T3.2 -A- Expanding the operating range of hydraulic turbines and pump-turbines.

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SUPPLY of ELECTRICITY

HYPERBOLE: FP7 n° 608532 Sept. 2013 – Jan 2017

Broadening the hydraulic turbine operating range for a lean grid integration of new renewable energy resources

Prof. François Avellan, Eng. Dr.

September 30, 2014

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

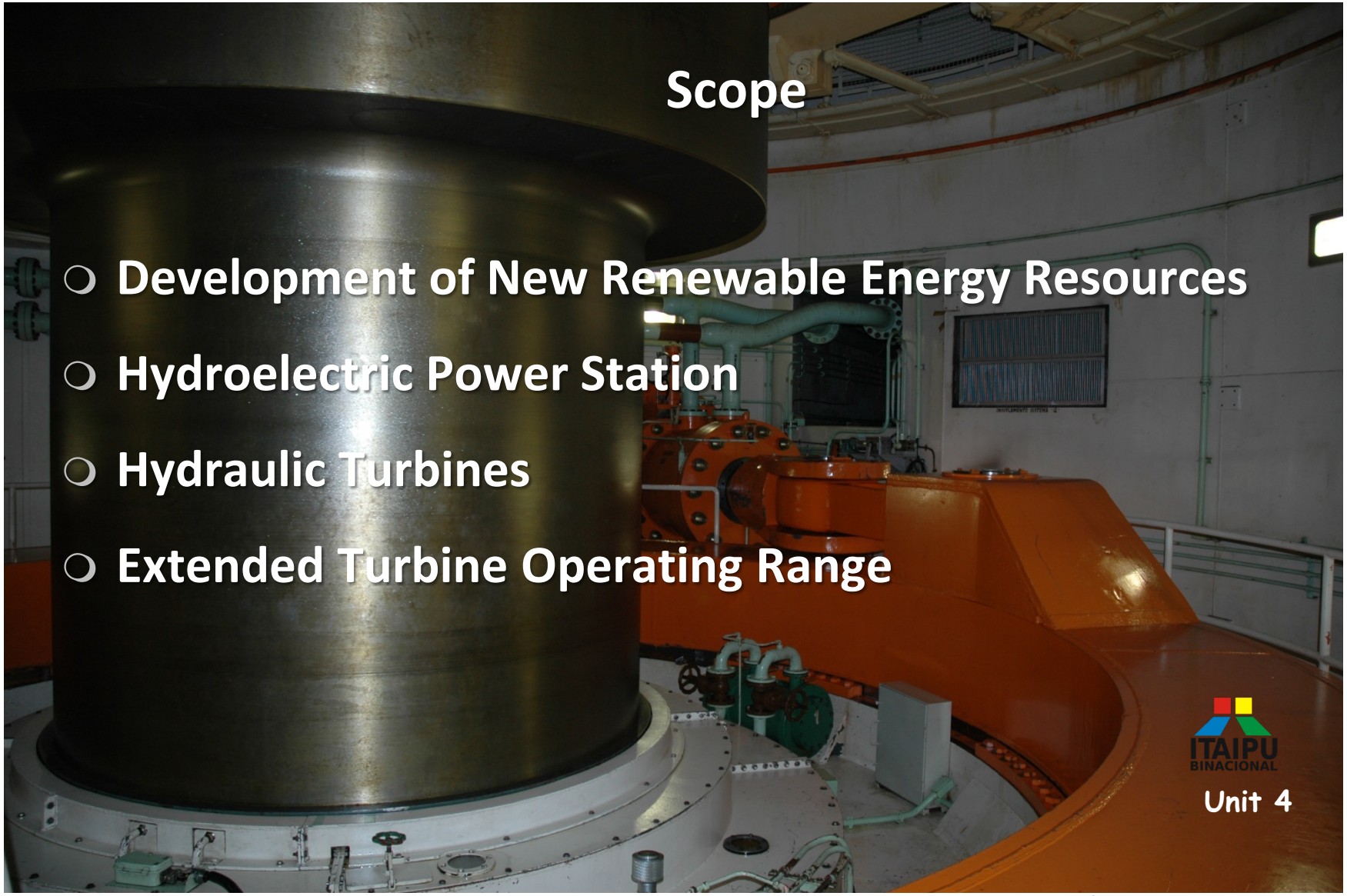
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

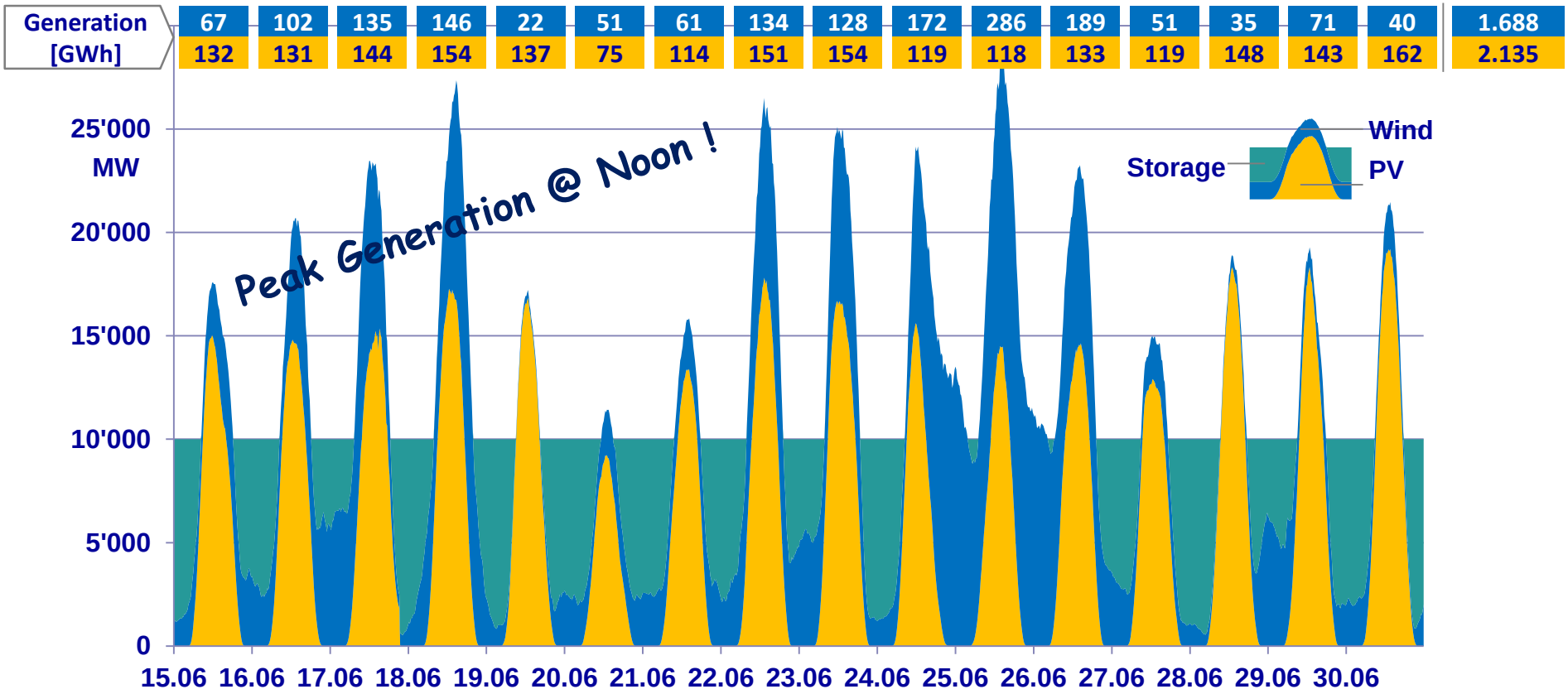
Scope

- Development of New Renewable Energy Resources
- Hydroelectric Power Station
- Hydraulic Turbines
- Extended Turbine Operating Range



Integration of New Renewable Energy Sources in Europe

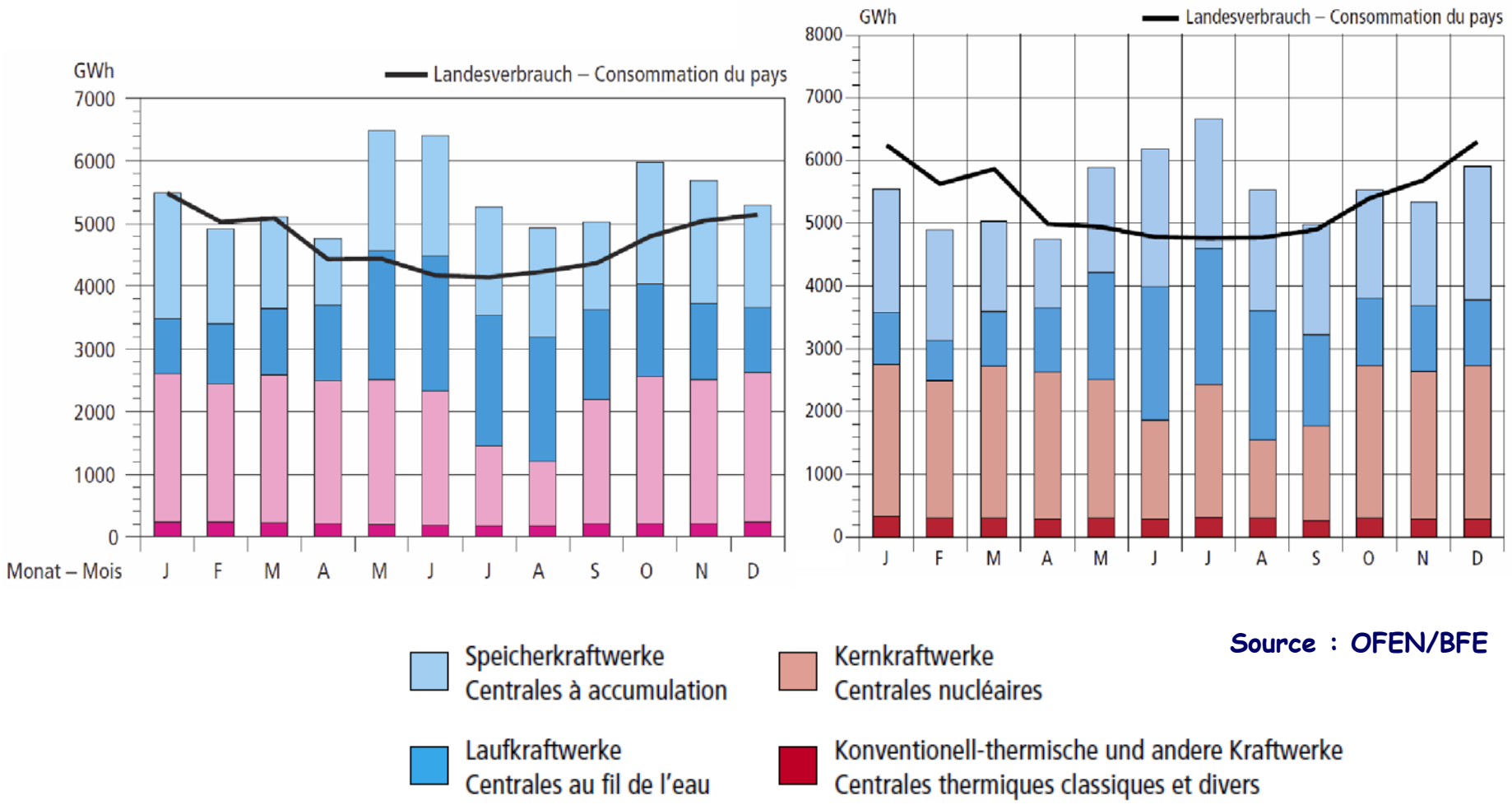
- Needs of Storage & Grid Primary and Secondary Control ?



NREs in Germany, Mid of June 2012 : 10 GW Storage Capacity?

2000: 1 negative month!

2010: 6 negative months!

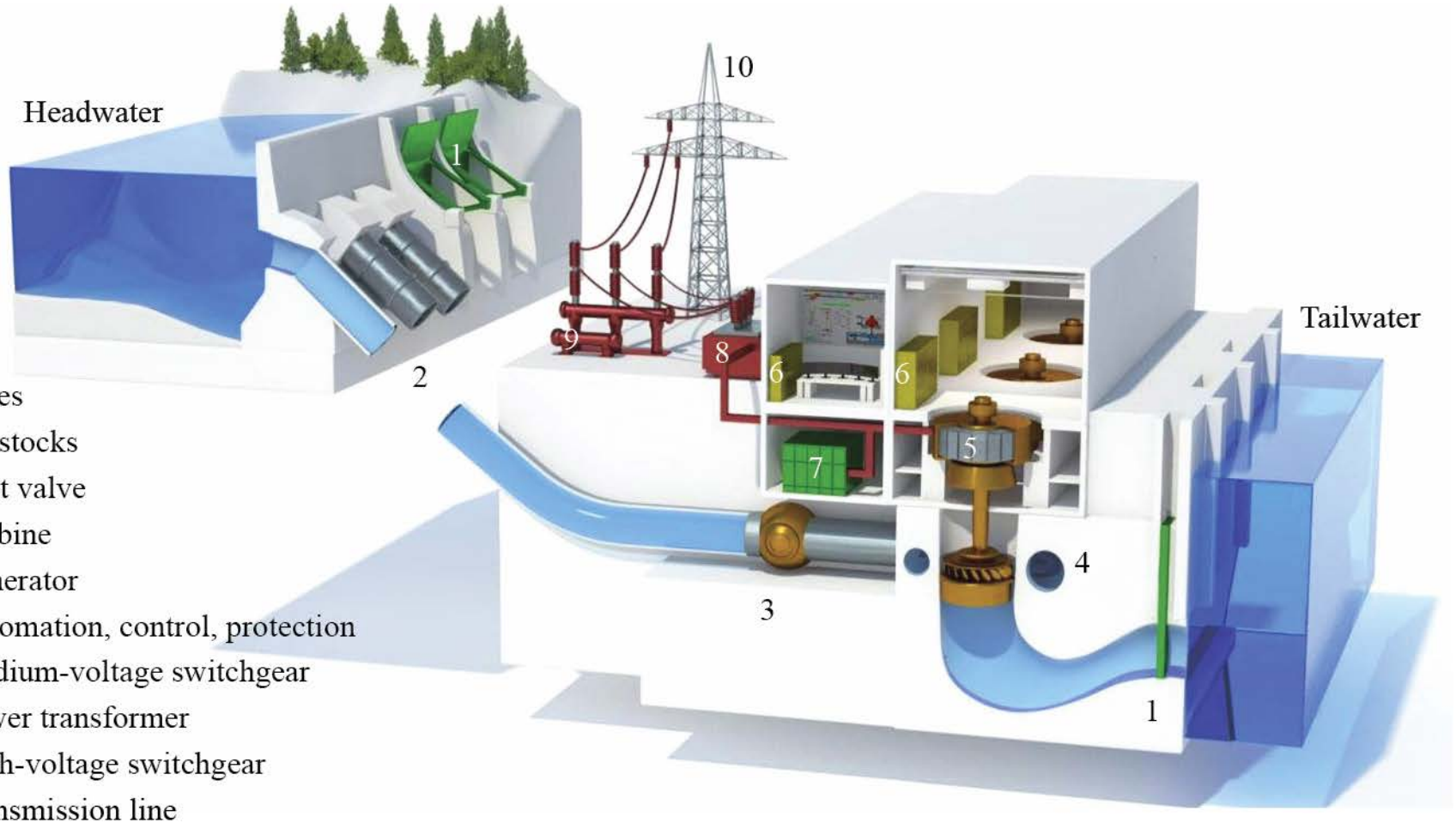


Source : OFEN/BFE

Swiss Electric Supply: Monthly Power Balance

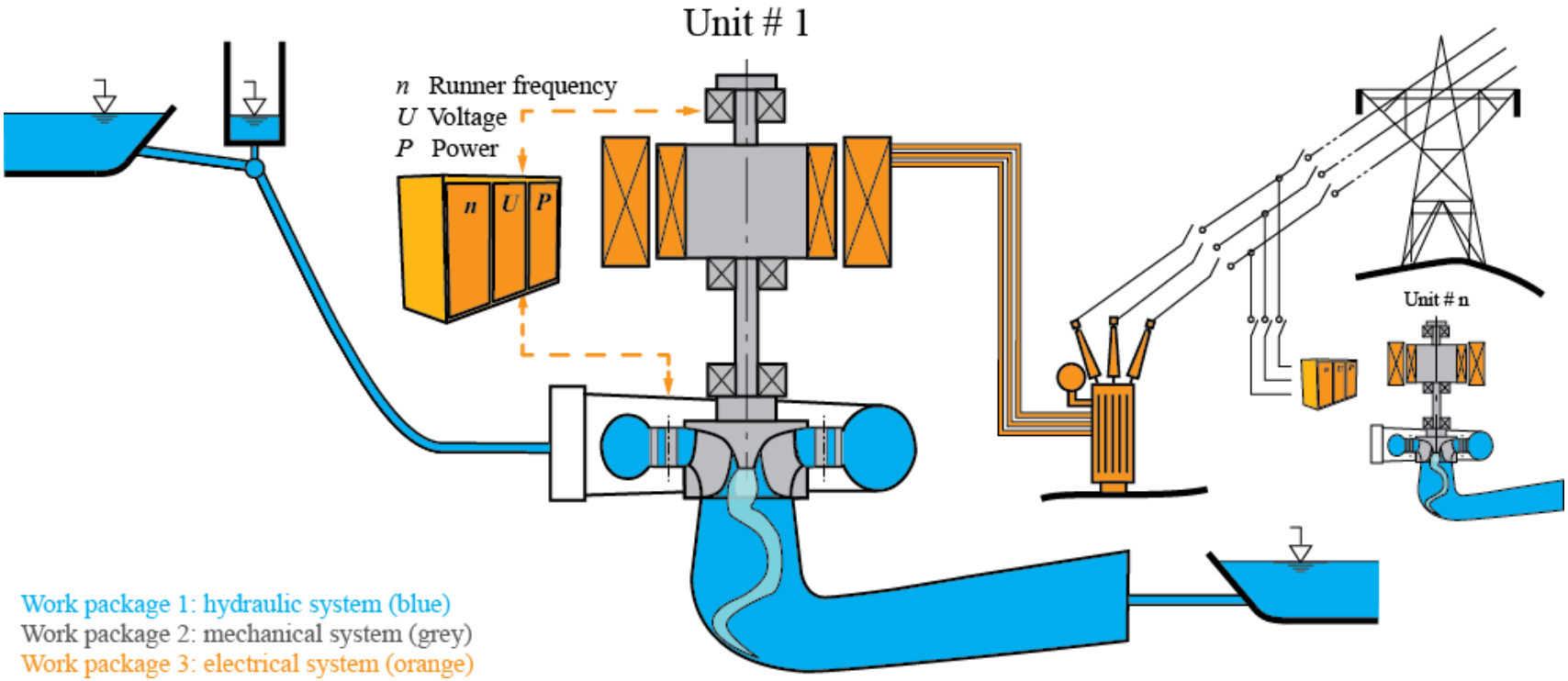
Operation Strategy Revision

Hydroelectric Power Station
Run-of-River Power Station Layout



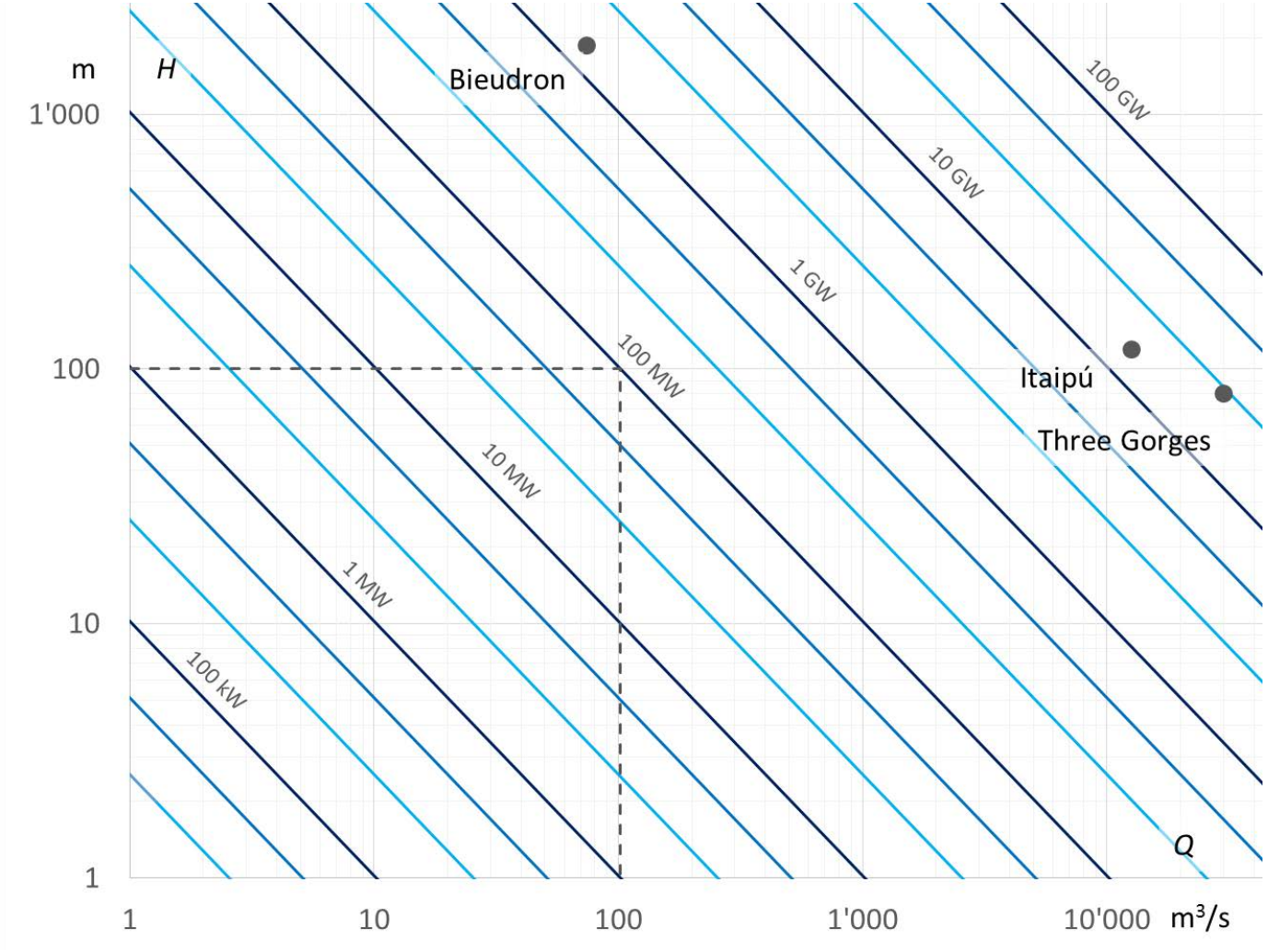
1 Gates
2 Penstocks
3 Inlet valve
4 Turbine
5 Generator
6 Automation, control, protection
7 Medium-voltage switchgear
8 Power transformer
9 High-voltage switchgear
10 Transmission line

Storage Hydroelectric Power Station Layout

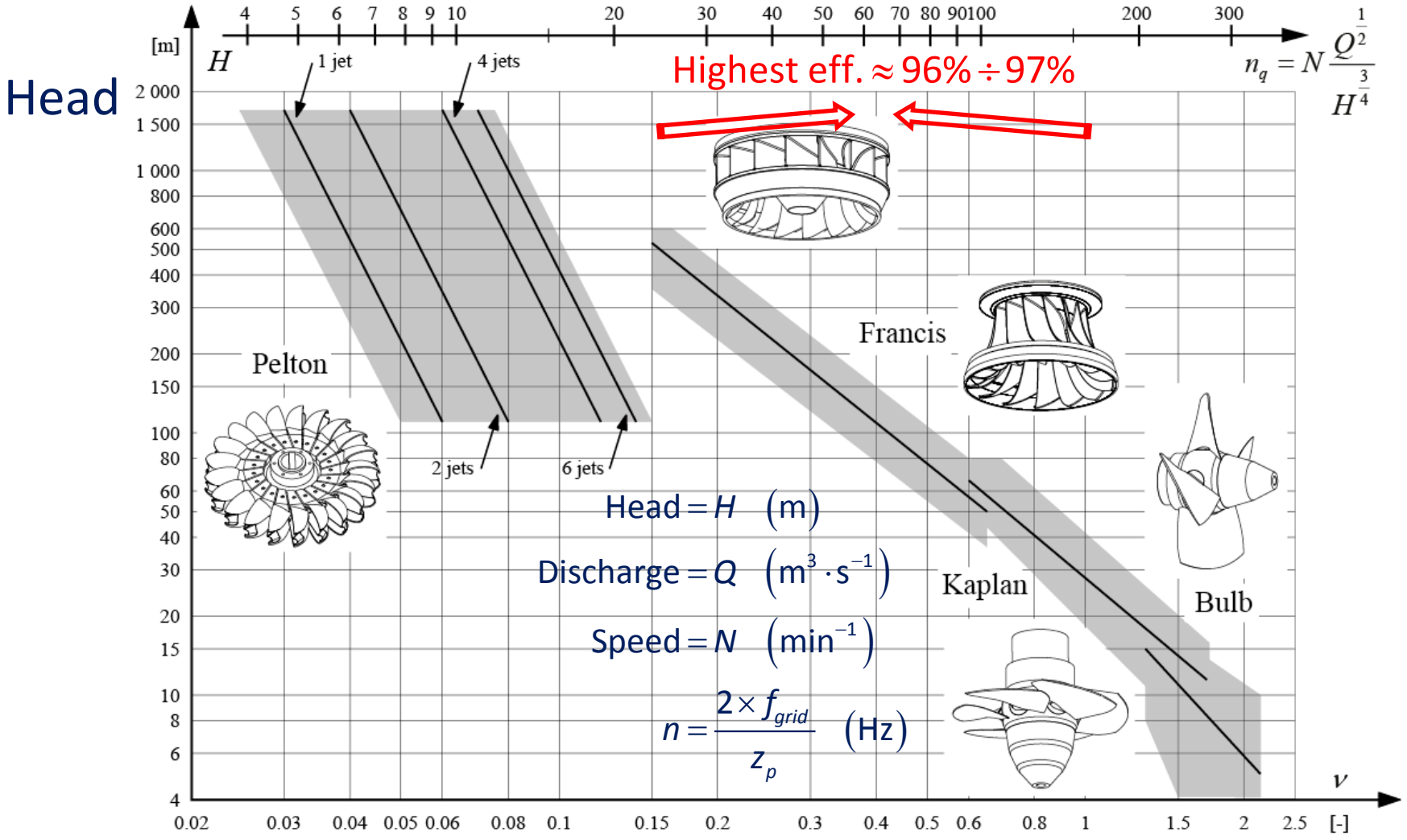


Capacity Chart of Hydroelectric Power Station

$$P_h = \rho Q \times gH$$



Best Suited Hydraulic Turbines



1'269 MW Bieudron Hydroelectric Power Station
3 Pelton Turbines

- **500 MVA Generators**
  - ✓ 14 poles, 35.7 MVA/pole
  - ✓ 428.5 min^{-1}
  - ✓ Water Cooled
- **423 MW Pelton Turbines**
  - ✓ 1'883 m Head
  - ✓ 25 m^3/s Discharge
  - ✓ 5 injectors
  - ✓ D_1 = 3.993 m
  - ✓ ~28 t Runner Mass

FVPM Flow Numerical Simulations
Impinging Jet on Pelton Buckets

Christian VESSAZ, EPFL doctoral work supported by the Ark Fondation

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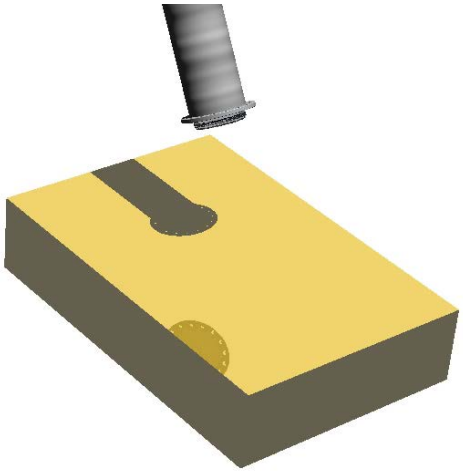
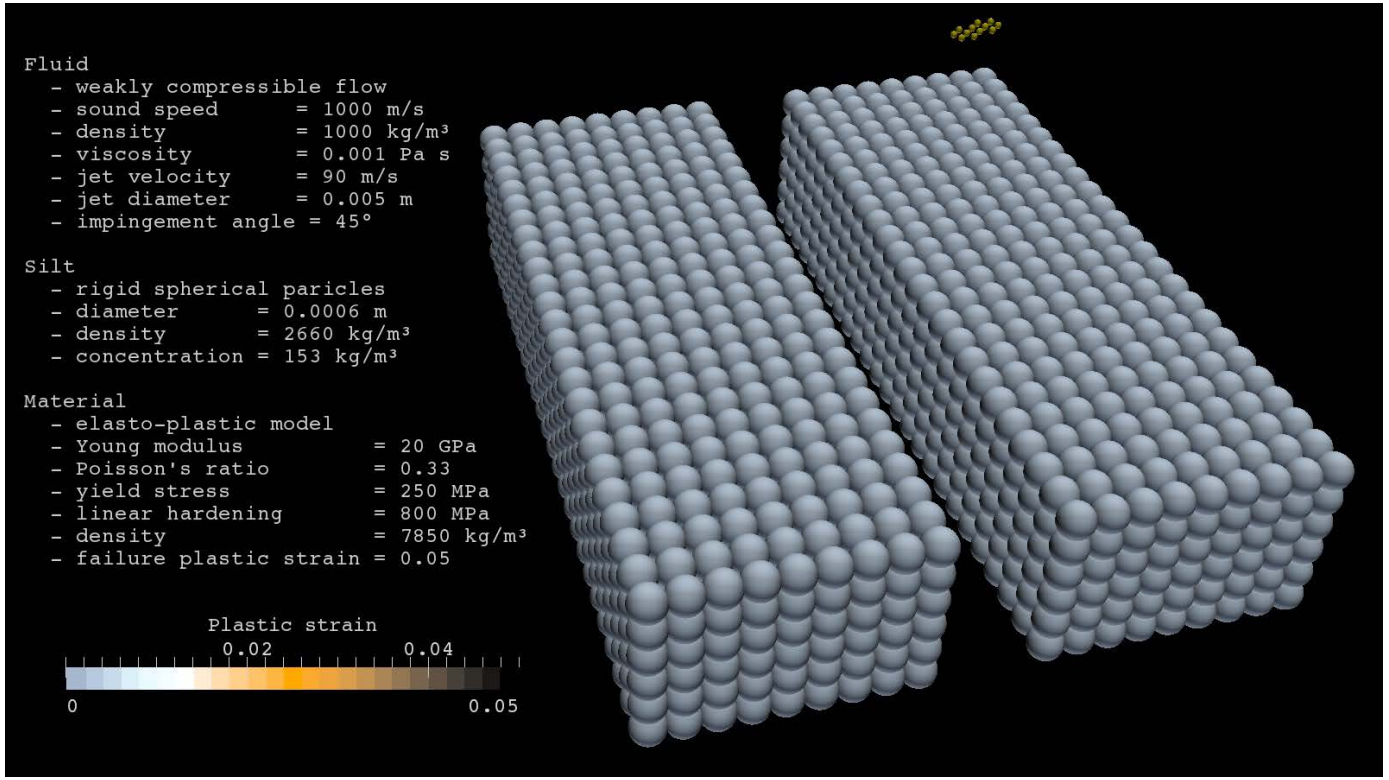
SCCER SoE T3.2 -B- Modeling silt erosion in turbine components for large hydro

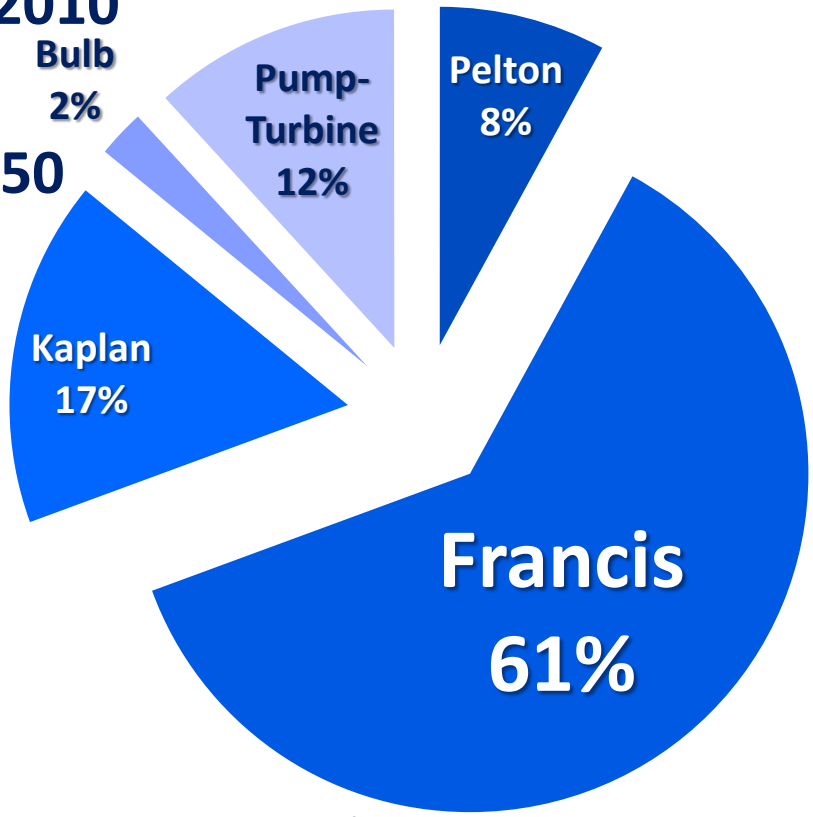




Ebrahim JAHANBAKHSH, "Simulation of Silt Erosion Using Particle-Based Methods", EPFL doctoral work N° 6284, 2014

Hydro Turbines International Market

- Capacity Breakdown by Types of Turbines
  - ✓ 1’038 GW Installed Capacity in 2010 Modernization Market
  - ✓ 1’000 GW to be built before 2050 Greenfields Project

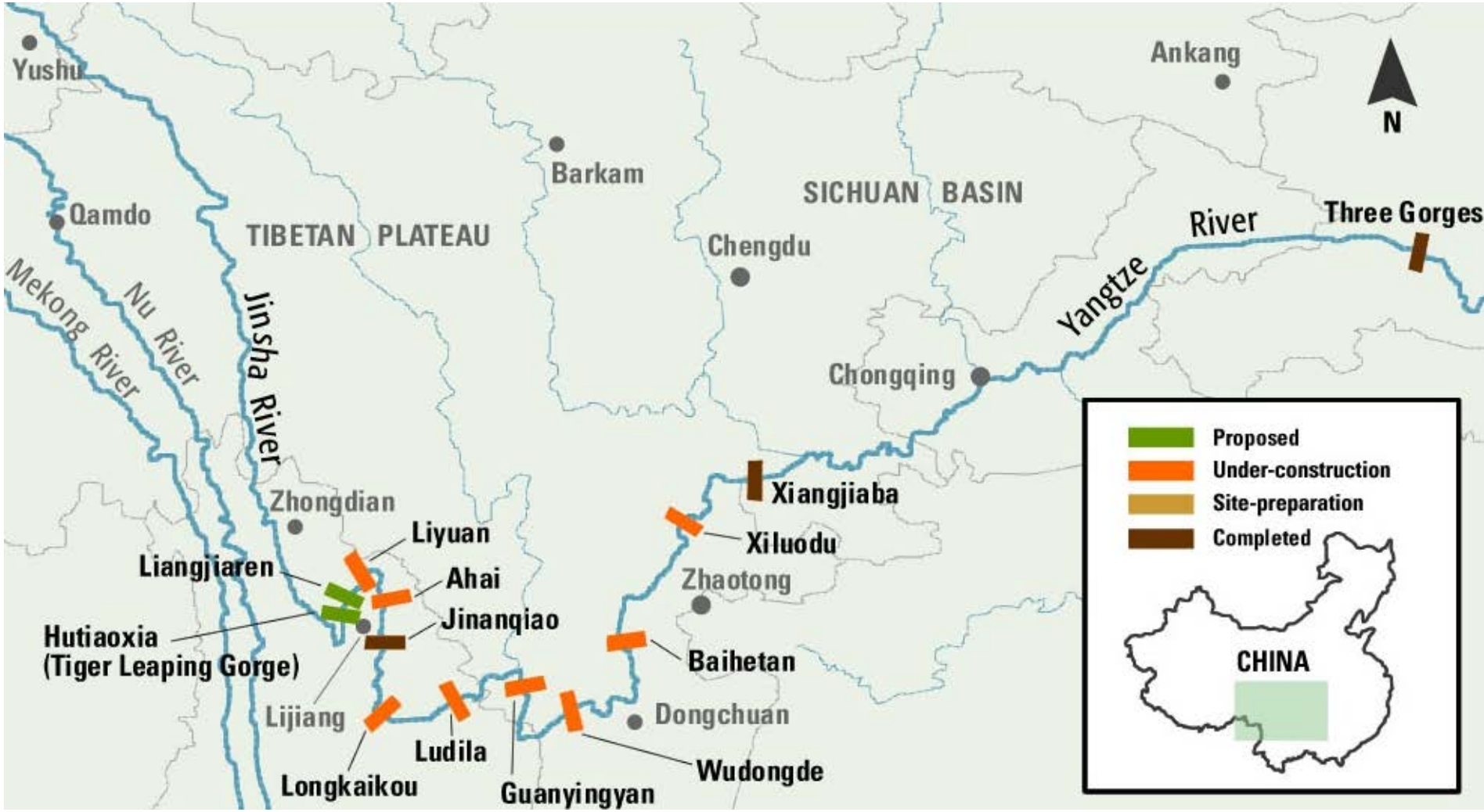


Major Hydroelectric Power Stations are Francis Powered

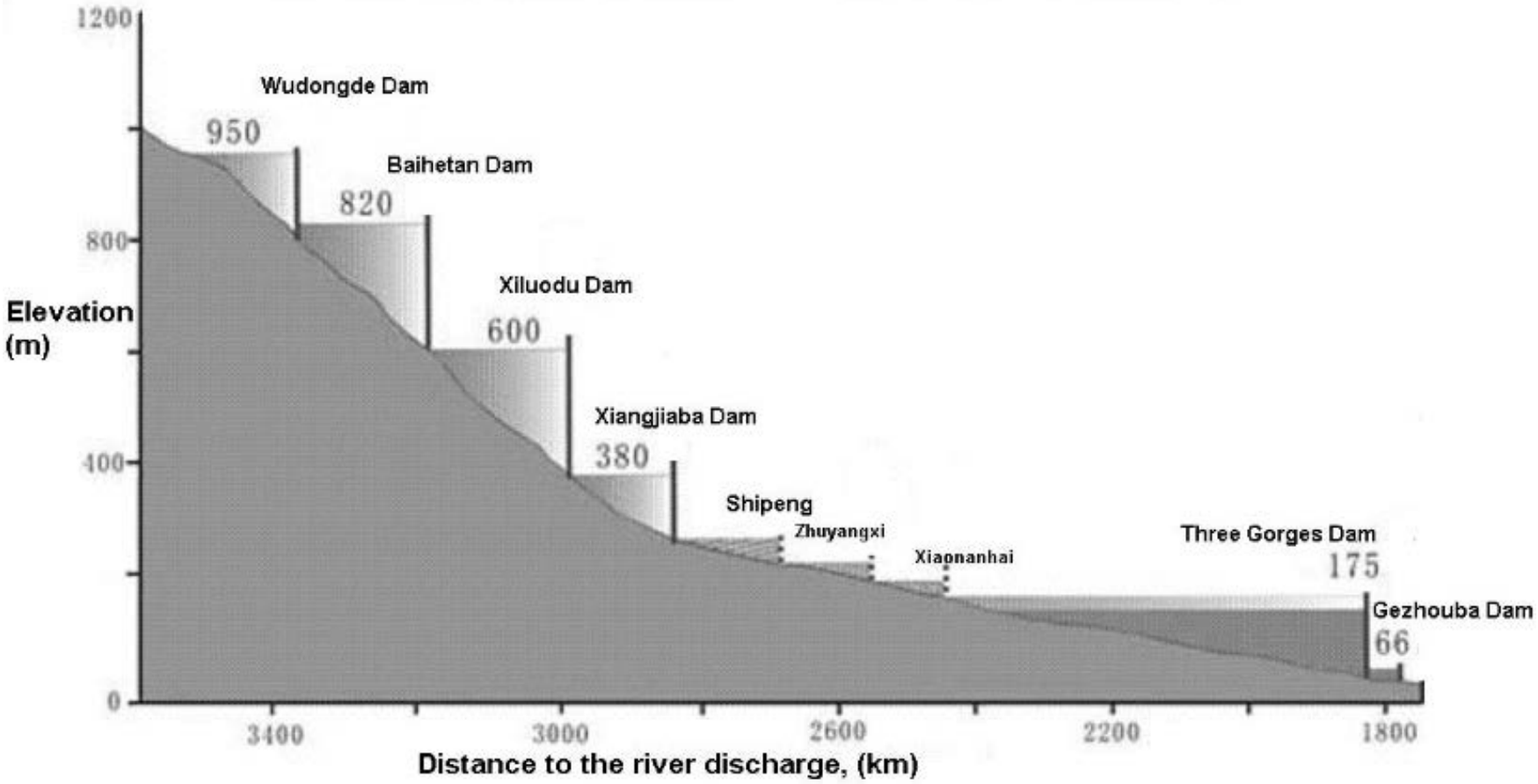
Hydropower Plant	Country	Capacity (MW)	Energy (TWh)	EPFL Model Testing	Type
Three Gorges	China	22'500	98.5	○	Storage
Itaipú	Brazil-Paraguay	14'000	98.3	✓	Storage
Belo Monte	Brazil	11'233	-	✓	Run-of-River
Guri (Raúl Leoni)	Venezuela	8'850	53.4	✓	Storage
Tucuruí	Brazil	8'370	41.4	✓	Storage
Grand Coulee	USA	6'809	20.0	✓	Storage
Longtan	China	6'426	18.7	○	Storage
Krasnoyarsk	Russia	6'000	20.4	○	Storage
Robert Bourassa (LG2)	Canada	5'616	26.5	✓	Storage
Churchill Falls	Canada	5'428	35.0	○	Storage

Tucurui Dam, Eletro Norte

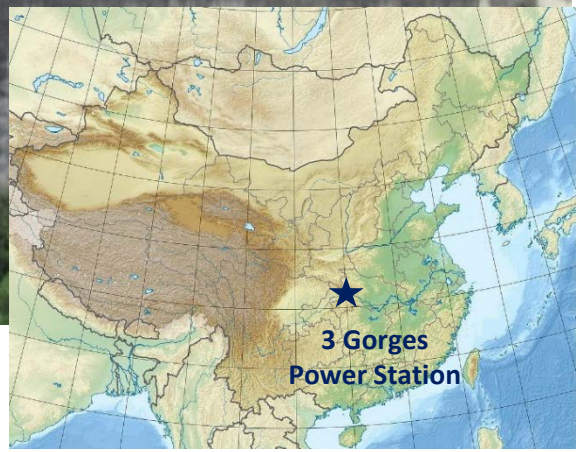
Jinsha-Yangtze Hydroelectric Scheme



Jinsha-Yangtze Hydroelectric Scheme



Three Gorges Dam, Right Bank



22'500 MW Three Gorges Power Station, Yang Tse River, P.R. China.

3 Gorges Francis Turbine
Spiral Case

3 Gorges Turbine Runner Outlet
Air Injection for Mitigating p-fluctuations

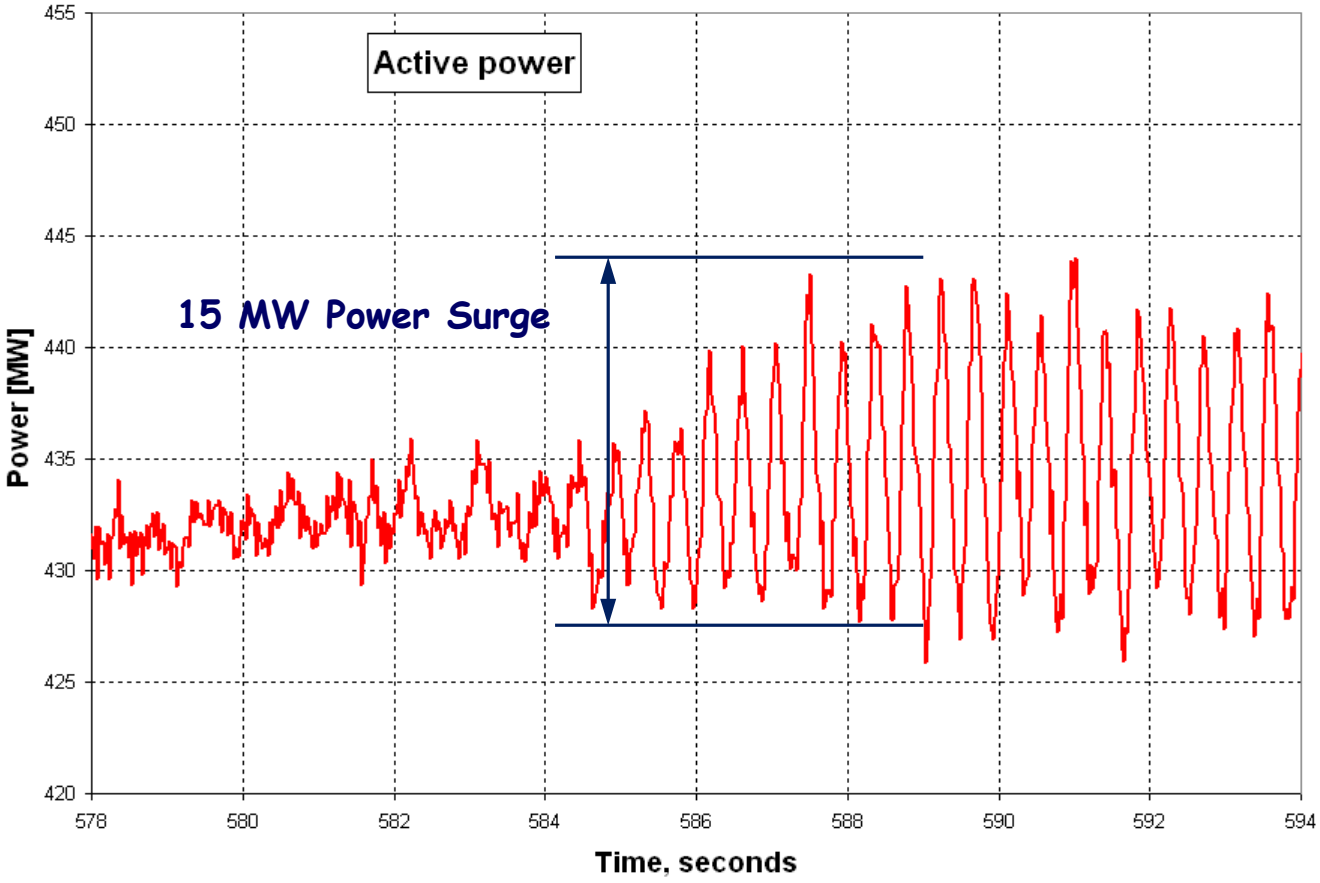
Gino BLOMMAERT, "Etude du comportement dynamique des turbines Francis: contrôle actif de leur stabilité de fonctionnement", EPFL Doctoral Thesis N°2222, 2000.

Xiangjiaba Power Station (Jinsha River, Yunnan)

Toward 1 GW Unit Capacity?

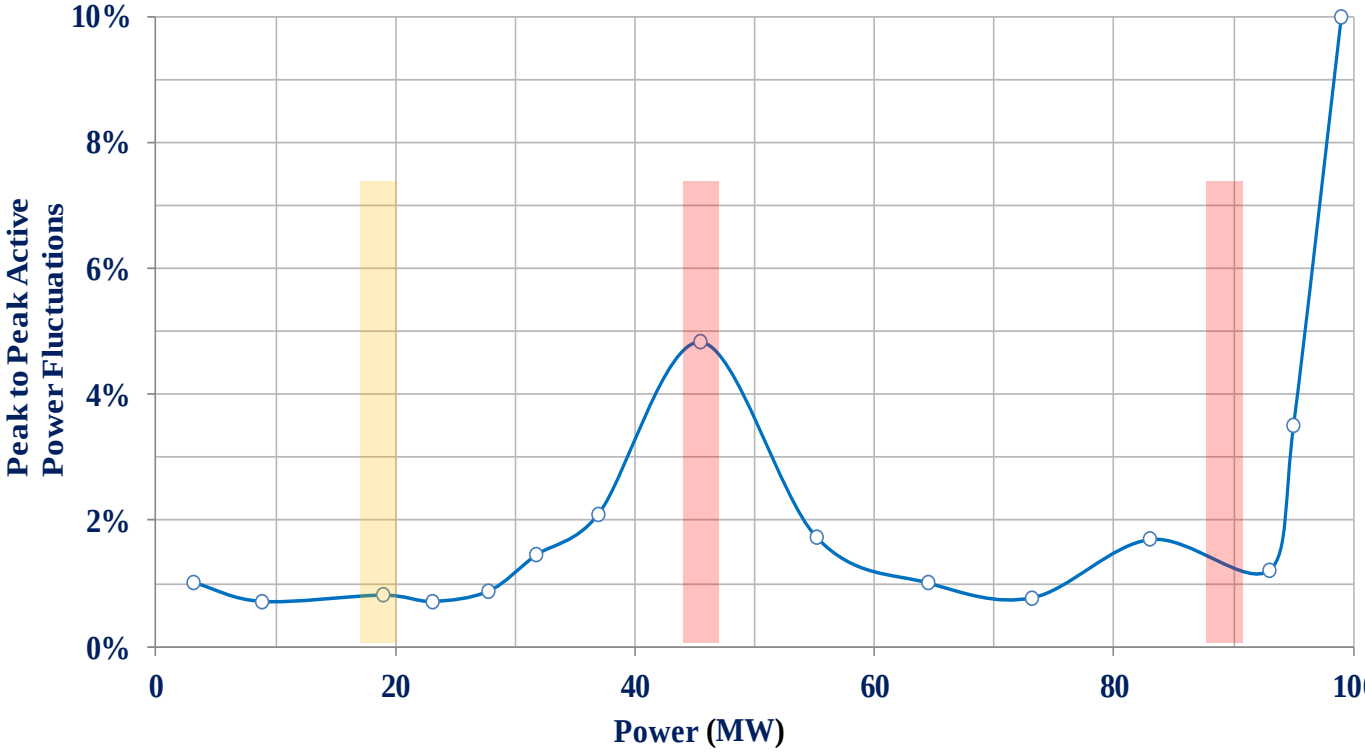
- 8 Francis Turbines
- 825 MW Max. Power
- 10.5 m Diameter
- ~ 406 000 kg

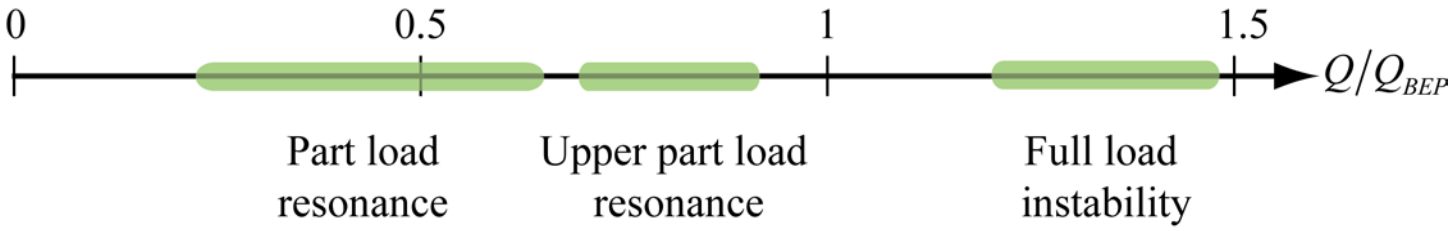
Generating Unit Dynamics



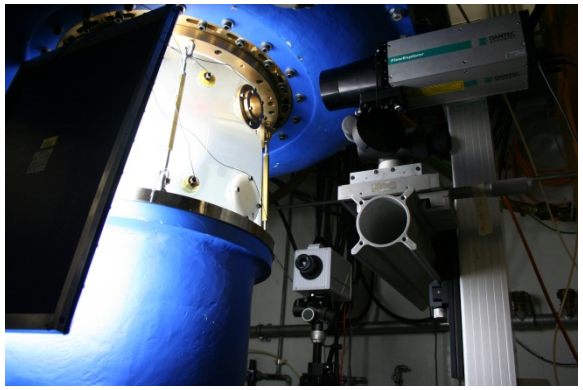
J. KOUTNIK, Ch. NICOLET , G.A. SCHOHL, F. AVELLAN, *"Overload Surge Event in a Pumped-Storage Power Plant"*, Proceedings of the 23rd IAHR Symposium on Hydraulic Machinery and Systems, Yokohama, Japan, Oct. 2006

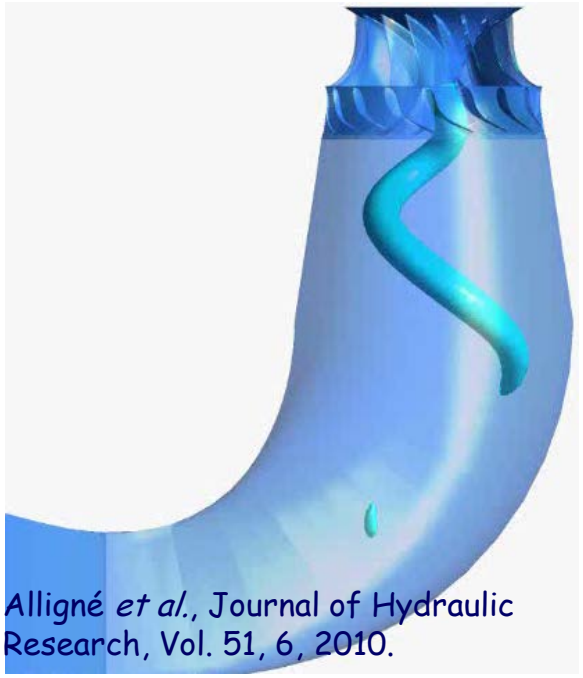
Power Surge


10%
8%
6%
4%
2%
0%
Peak to Peak Active Power Fluctuations
0
20
40
60
80
100
Power (MW)

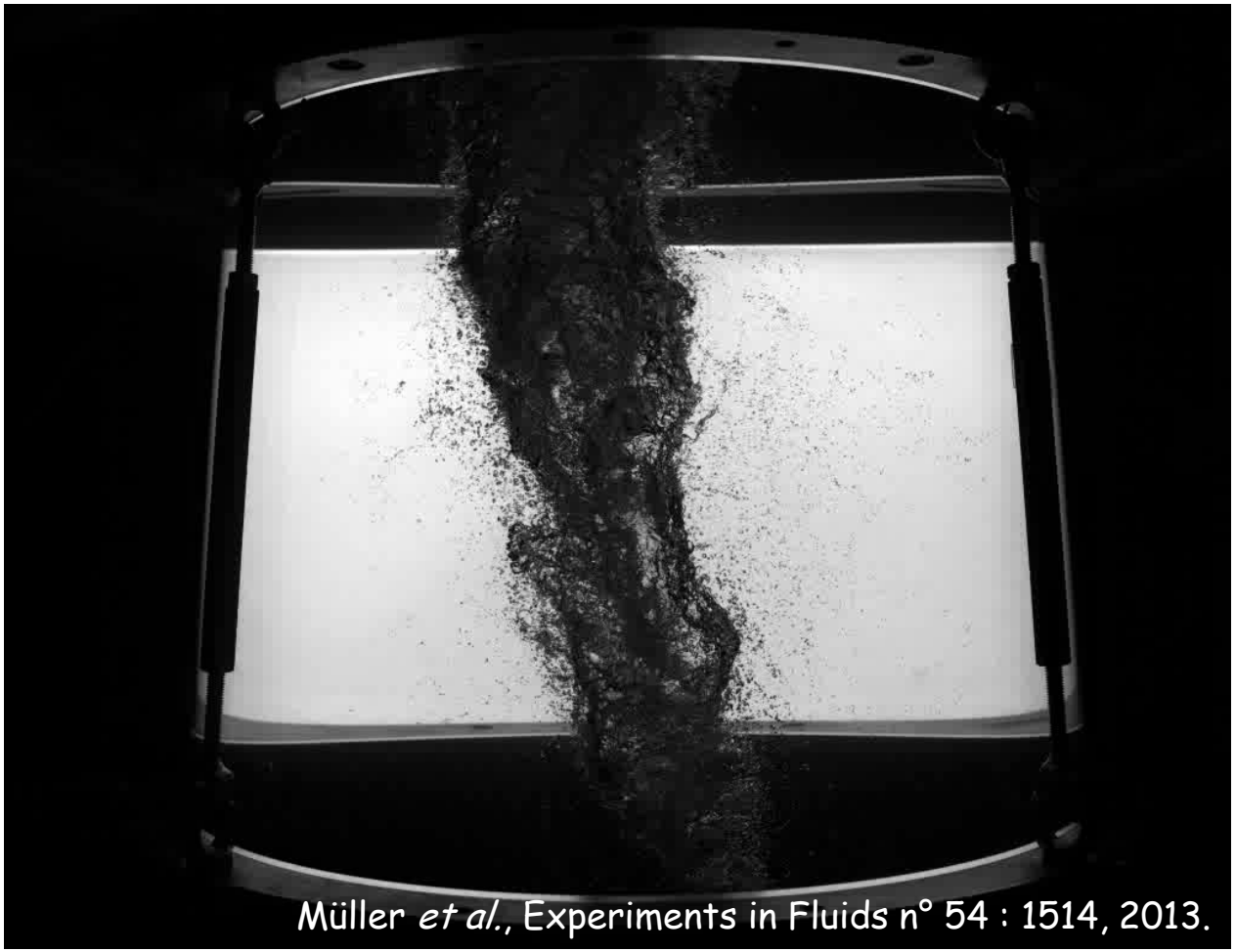

0
0.5
1
1.5
Q/Q_{BEP}
Part load resonance
Upper part load resonance
Full load instability

Unsteady Flow in Francis Draft Tube





Alligné *et al.*, Journal of Hydraulic Research, Vol. 51, 6, 2010.

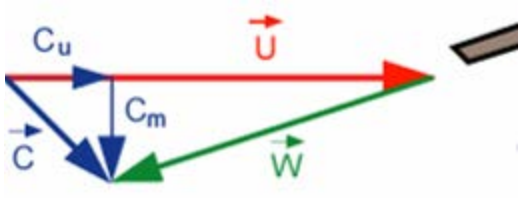


Müller *et al.*, Experiments in Fluids n° 54 : 1514, 2013.

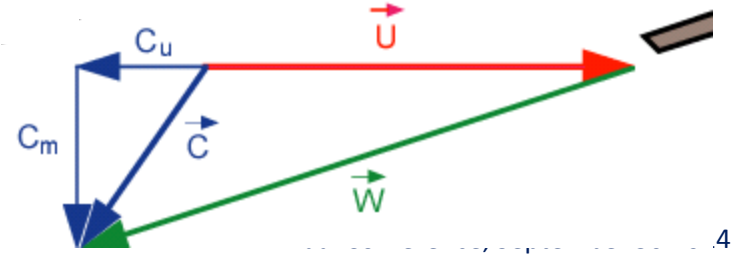
Simon Pasche PhD Work, SNF GRANT N° 200021_149818

Vortex Rope Development
Driving Parameters Discharge (Load) and σ

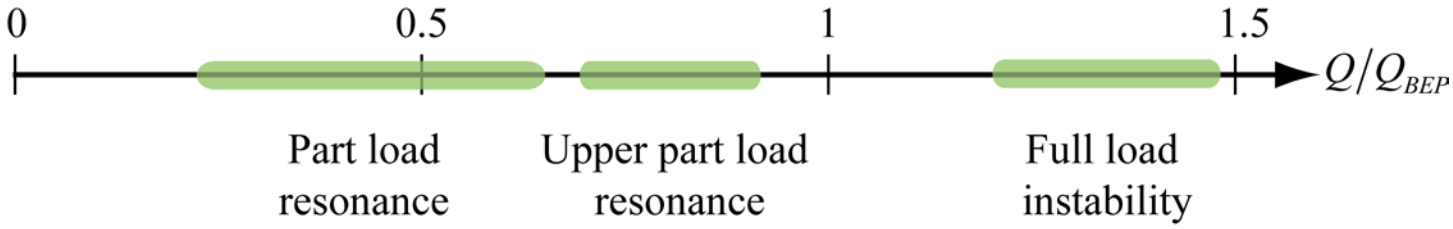
$Q < Q_{BEP}$

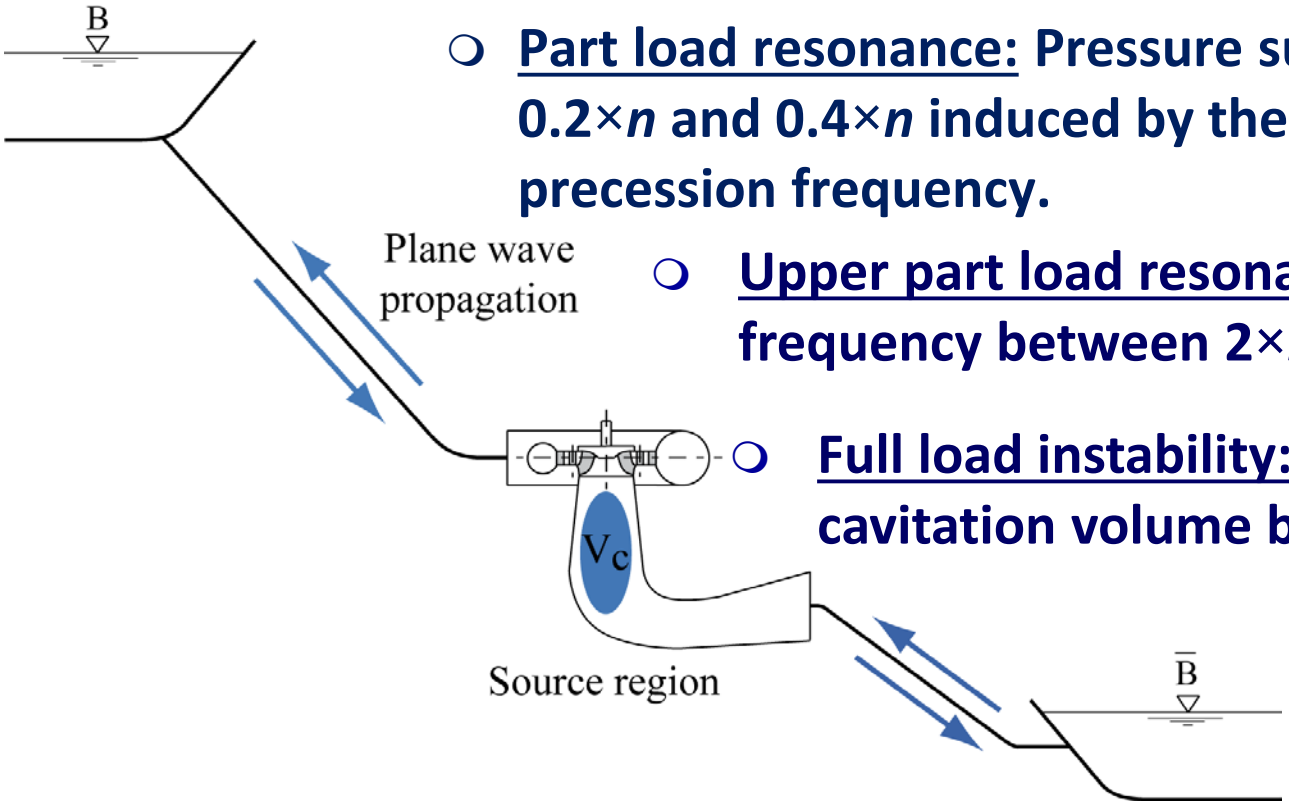


$Q > Q_{BEP}$



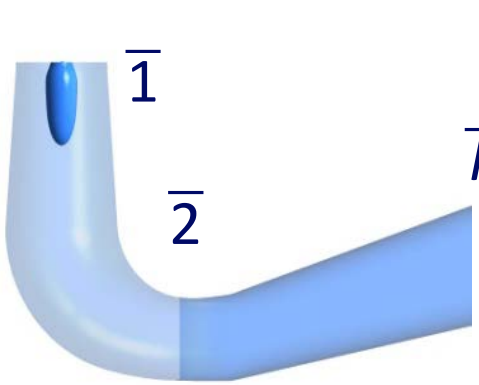
Pressure, Power Surges

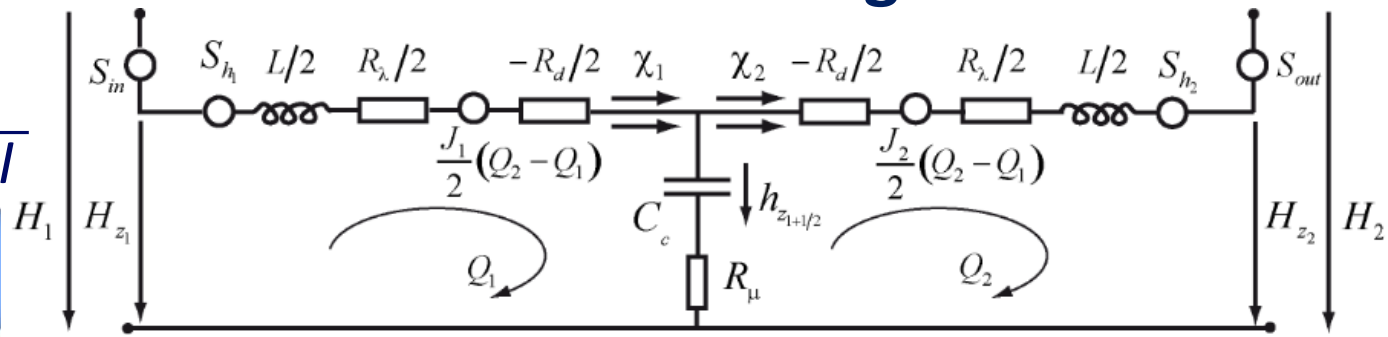




- **Part load resonance: Pressure surge frequency between 0.2×*n* and 0.4×*n* induced by the helical vortex rope precession frequency.**
- **Upper part load resonance: Pressure surge frequency between 2×*n* and 4×*n*.**
- **Full load instability: Axial pulsations of the cavitation volume between 0.2×*n* and 0.4×*n*.**

Cavitation Vortex Rope
1-D Transient Flow Modeling





ALLIGNE, S., NICOLET, C., TSUJIMOTO, Y., AVELLAN, F., Cavitation surge modelling in Francis turbine draft tube, Journal of Hydraulic Research, Volume 52, Issue 3, pp. 399-411, March 2014.

- **Compliance:** $C = \partial V_c / \partial H$
- **Mass Flow Gain Factor:** $\chi = \partial V_c / \partial Q$
- **Dissipation:** $R_{ve} = \dfrac{\mu_{equ}}{A \times \rho \times g \times dx}$

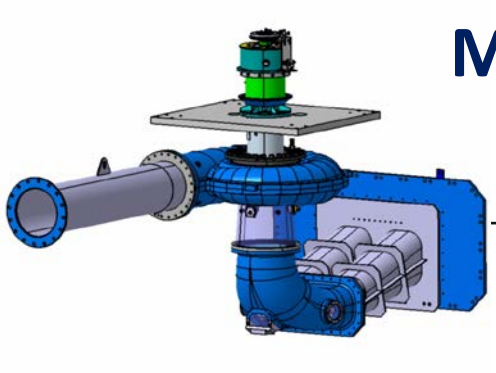
SIMSEN

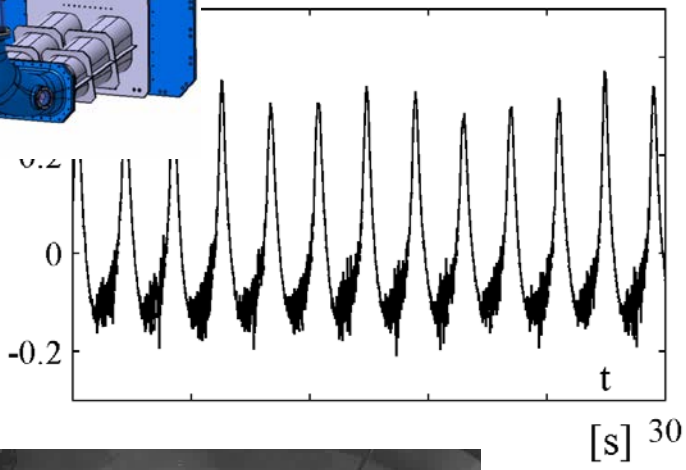
http://simsen.epfl.ch

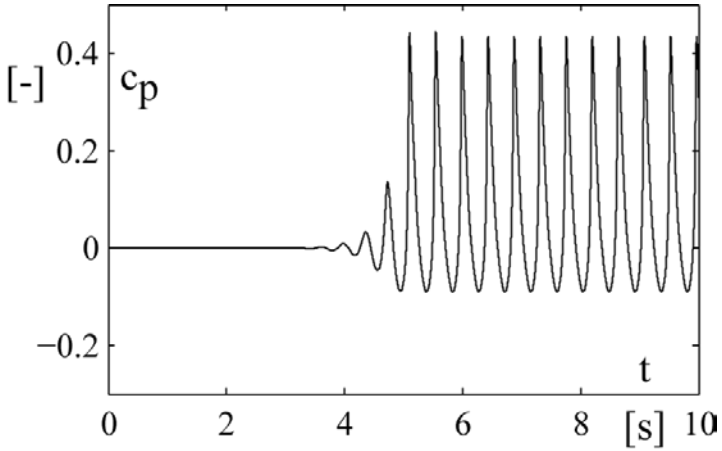
Full Load Operating Instability Field Tests

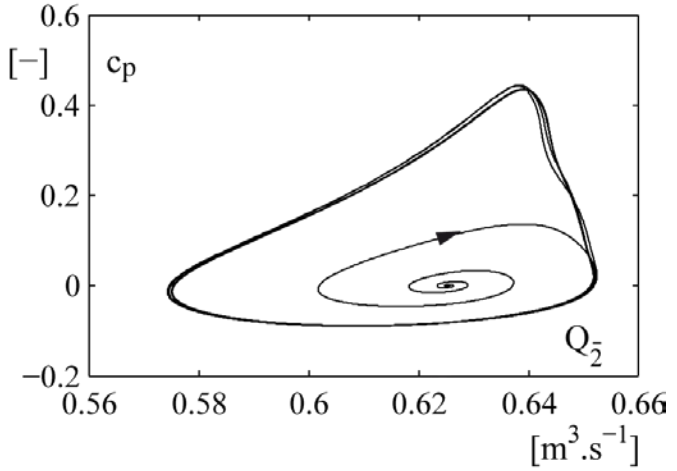
- **MICA Hydropower Station, Dam Spanning the Columbia River 135 km North of Revelstoke**

MICA Unit 2 Pressure Surge Simulation at Full Load









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FP7 Research Project
n° 608532 Sept. 2013 – Jan 2017

ALSTOM

ANDRITZ Hydro

VOITH

Power Vision Engineering

CDIF UPC
Center Industrial Diagnostics

Universität Stuttgart

INESCPORTO

Hes·so VALAIS WALLIS

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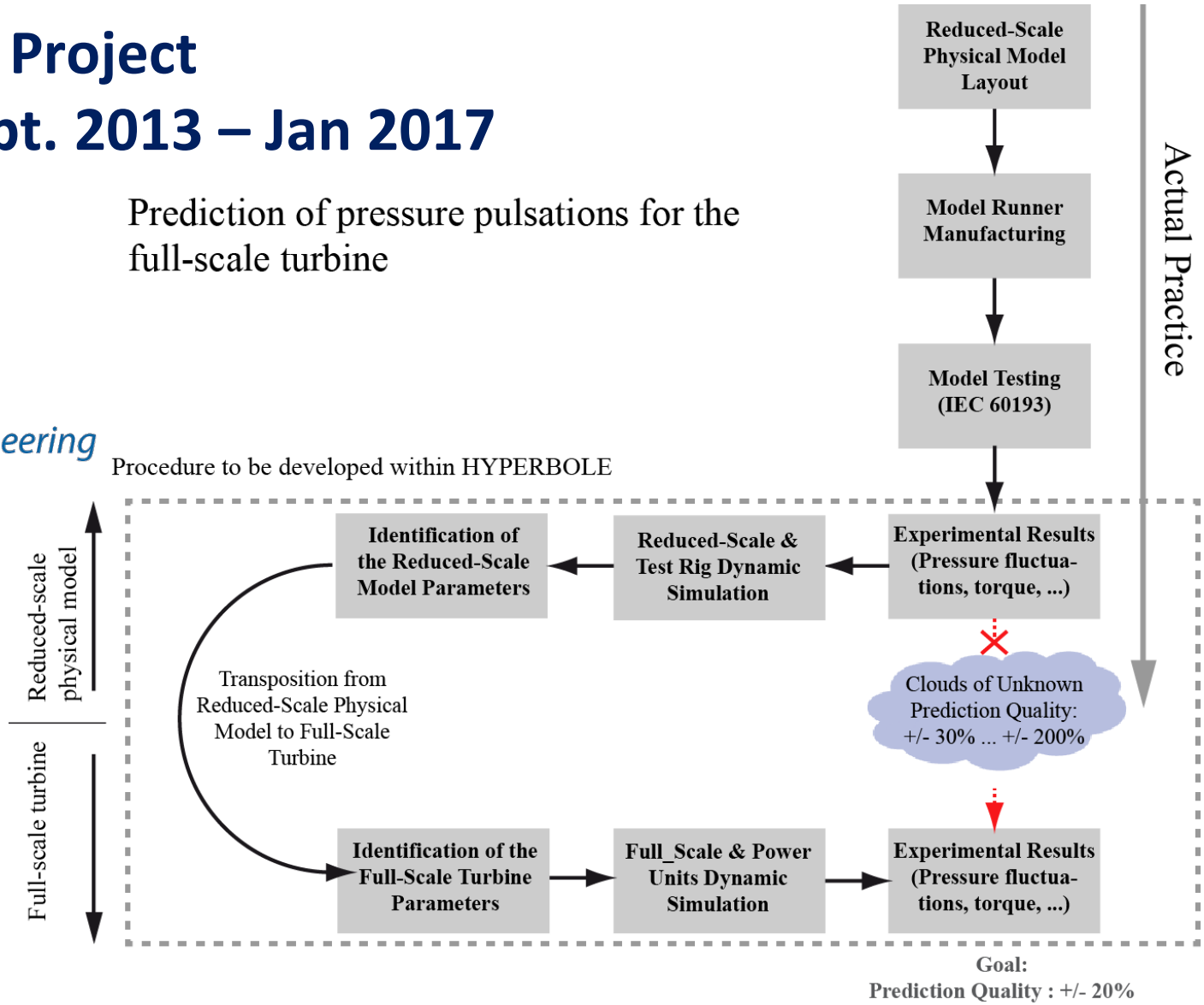
Prediction of pressure pulsations for the full-scale turbine



https://hyperbole.epfl.ch

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HYPERBOLE

HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies

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