HYPERBOLE

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

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https://hyperbole.epfl.ch/

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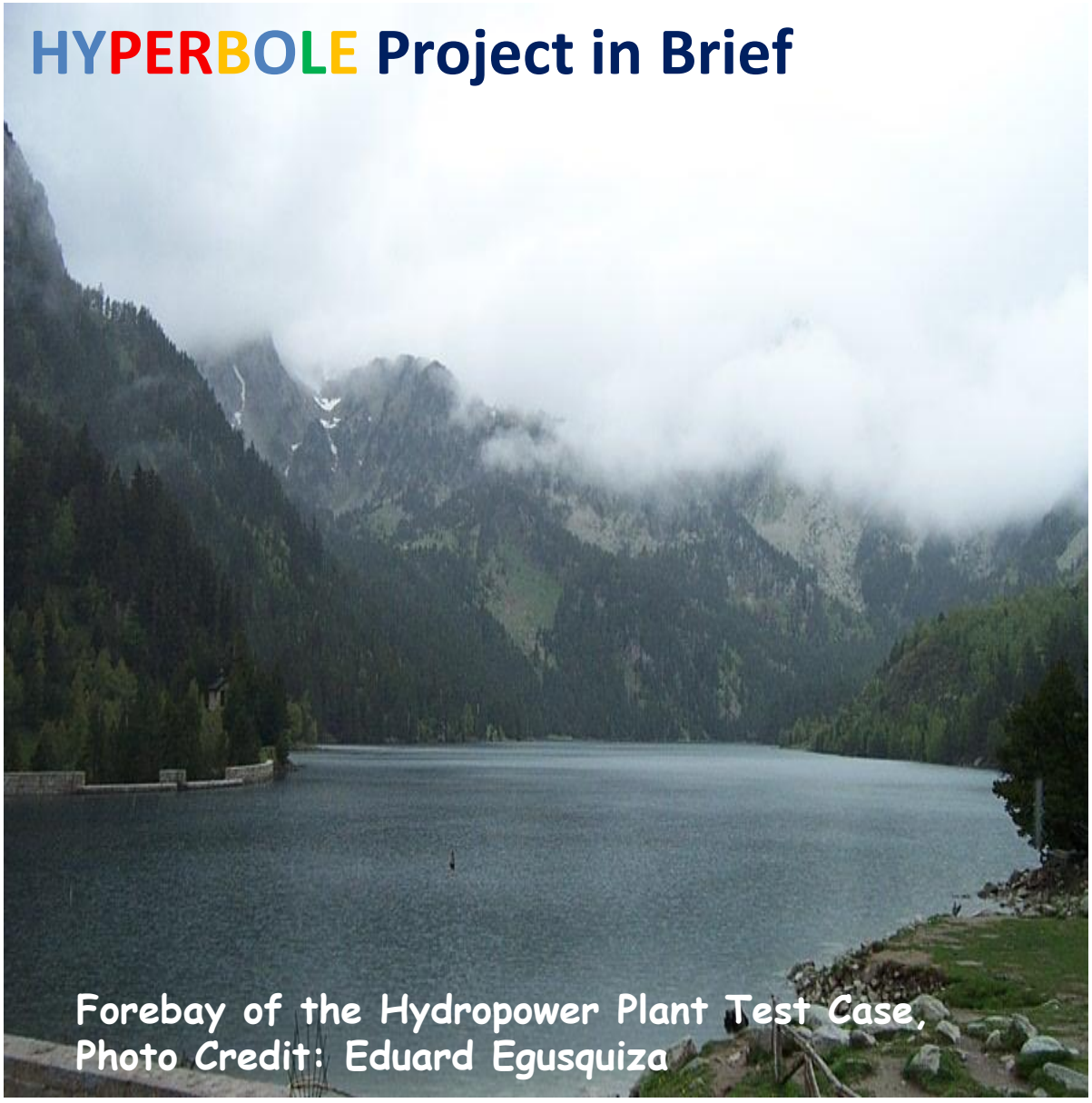
European Commission

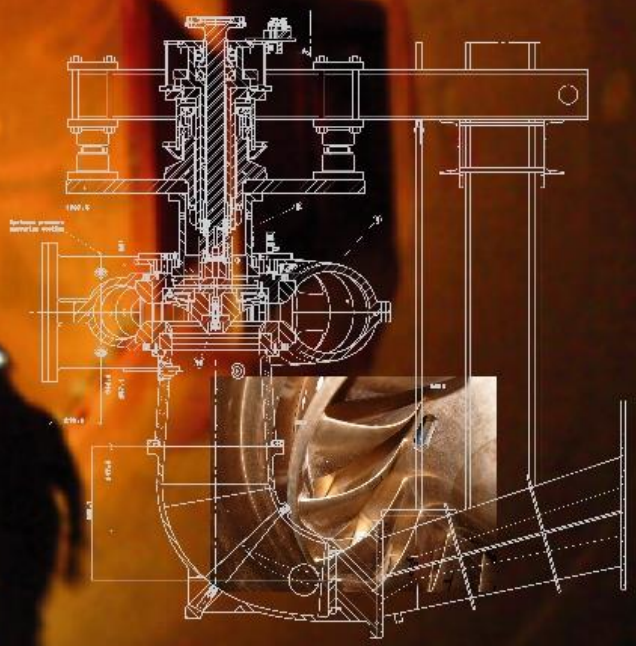
HYPERBOLE Project in Brief

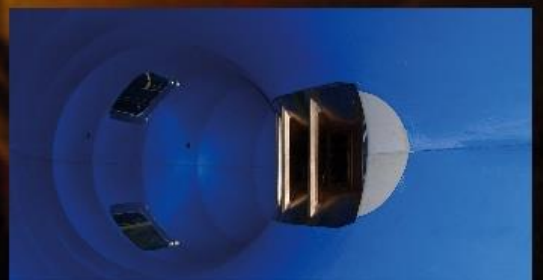
- Background
- Objectives
- Methodology
- Example:
  Francis Operation
  at Deep Part Load
- Outlook

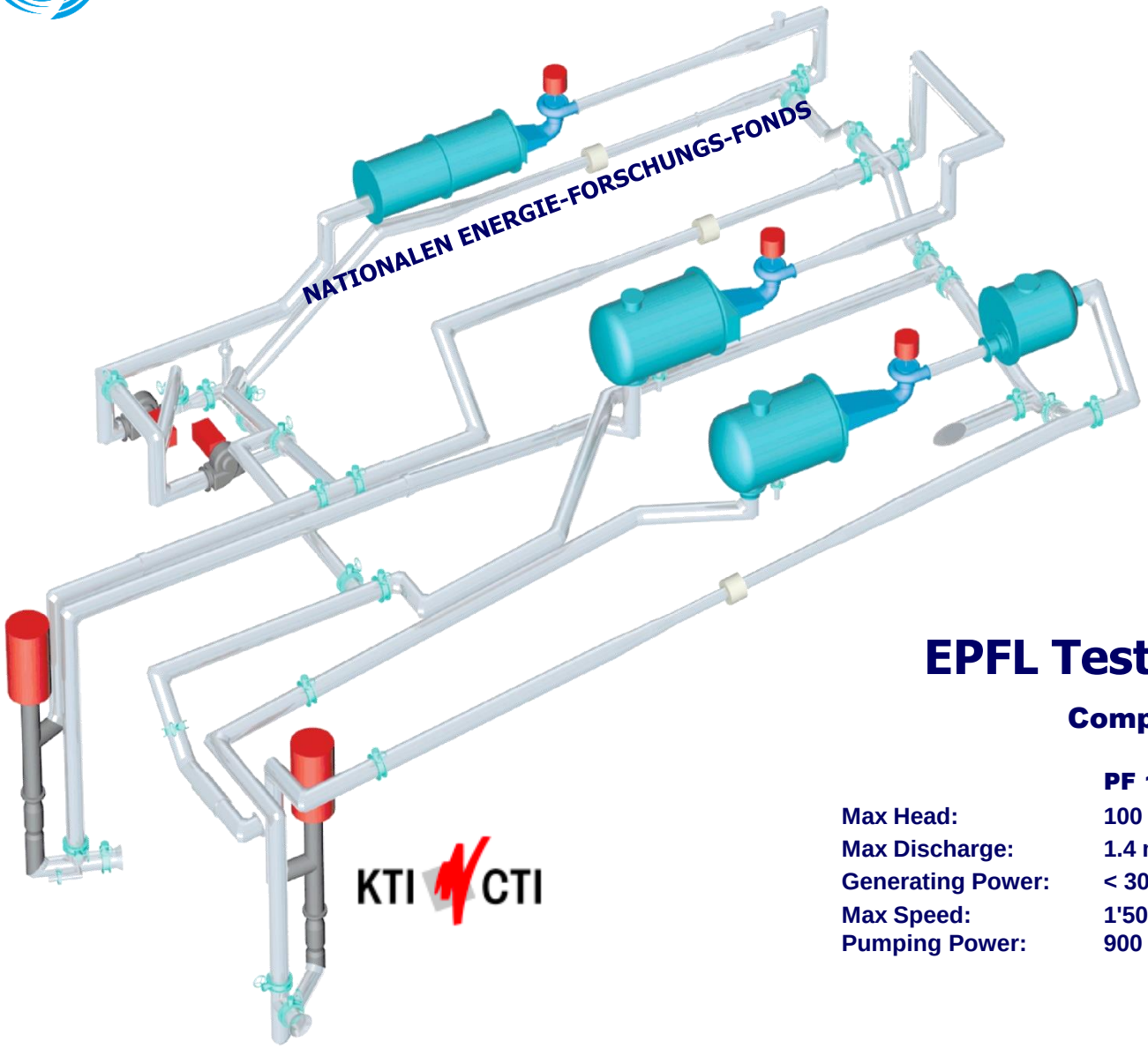

Forebay of the Hydropower Plant Test Case,
Photo Credit: Eduard Egusquiza

Reduced Scale Physical Model of Hydropower Plant Hydraulic Turbines or Pump-Turbines

- Field Survey
- Reduced Scale Model Engineering and Construction
- Base Line Tests
- New Design Assessment
  - ✓ Operating Range
  - ✓ Efficiency
  - ✓ Cavitation
  - ✓ p- fluctuations
  - ✓ Runaway speed
  - ✓ etc.







Experimental Infrastructure

- Research
- Education
- Experimental Validation

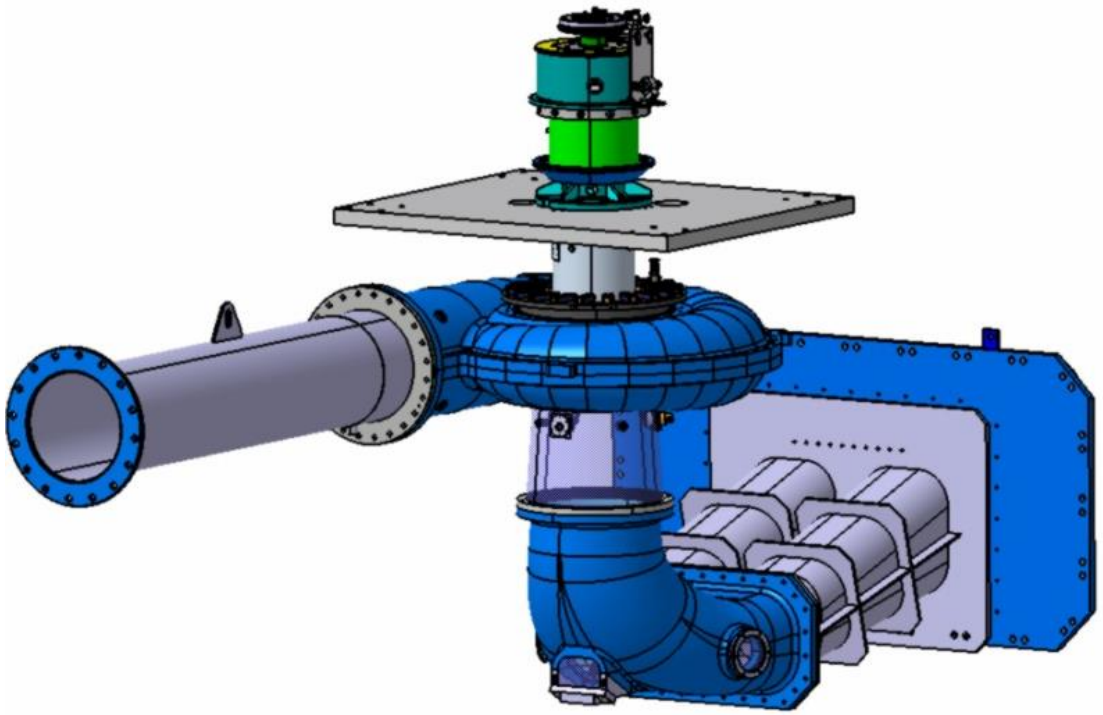
EPFL Testing Facilities

Complying IEC 60193 Standards
Efficiency Uncertainty <2 ‰

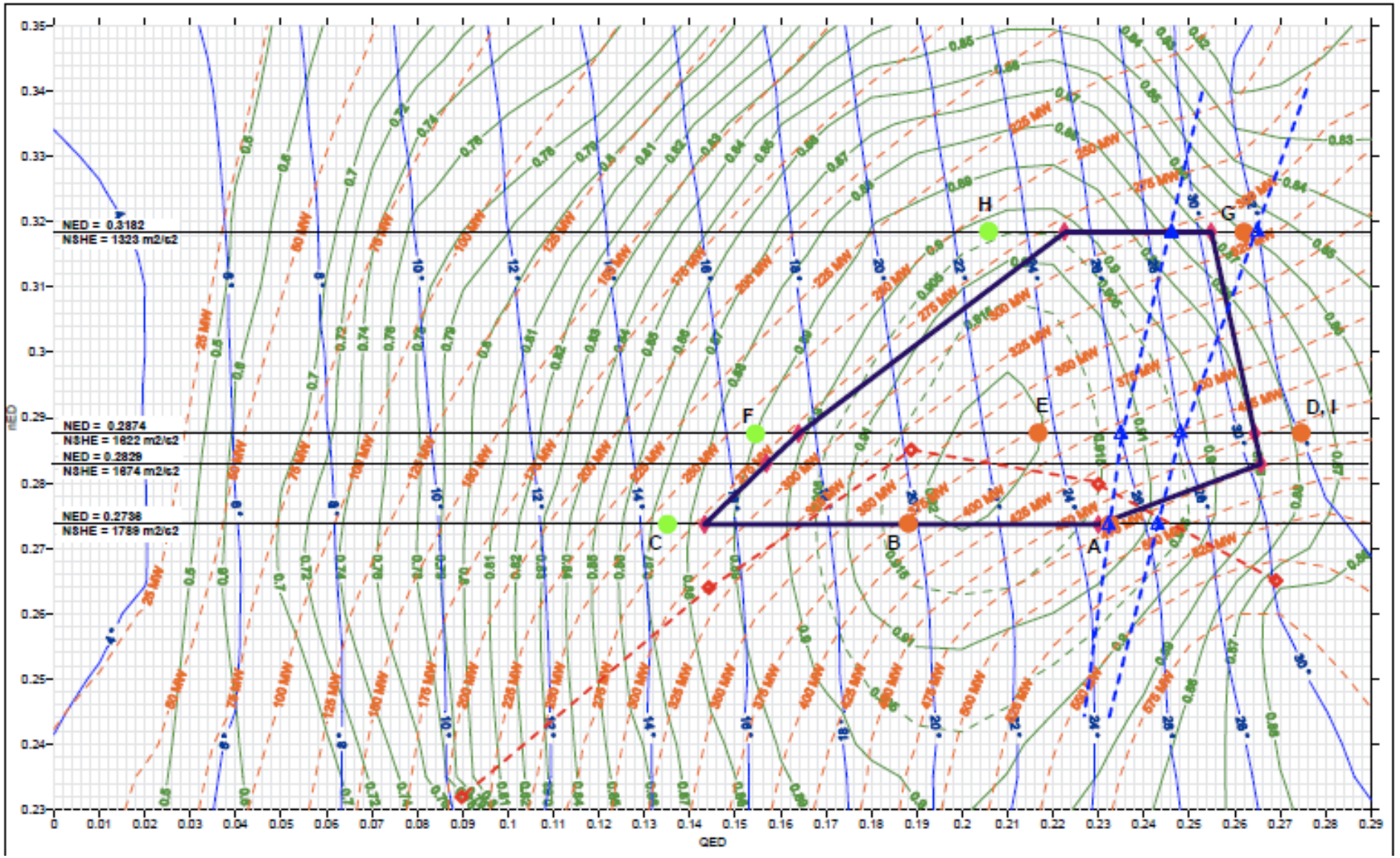
	PF 1	PF 2	PF 3
Max Head:	100 mCE	120 mCE	100 mCE
Max Discharge:	1.4 m^3/s	1.4 m^3/s	1.4 m^3/s
Generating Power:	< 300 kW	< 300 kW	< 300 kW
Max Speed:	1'500 rpm	2'500 rpm	2'500 rpm
Pumping Power:	900 kW	1000 kW	2 x 400 kW

IEC Model Tests

- E-Q Hill-Chart
- Efficiency
- Cavitation
- p-Fluctuations
- Runaway Speed
- Axial Thrust
- Guide Vanes Torque
- Etc.

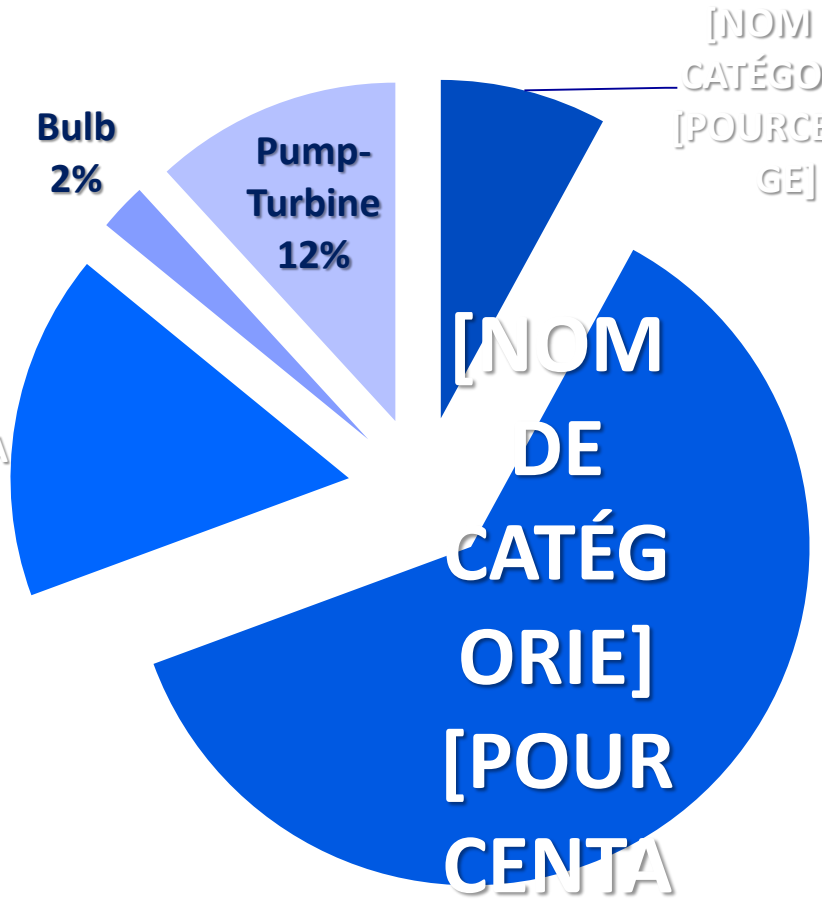


- Reduced Scale Physical Model

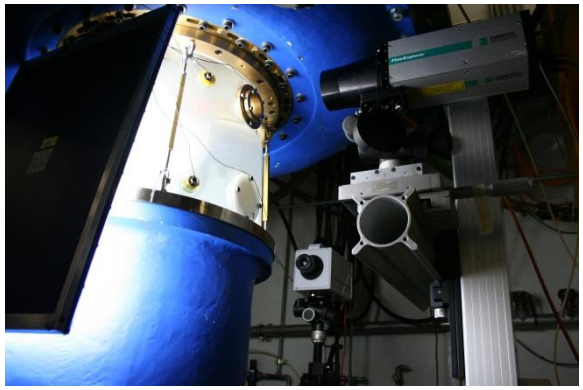

NED = 0.3182
NSHE = 1323 m2/s2
NED = 0.2874
NSHE = 1822 m2/s2
NED = 0.2826
NSHE = 1874 m2/s2
NED = 0.2736
NSHE = 1789 m2/s2
A
B
C
D, I
E
F
G
H
QED
NED

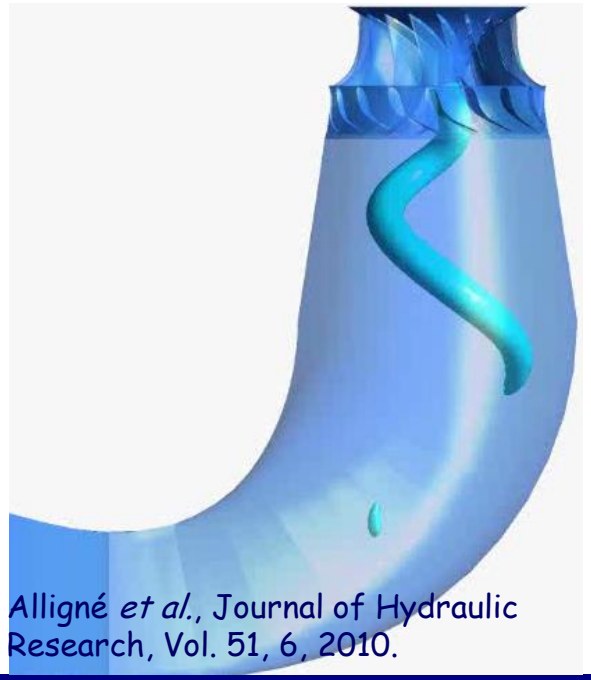
Hydro Turbines International Market

- 1’000 GW to be installed before 2050 Greenfield Projects
- 1’111 GW Installed Capacity in 2013 Modernization Market
- 17% of the World electricity
- 12% of the European generation

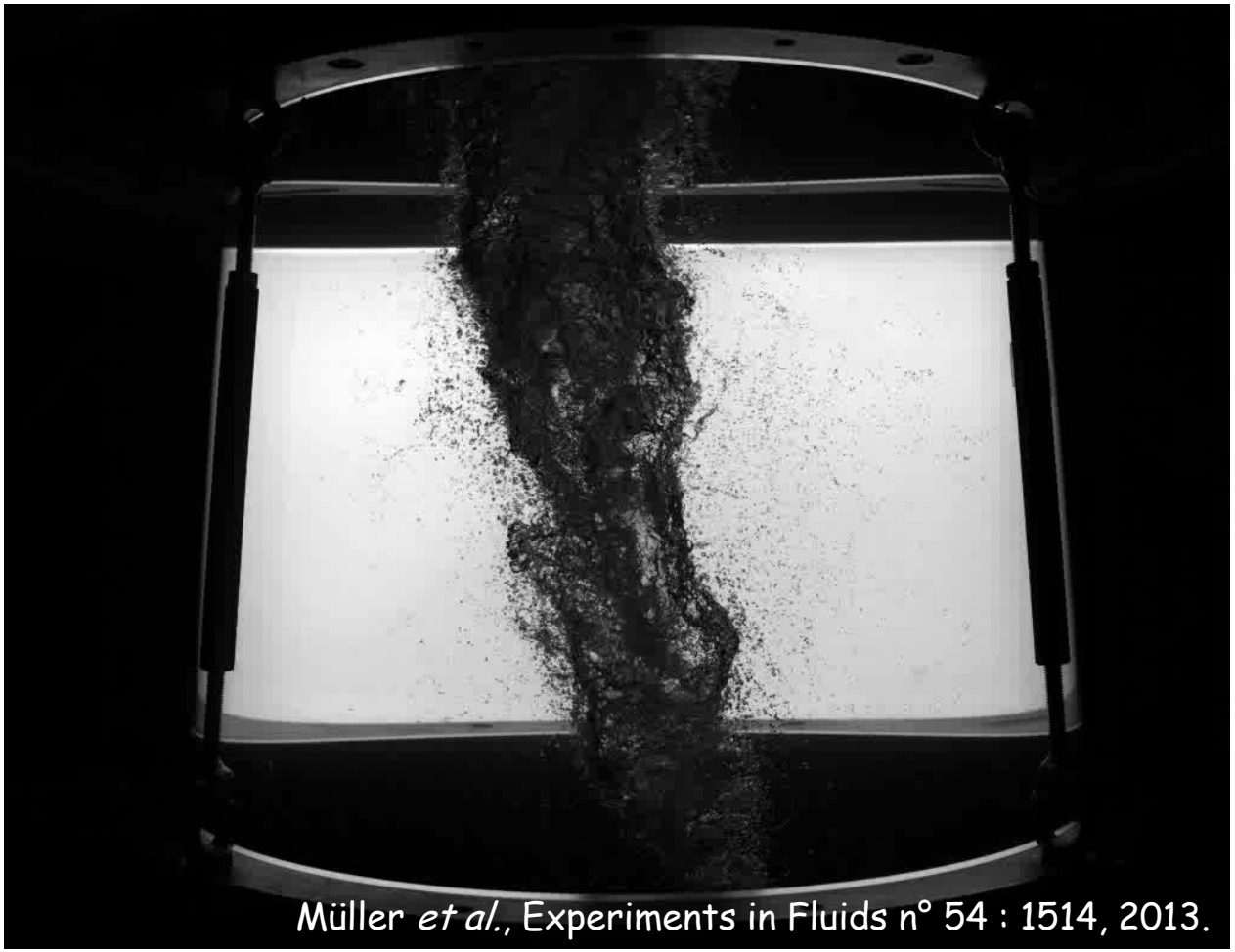


Unsteady Flow in Francis Draft Tube





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

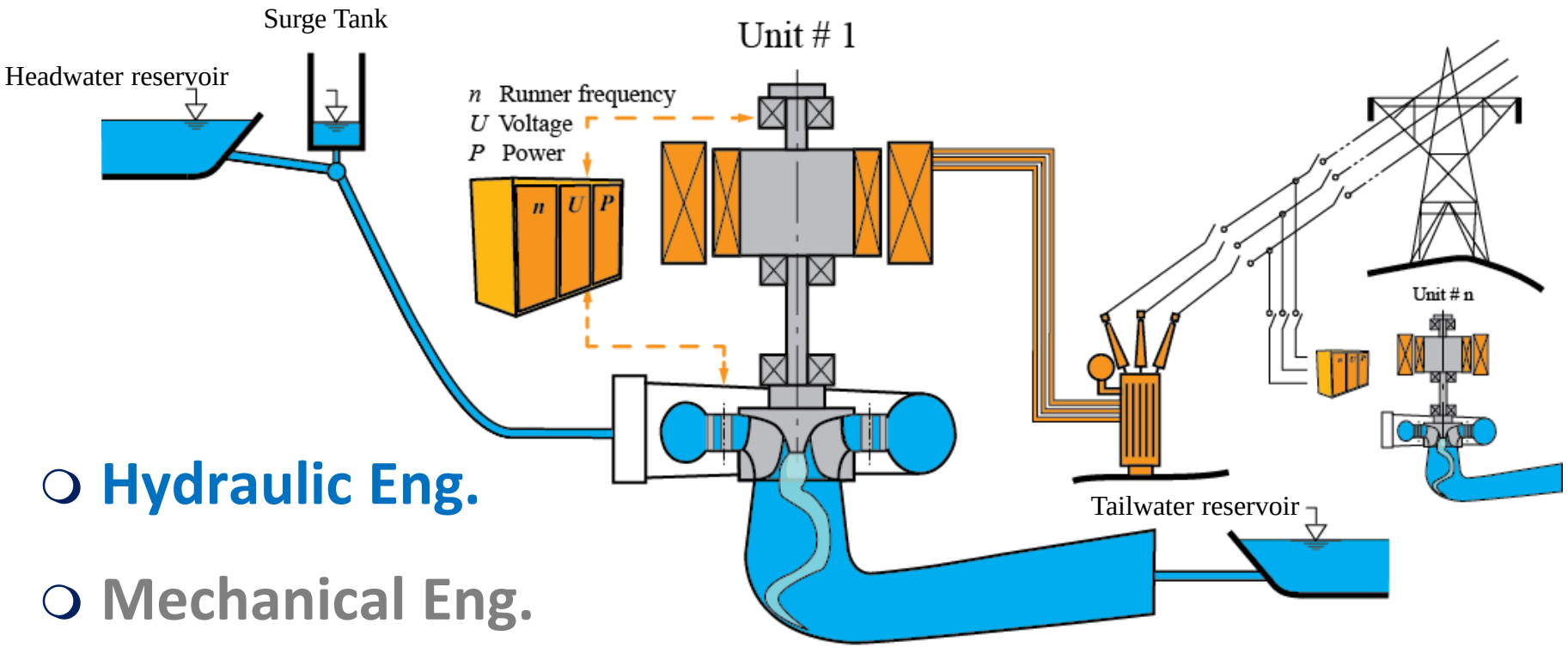
HYPERBOLE

ERC/FP7-ENERGY-2013-1-Grant N° 608532

- HYdropower plants PERformance and flexiBle Operation"towards Lean integration of new renewable Energies
  - ✓ Dynamic Assessment of Francis Turbines & Pump-Turbines
  - ✓ 42 Months, EUR 6.3 Mio
  - ✓ EUR 4.3 Mio Supported by European Commission
  - ✓ 1st Sept. 2013 ÷ 28th Feb. 2017
- Consortium coordinated by EPFL

Center Industrial Diagnostics

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



- Hydraulic Eng.
- Mechanical Eng.
- Electrical Eng.
- System Approach

HYPERBOLE

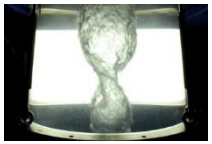
ERC/FP7-ENERGY-2013-1-Grant 608532

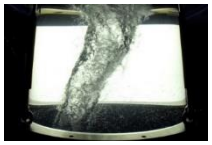
HYPERBOLE Objectives

- Understanding the root causes of the operating range limitations (WP1, WP2, WP3)
  - ✓ Reduced Scale Physical Model Testing
  - ✓ Flow and Structure Numerical Simulations
  - ✓ 430 MW Francis Turbine Case Study
  - ✓ 220 MW Pump-Turbine Case Study
- Modeling and simulation of the hydropower plants dynamics over the full range of operation (WP4, WP5)
  - ✓ Transient Simulation
  - ✓ Hydro-acoustic Parameters
  - ✓ Francis Turbine Extensive Monitoring and Field Tests
- Enabling NRE(s) development (WP6)
  - ✓ Portugese Transmission System Case Study
  - ✓ Impact of Pumped Storage Plant

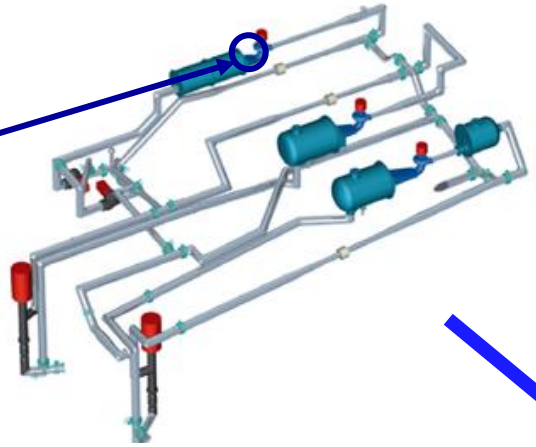
Generating Unit Dynamics

Flow Instabilities in the Draft Tube



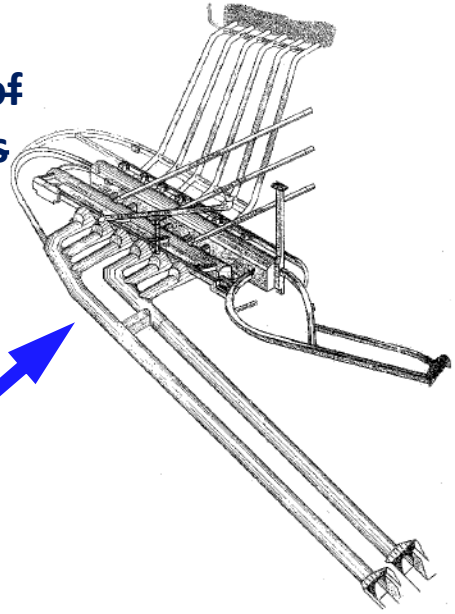


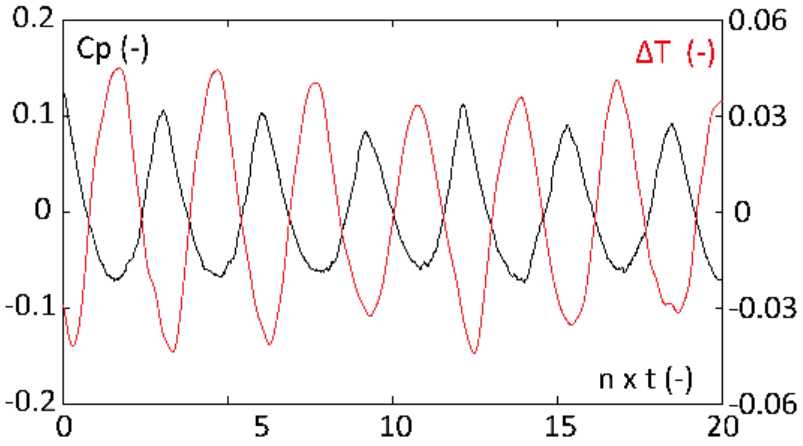
Reduced Scale Physical Model



~~**Direct transposition of pressure fluctuations**~~

Hydropower Plant





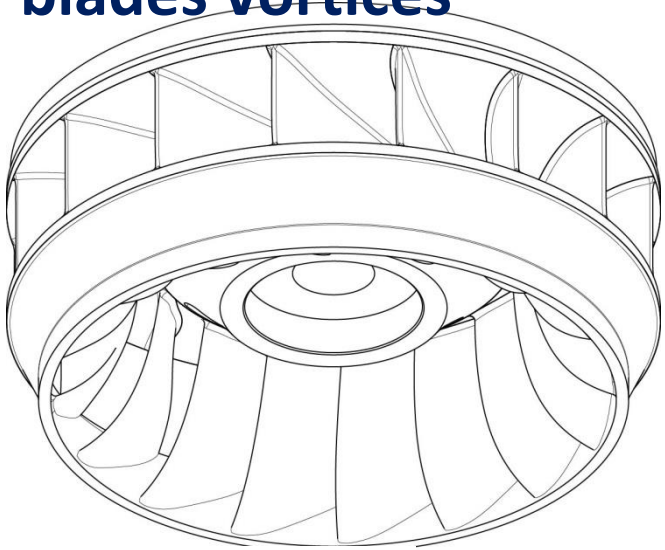
1D simulation model

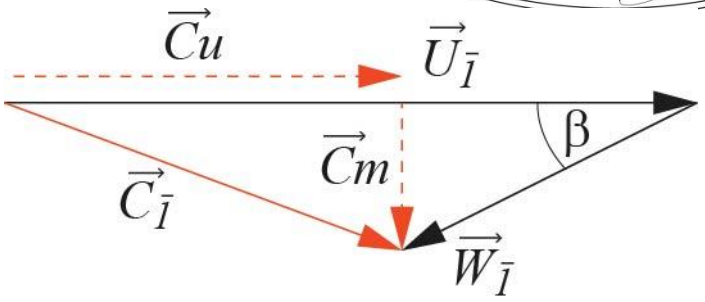
SIMSEN

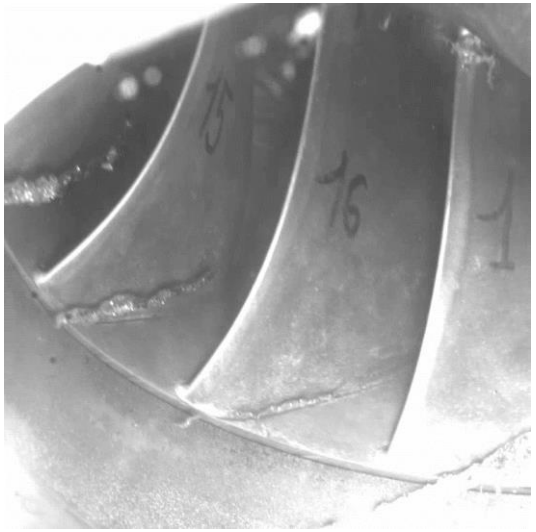
HYPERBOLE Deep part load operating conditions Q << QBEP

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

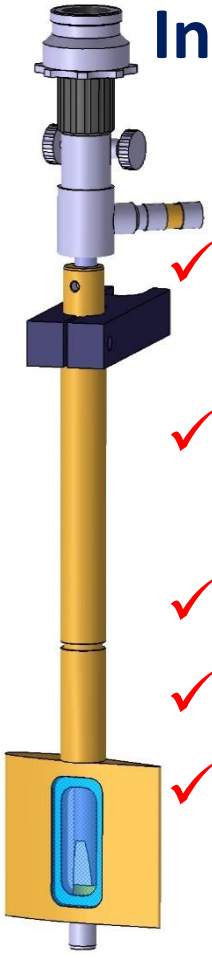
- Inter blades vortices





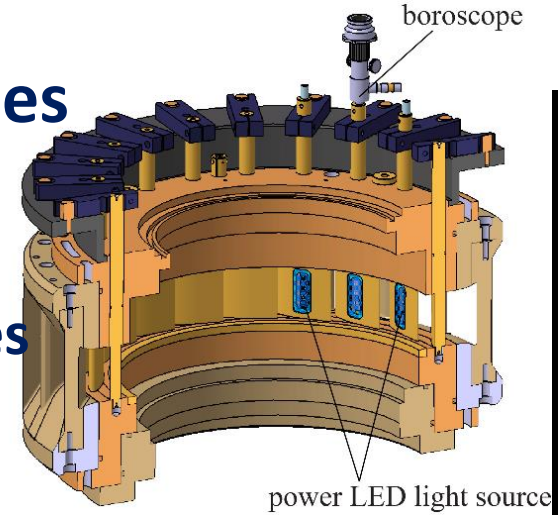


Deep part load
Inter blades vortices

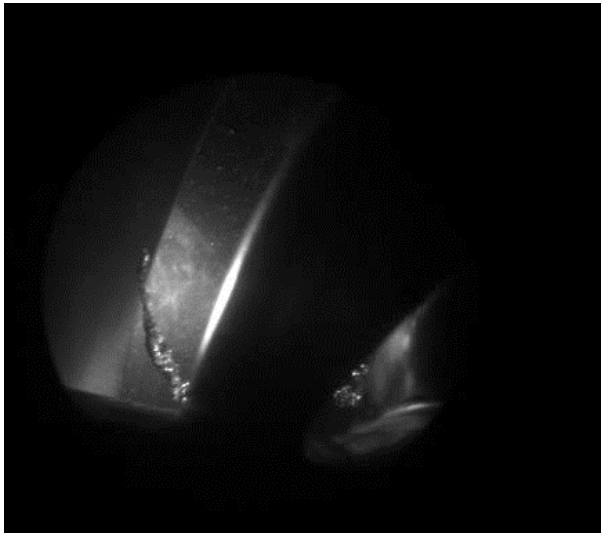


Visualization

- ✓ Hollow guide vanes with window
- ✓ Boroscope with swiveling prism
- ✓ High Speed Camera
- ✓ High intensity Xenon flash
- ✓ Compact power LED



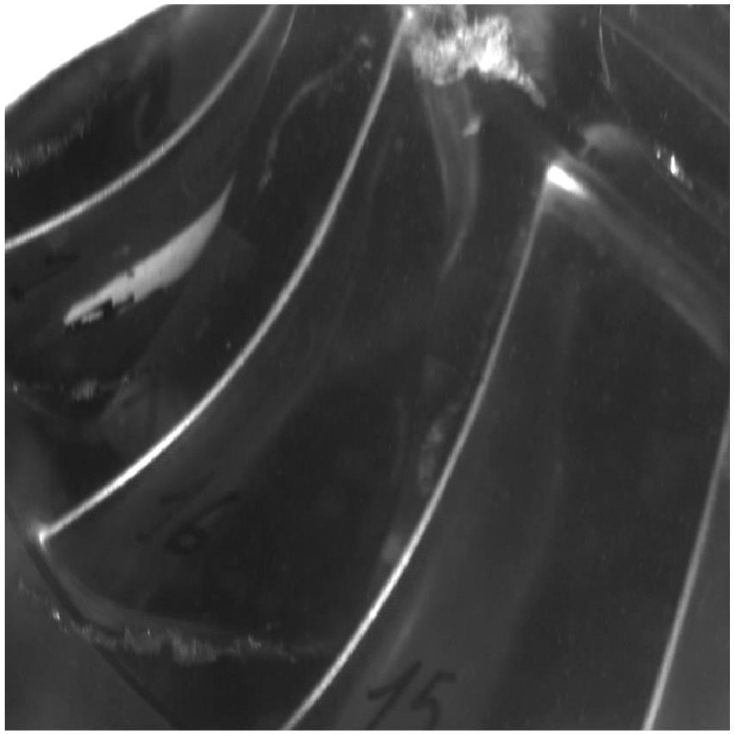
HYPERBOLE

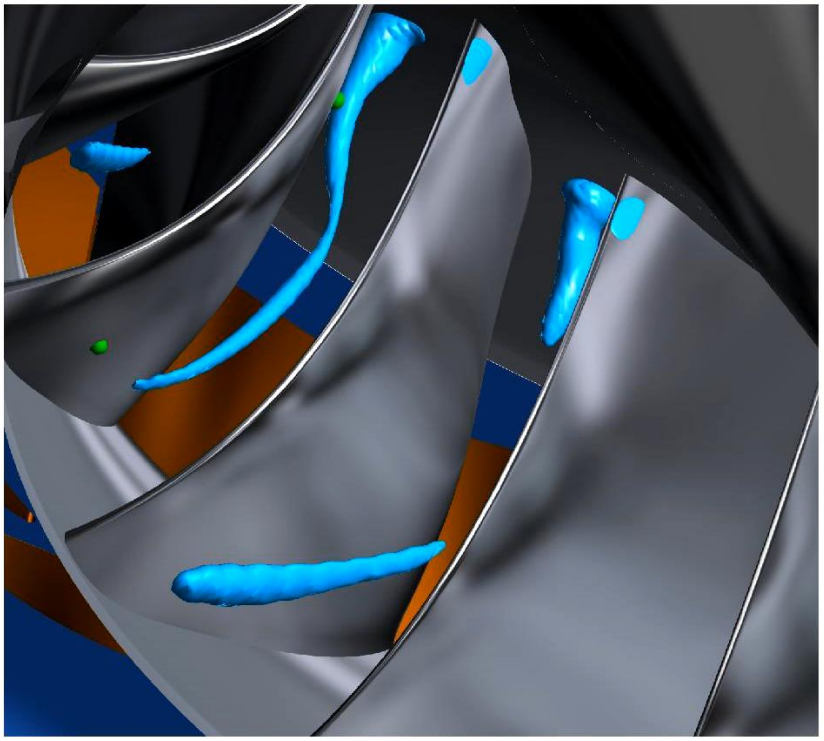


HYPERBOLE

Deep part load
Inter blades vortices

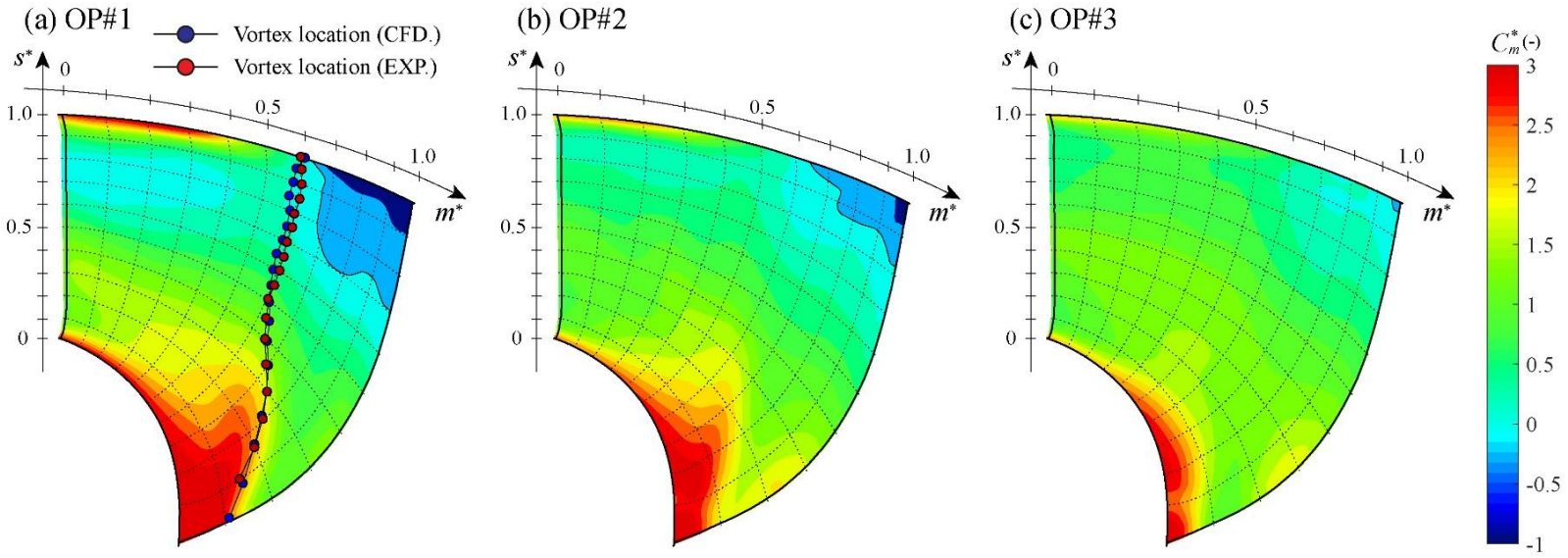
- Flow Numerical Simulations





✓ Void Fraction 10% Isosurface

Inter-blade cavitation vortices at deep part load



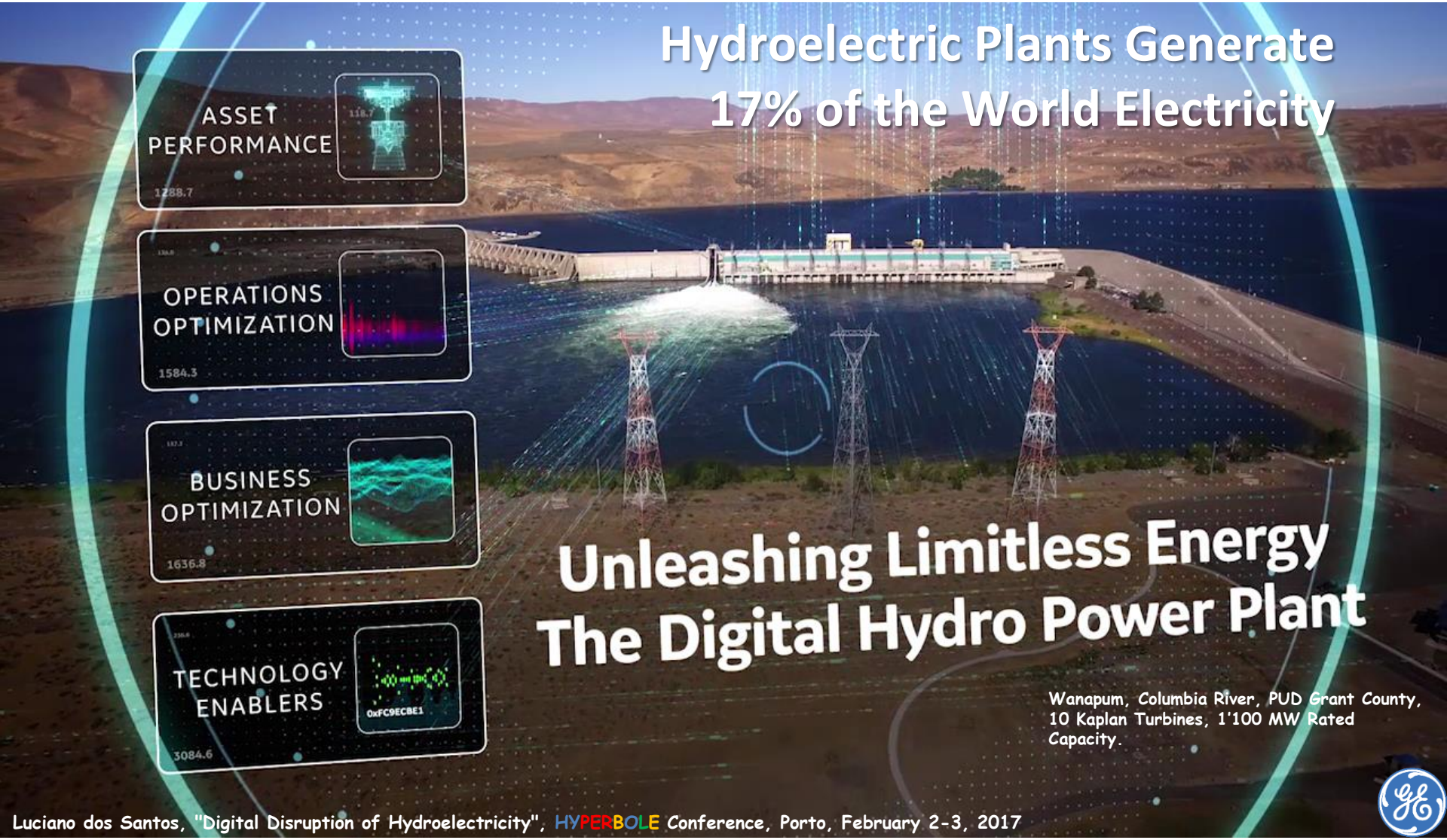
- Average meridional velocity on the meridional plane (runner blade)
- Backflow region at the hub linked with inter-blade vortex development

Yamamoto et al. (2017), ""Experimental evidence of inter-blade cavitation vortex development in Francis turbines at deep part load condition". Experiments in Fluid, Under review.

Yamamoto K., (2017), "*Hydrodynamics of Francis turbine operation at deep part load condition*", EPFL Doctoral Thesis

Outlook

- Unprecedented set of experimental and numerical simulation results
- Digital Avatar of Generating Unit Dynamics
- Enhanced Condition of Operation
- Advanced Maintenance



Hydroelectric Plants Generate 17% of the World Electricity

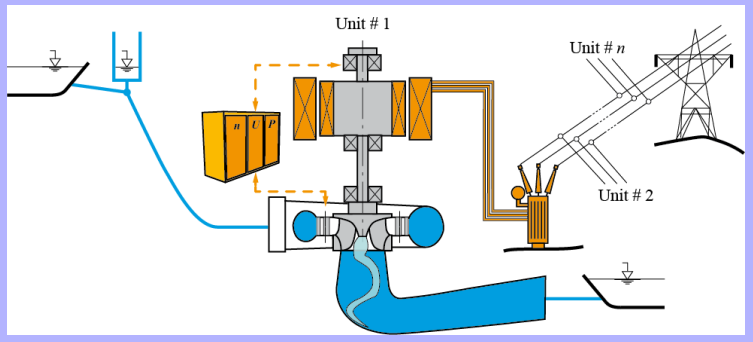
Unleashing Limitless Energy
The Digital Hydro Power Plant

Wanapum, Columbia River, PUD Grant County, 10 Kaplan Turbines, 1'100 MW Rated Capacity.

HPP Operating Conditions: Z_{up}, Z_{down}, P_{set1}, P_{set2}, etc.

Off-Line Simulations for Specific Scenarios and Conditions

Actual Hydropower Plant



Real-Time Condition Monitoring

Comparison, Upgrading

Reaction to Abnormal Operation

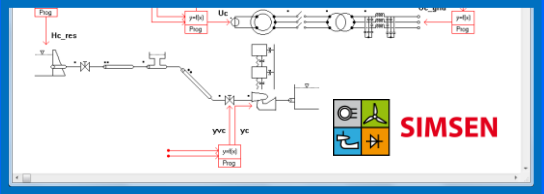
Lifetime Prediction, Failure Forecast

Management Recommendations, Maintenance

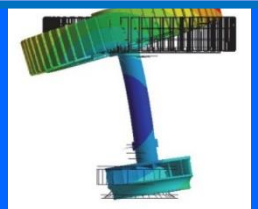
Calculated Parameters

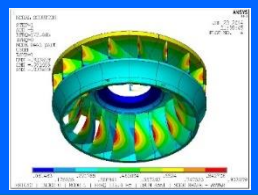
Digital Hydropower Plant Dynamics Avatar

1D Hydroelectric System Simulation

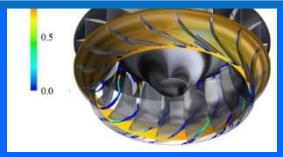


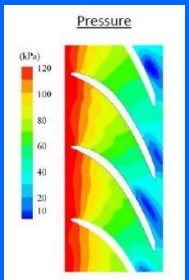
Dynamics FEA + Rotor





3D Computational Fluid Dynamics





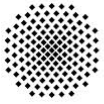
HYDROVOLUTION Research Proposal:
Digital Avatar of Hydropower Plant Dynamics for Enabling Enhanced Services to the European Grid

Conclusions

- Opportunity to run HYPERBOLE Research Project
- 450 MW Turbines as a Test Case
  - ✓ Reduced Scale Physical Model for Turbines of Hydropower Plant
  - ✓ Access to Prototype for experimental investigations (monitoring and on-board instrumentations)
- Unprecedented set of experimental and numerical simulation results
- Digital Avatar of Generating Dynamics

THANK YOU FOR YOUR ATTENTION




Special thanks to the Partners of the HYPERBOLE Consortium

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Model Testing by the Numbers @ EPFL

- Since 10 Years …..
  - ✓ 80'000 MW Installed Capacity
  - ✓ 85 Hydropower Projects for 23 Countries
  - ✓ 19'594 MW in PR China
  - ✓ 19'316 MW in Brazil
  - ✓ 16'205 MW in Canada
  - ✓ 19 Reduced Scale Physical Models