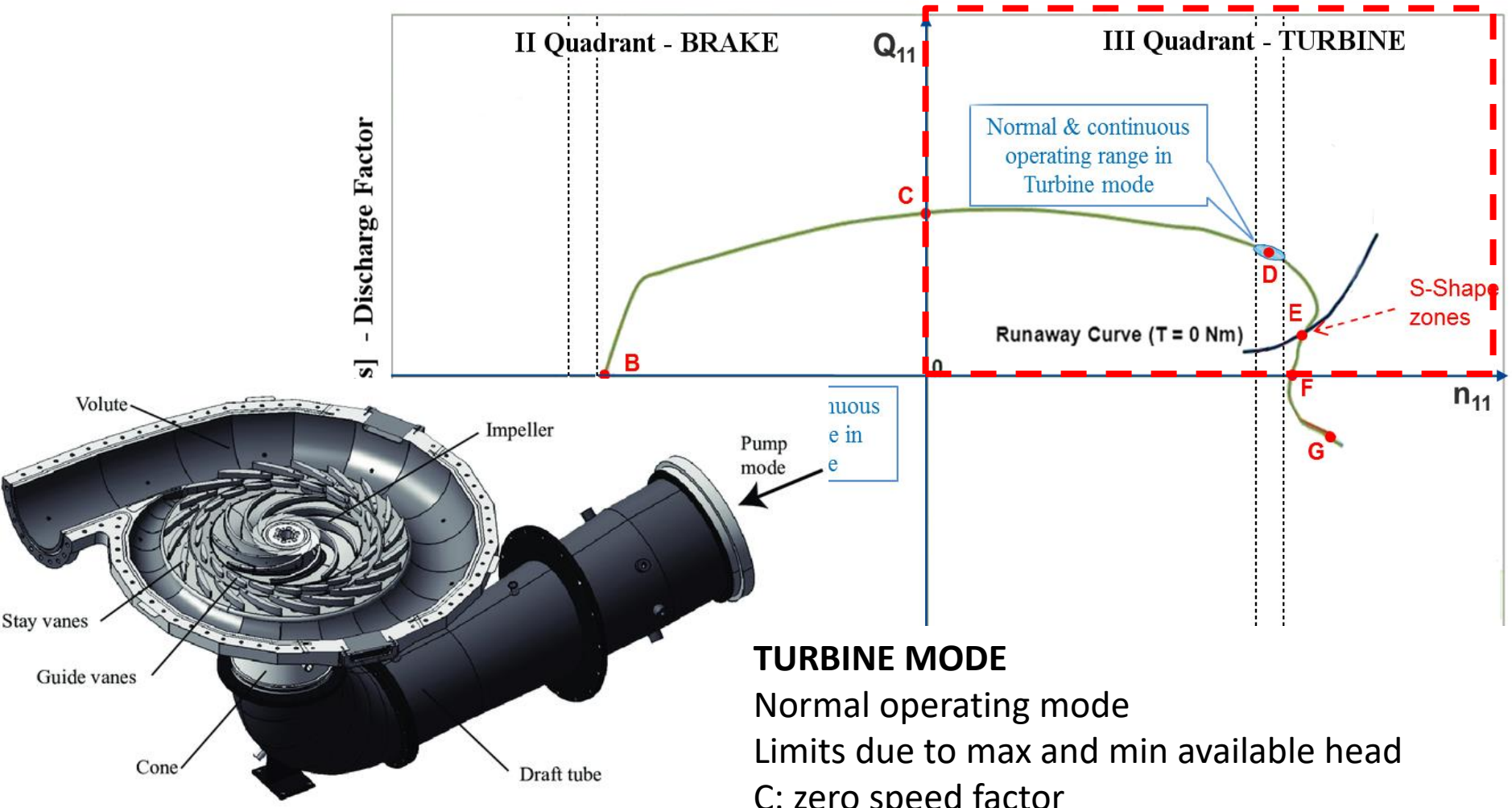




PUMPING MODE

Normal operation in pumping mode

Limits due to max and min head



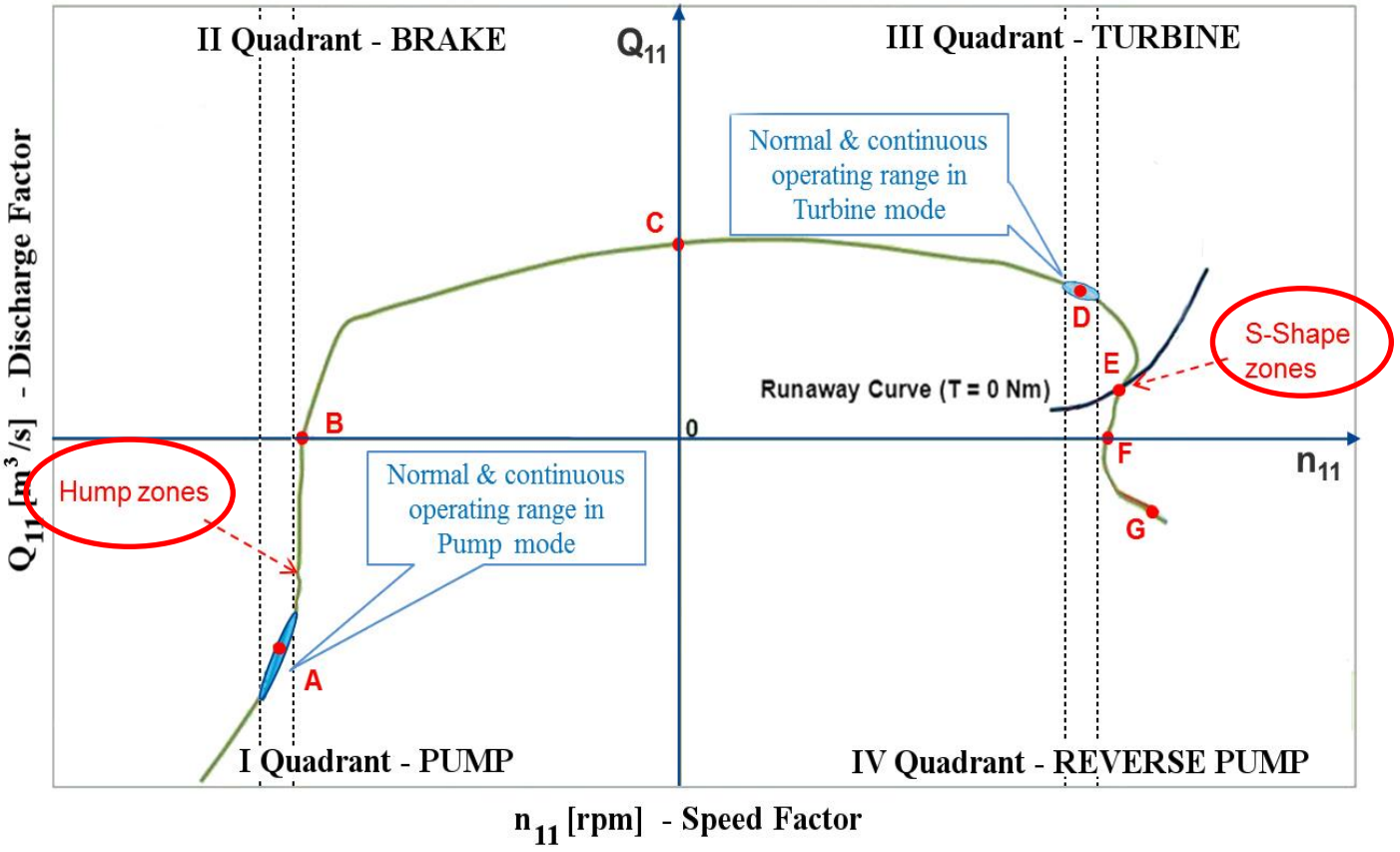
TURBINE MODE

Normal operating mode

Limits due to max and min available head

C: zero speed factor

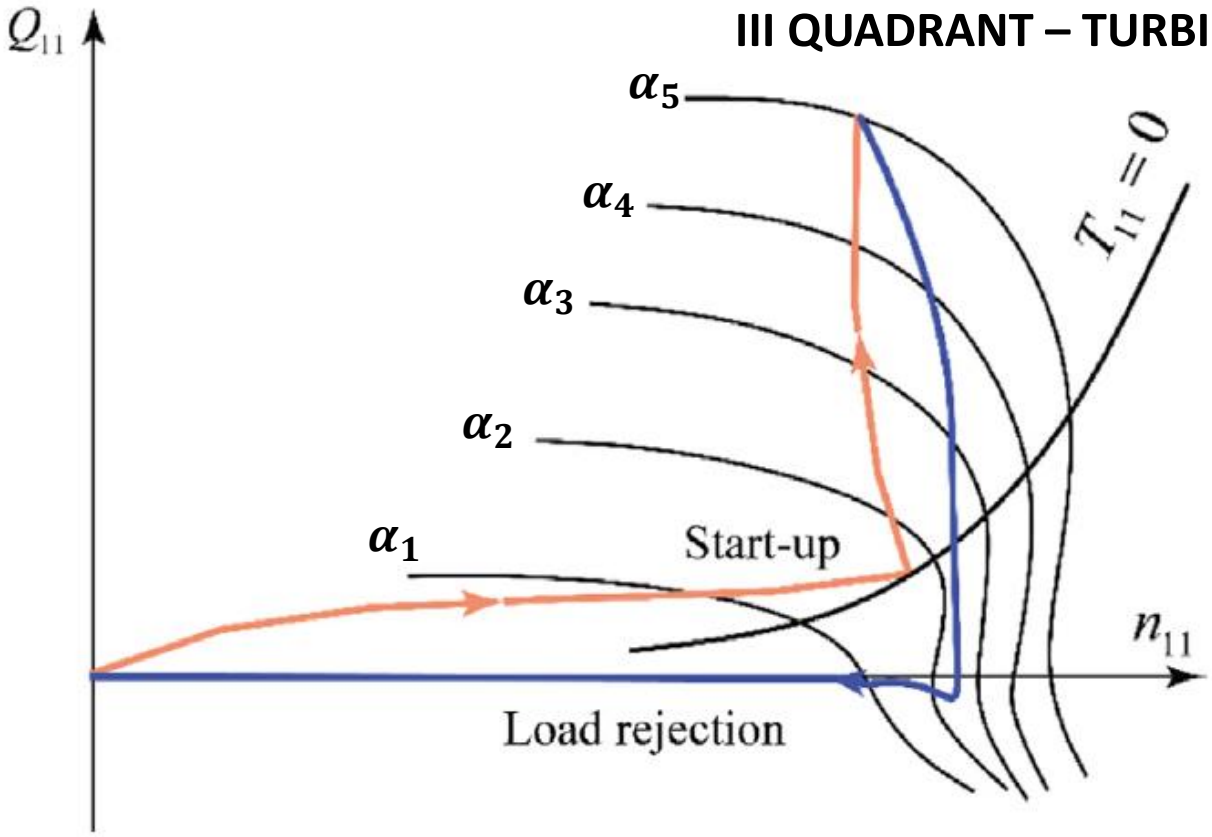
E: runaway



The capability of PHES plants in providing grid services is mainly limited by unstable behaviours both in pumping than in generating mode:

HUMP ZONE **S-SHAPE ZONE**

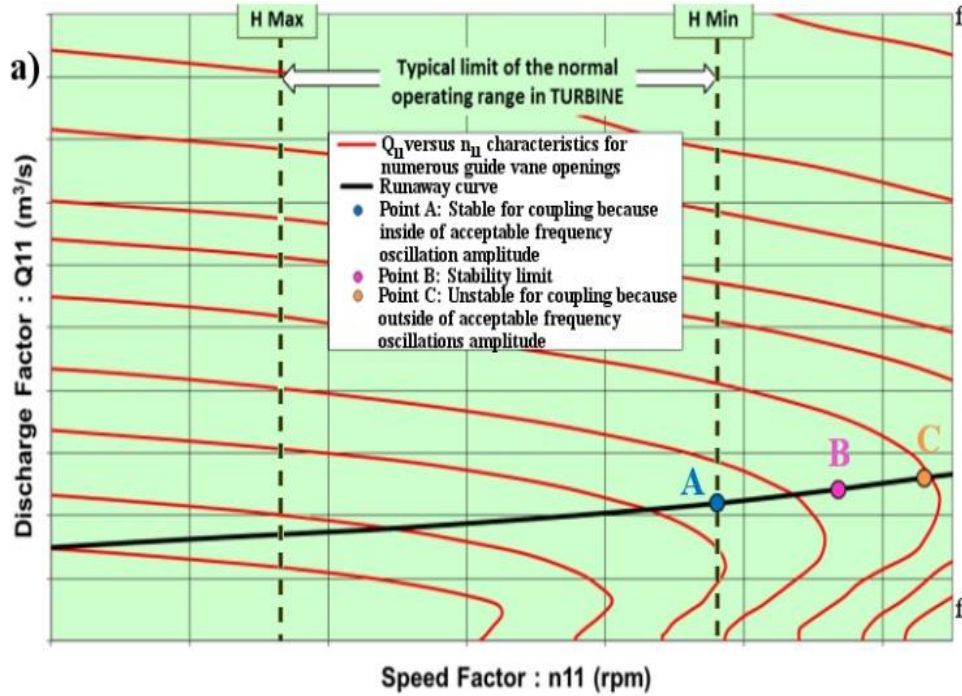
III QUADRANT – TURBINE MODE

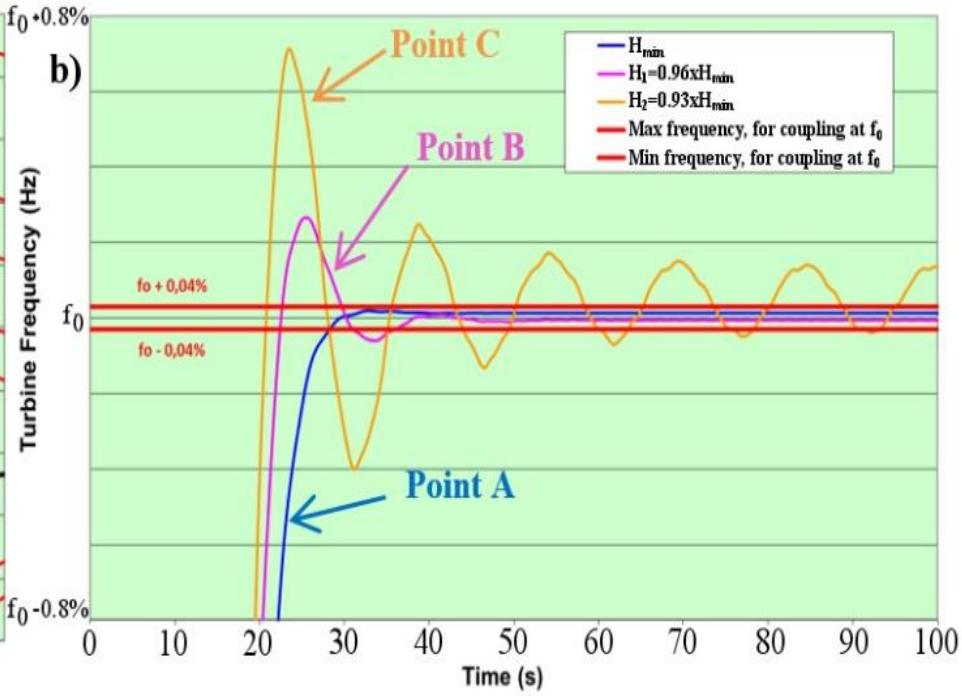


Start-up of a RTP:

- bring to a stable operation close to runaway curve.
- a slight opening of the guide vanes
- Frequency must be synchronized with the grid frequency (± 0.04%)

Turbine start-up and synchronization





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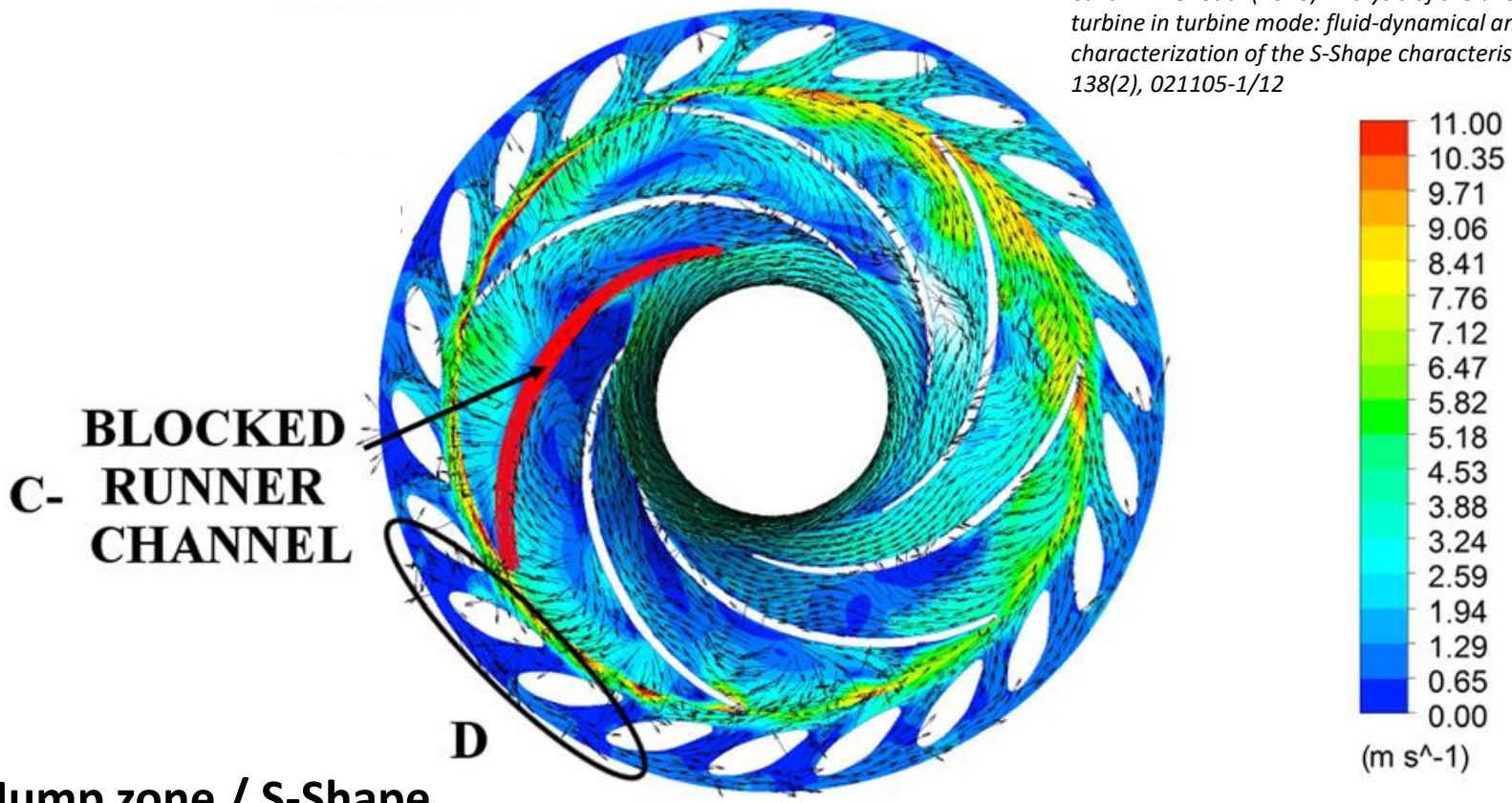
Hump zone / S-Shape

Cavazzini G. et al (2016) Analysis of the unstable behavior of a pump-turbine in turbine mode: fluid-dynamical and spectral characterization of the S-Shape characteristic, ASME J Fluids Eng, vol. 138(2), 021105-1/12

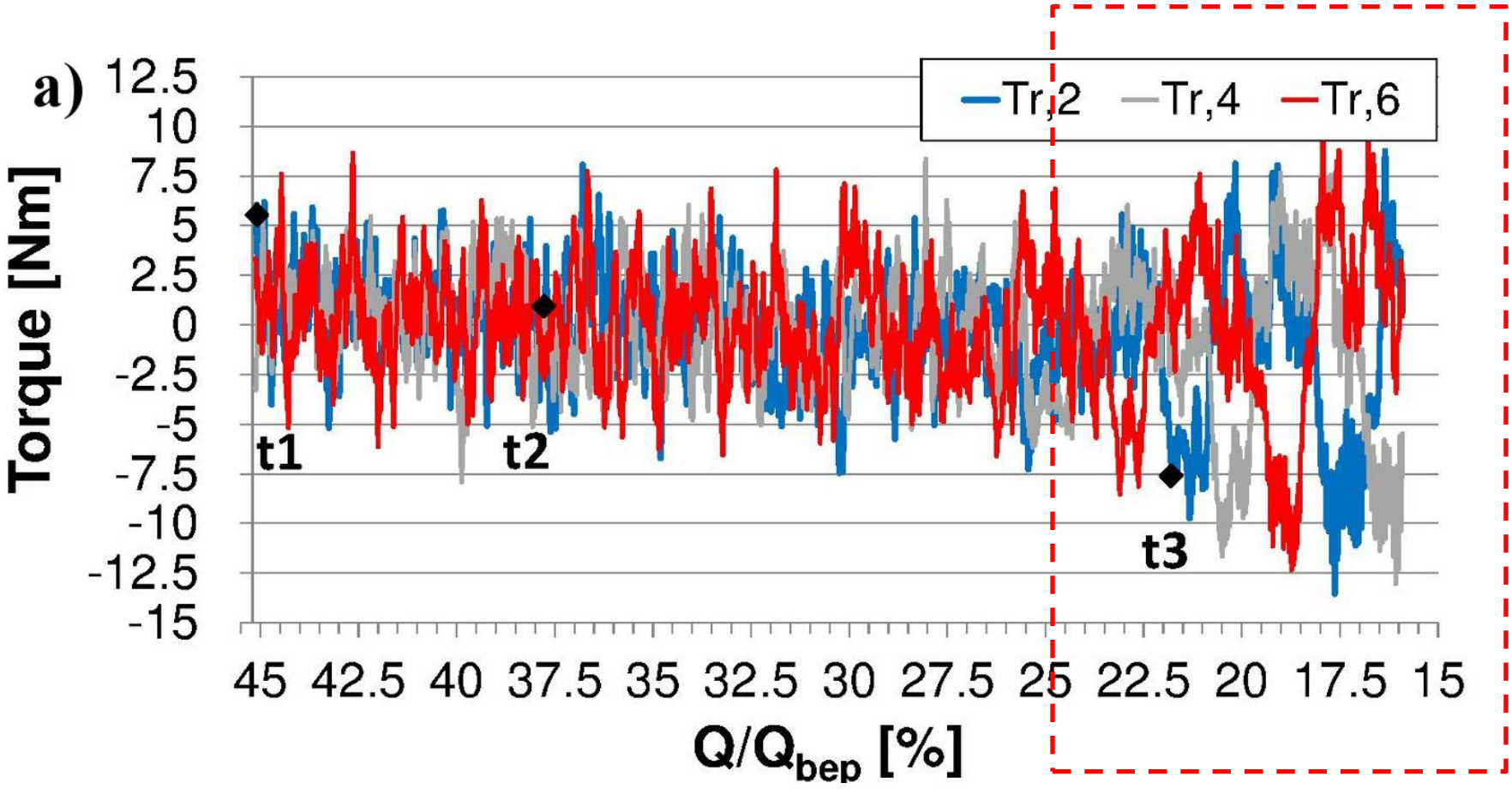


Hump zone / S-Shape

- Flow separations
- Backflow near the inlet throat of some channels

→ In the unstable operating region the machine experiences unsteady full blockages of the flow in both runner and guide vane channels

Hump zone / S-Shape



Unstable operating zone

Cavazzini G. et al (2016) Analysis of the unstable behavior of a pump-turbine in turbine mode: fluid-dynamical and spectral characterization of the S-Shape characteristic, ASME J Fluids Eng, vol. 138(2), 021105-1/12

General Performances	50 to 500 MW 200 to 350 MW	Output/Input Most Typical values
	>> 8 hours full load	Storage capacity
	75 to 1500 m ~100 to ~600 m	Head Range Single stage reversible pump-turbine
	> 80%	Cycle efficiency
Reaction Time	~15 s	50% to 100% Generation
	< 2 min	0% to 100% Generation
	~ 1 min (TS) / ~4 min (VS)	0% to 100% Pumping
	~ 1 min (TS) / ~8 min (VS)	100% Generation to 100% Pumping
Ancillary Services	15% (TS) / 25% (VS) to 100%	Production adjustment range
	~0% (TS) / 70% (VS) to 100%	Pumping power adjustment range
	Reactive power, Primary frequency response, Black start capability	

EERA-EASE (2017). Joint EASE/EERA recommendations for a European Energy Storage Technology Development Roadmp – 2017 Update

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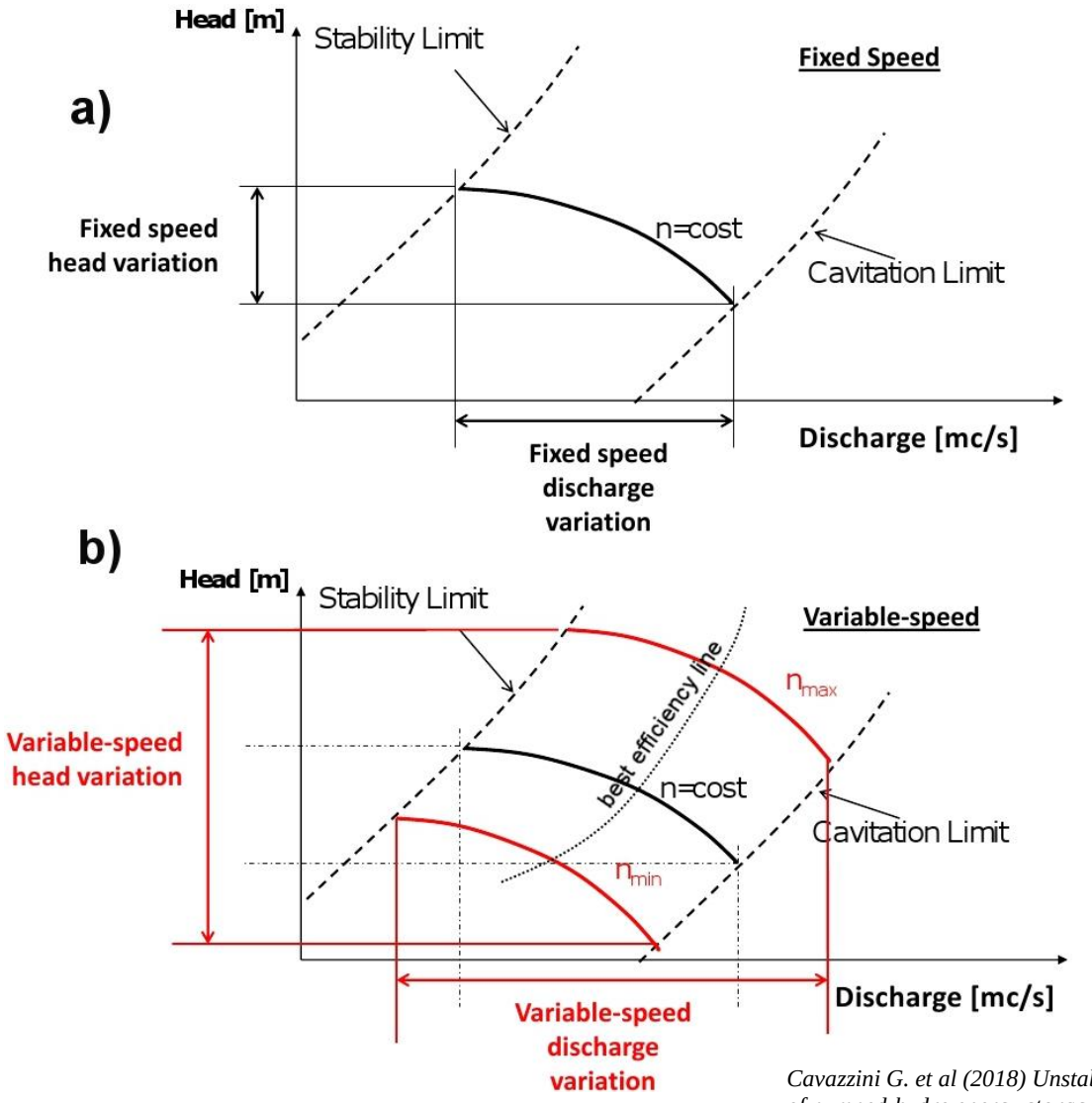
Limited regulation in pumping mode
(hydraulic short circuit)



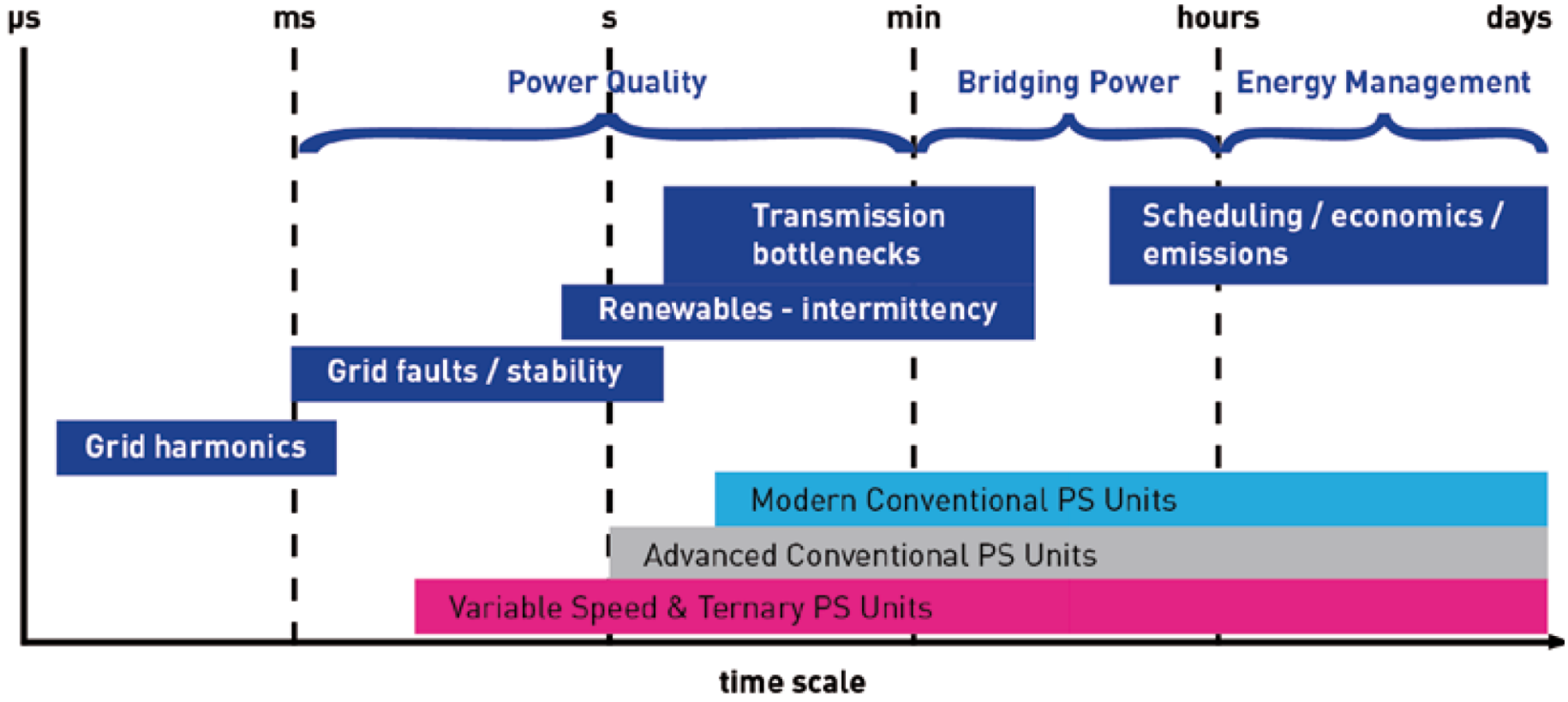
$$P = \frac{\rho Q g h}{\eta}$$

VARIABLE SPEED TECHNOLOGY

Variable-speed pump-turbine technology allows to extend the pump-turbine working range

increase the regulation capacity of the plant in pumping mode

Cavazzini G. et al (2018) Unstable behaviour of pump-turbines and its effects on power regulation capacity of pumped-hydro energy storage plants. Renewable and Sustainable Energy Reviews, 94: 399-409



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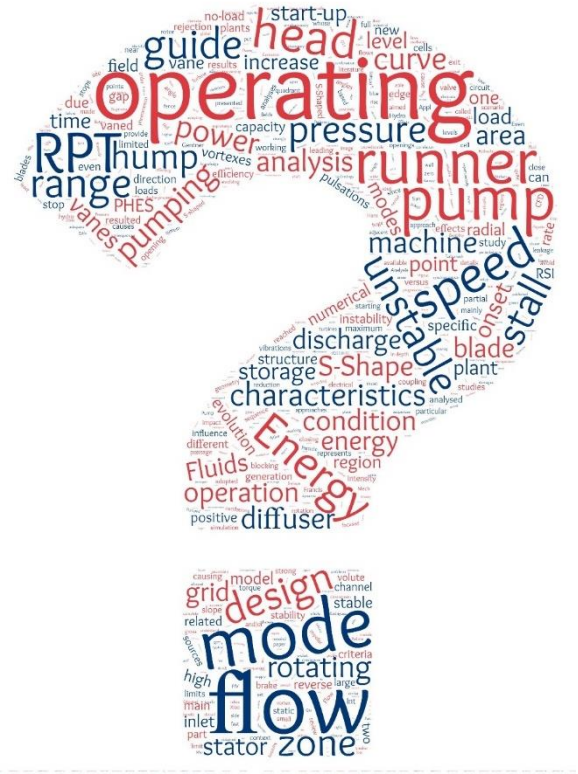
Conclusions



- To improve pumped-hydro flexibility, it is necessary to:
  - Develop innovative control/**design** strategies able to destroy the «organized» nature of the instabilities
  - Improve ICT technologies: information, intelligent and interactive (**digitalization**)

- To provide fast flexibility services, it is necessary to **hybridize** with complementary energy/power storage systems
  - Optimal hydribidization
  - Innovative control strategies

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Thank you!

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