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SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Modernization of Hydropower plants

Prof. François Avellan, Eng. Dr.

September 12, 2016

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
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Swiss Confederation

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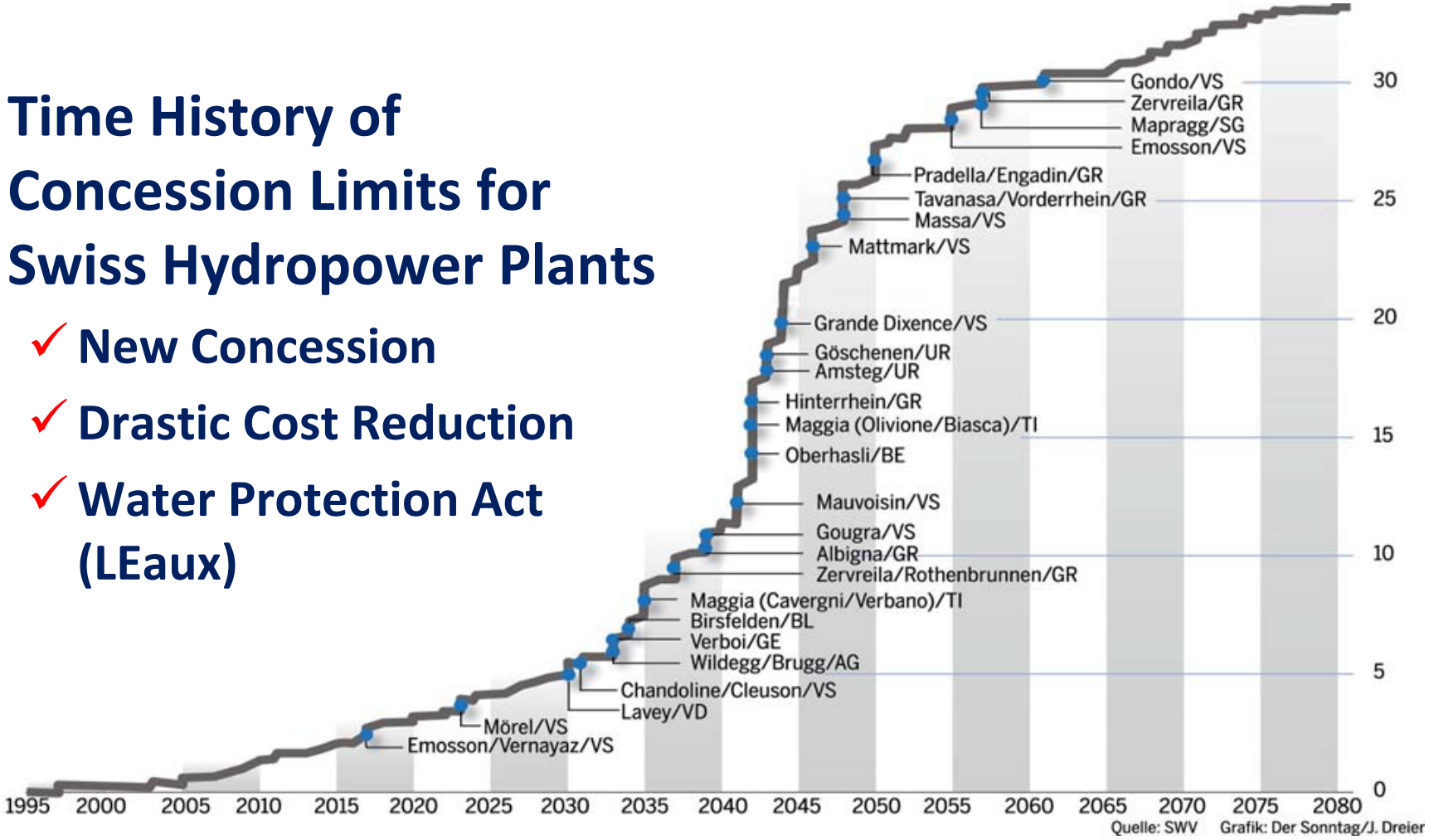
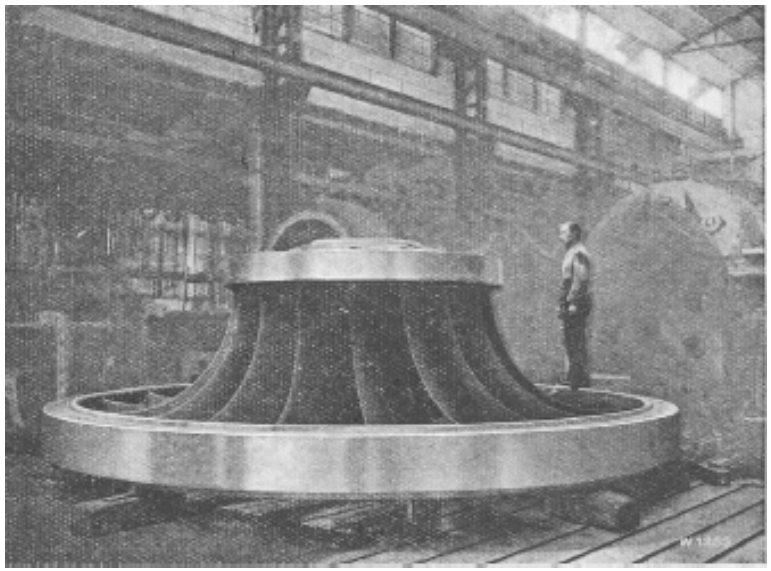
Reasons for Modernization

- Time History of Concession Limits for Swiss Hydropower Plants
  - ✓ New Concession
  - ✓ Drastic Cost Reduction
  - ✓ Water Protection Act (LEaux)



Reasons for Modernization

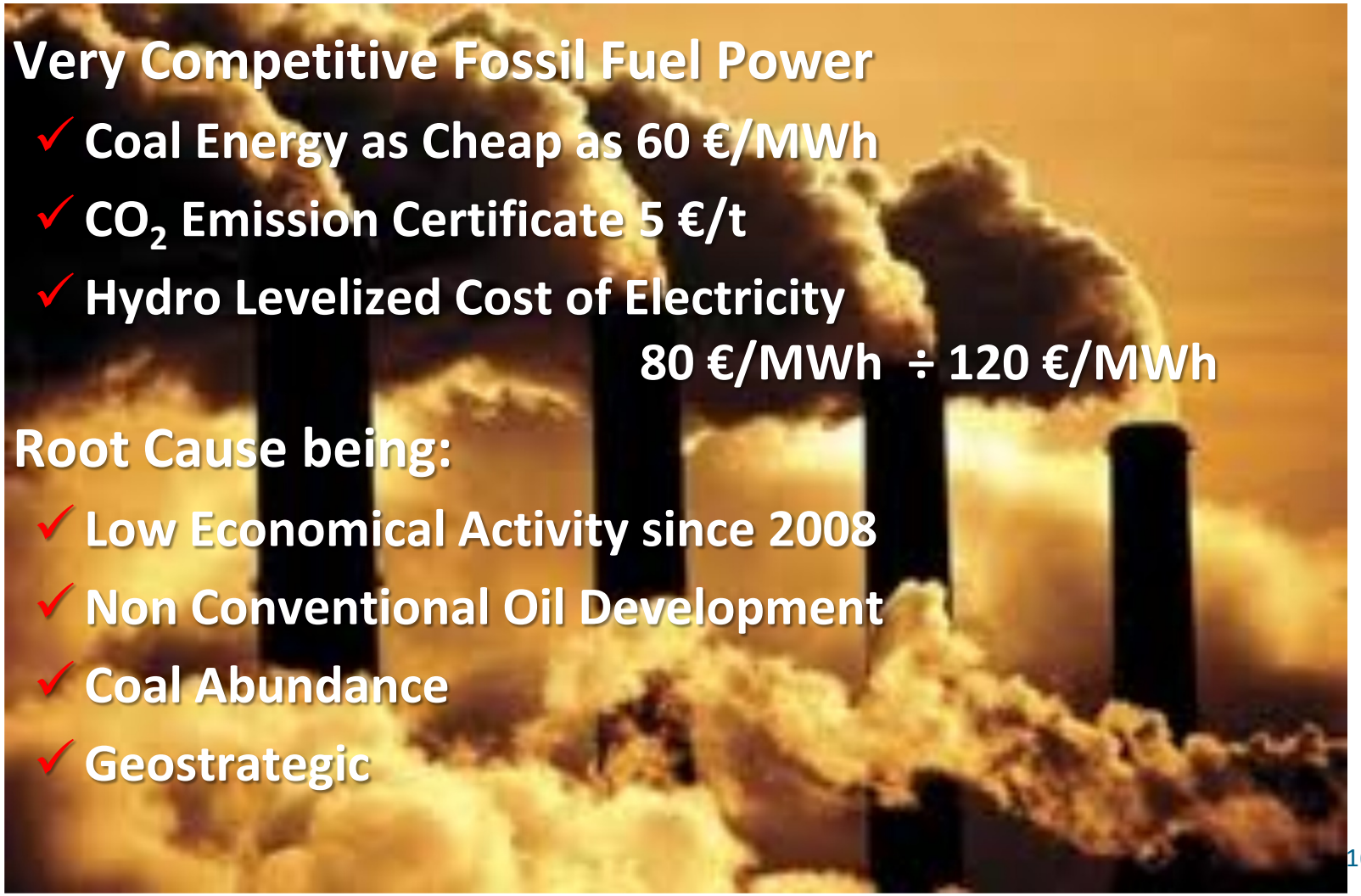
- **Technology Obsolescence**



Roue Escher Wyss de Chancy Pougny (GE)
Bulletin technique de la Suisse romande (1924)

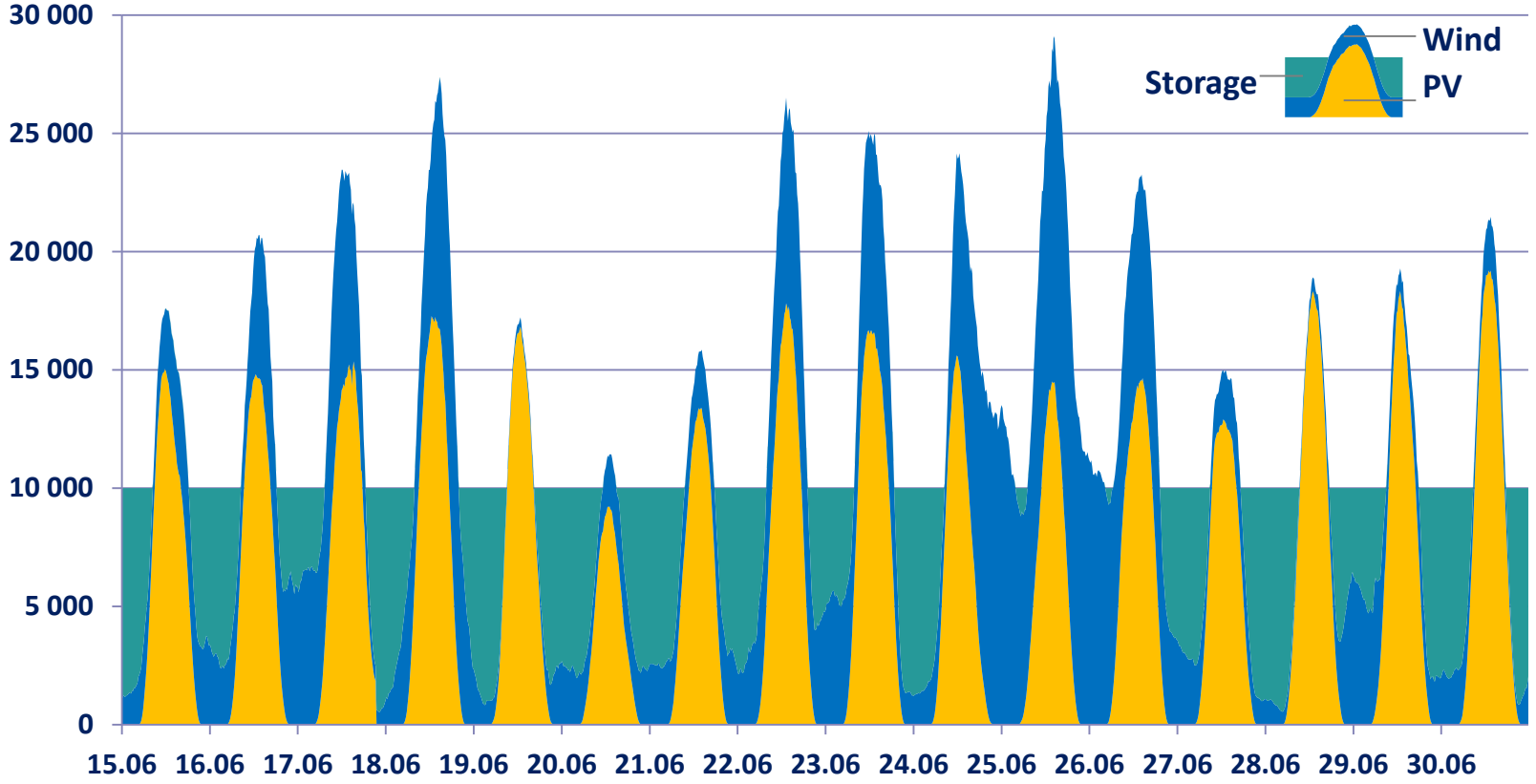
New Kaplan Unit ANDRITZ Hydro de Chancy Pougny
HYDRO News n°17 , May 2010

Reasons for Modernization
New Power Generation Paradigm



- Very Competitive Fossil Fuel Power
  - ✓ Coal Energy as Cheap as 60 €/MWh
  - ✓ CO_2 Emission Certificate 5 €/t
  - ✓ Hydro Levelized Cost of Electricity
    80 €/MWh ÷ 120 €/MWh
- Root Cause being:
  - ✓ Low Economical Activity since 2008
  - ✓ Non Conventional Oil Development
  - ✓ Coal Abundance
  - ✓ Geostrategic

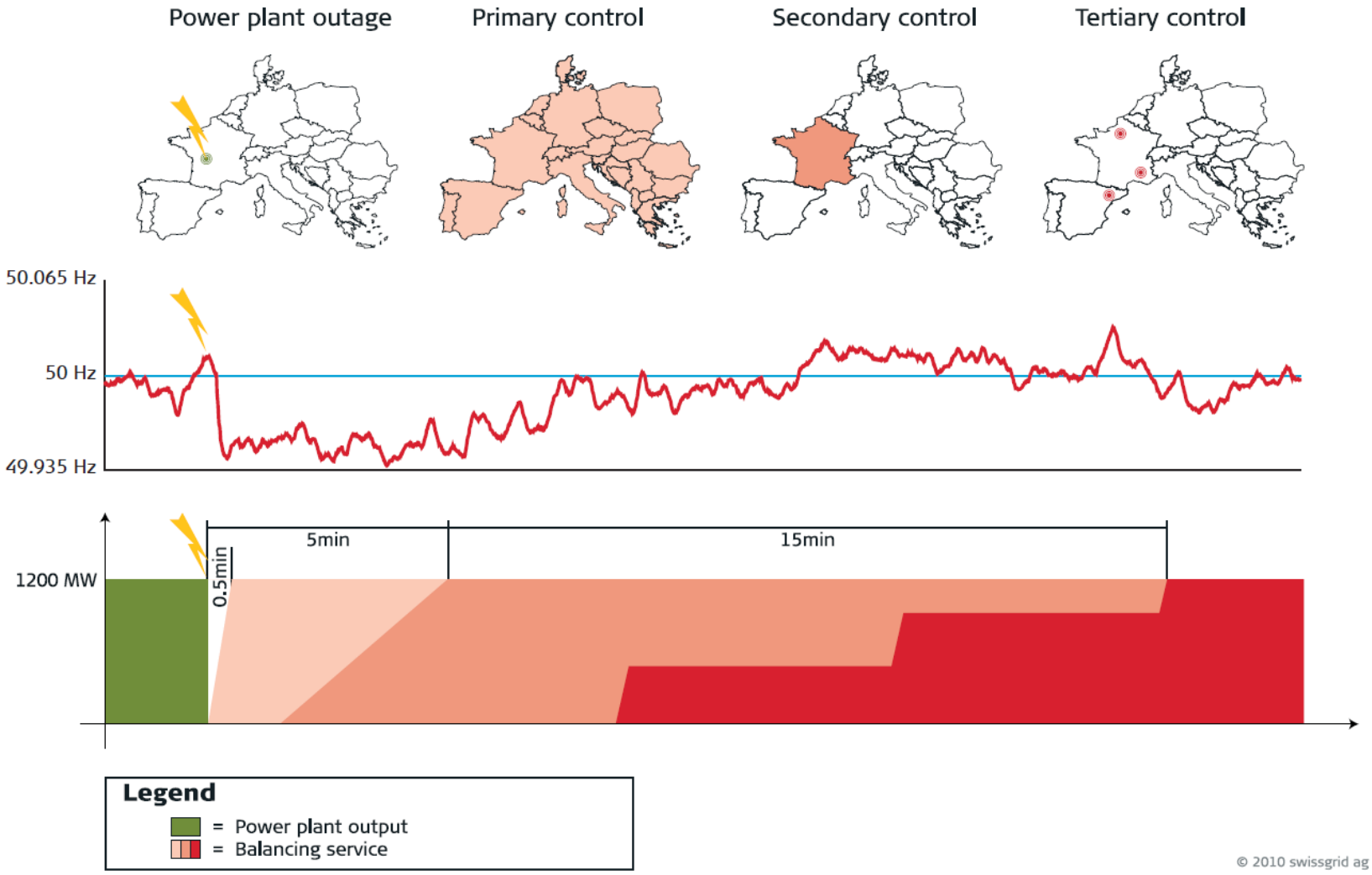
Integration of Subsidized NREs in Europe ?



- Opportunity of Services to the Power System
- Non Dispatchable Generation
- Trading Pattern Disruption

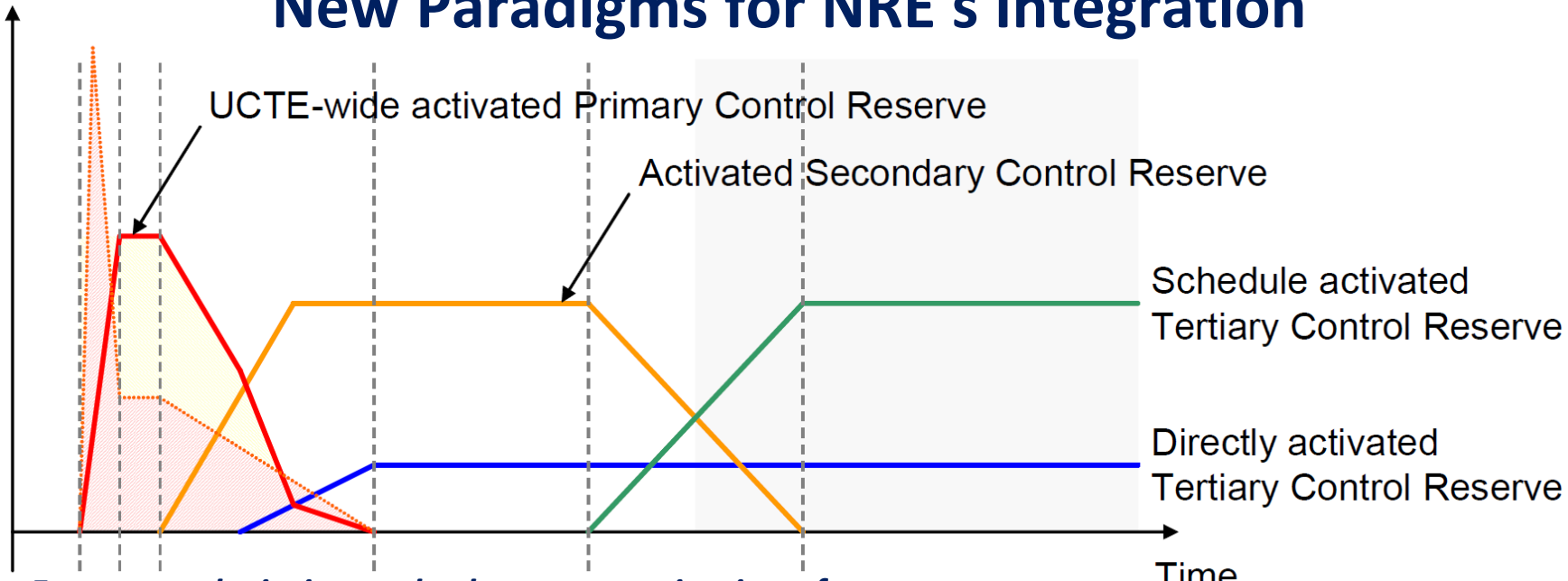
NREs Generation in Germany, Mid of June 2012 : 10 GW Storage Capacity?

Balancing Services



Martin Beck, Marc Scherer: "*Overview of ancillary services*", swissgrid, pp.1-6, 2010.

New Paradigms for NRE's Integration



Frequency deviation and subsequent activation of reserves

- 2012 UCTE www.entsoe.eu
  - ✓ 30 s Sustained Primary Control
- 2016 UK nationalgrid
  - ✓ 9 s Sustained Primary Control

http://www2.nationalgrid.com

- UK nationalgrid invitation to tender for enhanced services
  - ✓ 0.5 s to 1 s Response
  - ✓ 9 s duration
- What to expect ?

Challenging Dispatchable Technologies

- Storage Hydropower Plants
- Pumped Storage Power Plants
- Gas Turbines
- Power Curtailment
- Compressed Air Energy Storage
- Battery Storage Banks
- Molten Salt
- Etc.

Linthal (GL) 250 MW Variable Speed Pump-Turbine Unit

ALSTOM Hydro

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Hydropower Modernization

- Time Life Extension
  - ✓ Due Diligence
  - ✓ Not Only Equipment Refurbishment!
- New operation paradigm
  - ✓ Services to the Power System
  - ✓ Ancillary Services
- Production Flexibility
  - ✓ Storage Capacity Increase
  - ✓ Extended Operating Load Range
  - ✓ Fast Ramp Up/Down
  - ✓ Black Start
- Water Protection Act Compliance (Leaux)
  - ✓ Hydro Peaking Mitigation
- Drastic Reduced Costs vs. Greenfield Projects

Ruppoldingen (SO) 2 x 10.5 MW Bulb Units, 115 GWh, 4 m ÷ 6.5 m Head

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RENOV Hydro

Methodology and tool development for hydropower potential evaluation and optimization

Power Vision Engineering

FMV

groupe E

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Office fédéral de l'énergie OFEN

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

SIMSEN

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Hydropower Modernization Technical Challenges

- System Approach
  - ✓ Safety
  - ✓ Reliability
- Hydraulic Structure
  - ✓ Dam Height Increase
  - ✓ Water Ways Improvement
  - ✓ Hydro Peaking Mitigations;
- Generating Unit
  - ✓ Turbine Digital Twin Enabling Flexible & Safe Operation

New Impeller Experienced Cracks at the Blade Roots due to Rotor-Stator Interactions in a 430 MW Modernized Pump-Turbine

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HYPERBOLE

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

- **HYdropower plants PERformance and flexiBle Operation"towards Lean integration of new renewable Energies**
  - ✓ Dynamics of Francis Turbines & Pump-Turbines
  - ✓ 42 Months, 5 Mio EUR
  - ✓ 1st Sept. 2013 ÷ 28th Feb. 2017
- **Consortium coordinated by EPFL**

ALSTOM ANDRITZ VOITH Power Vision Engineering

Hes·so VALAIS WALLIS INESCPORTO LABORATÓRIO ASSOCIADO CDIF UPC Center Industrial Diagnostics Universität Stuttgart

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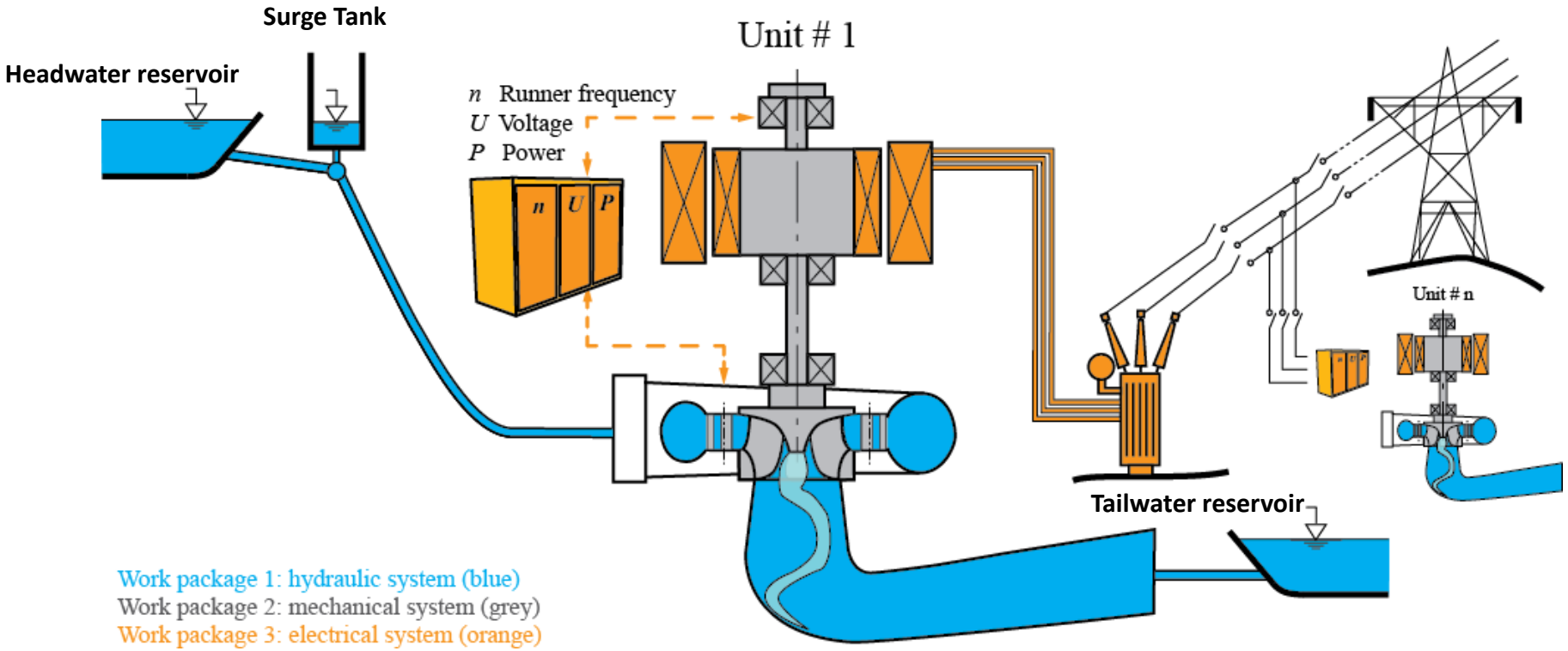
HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies



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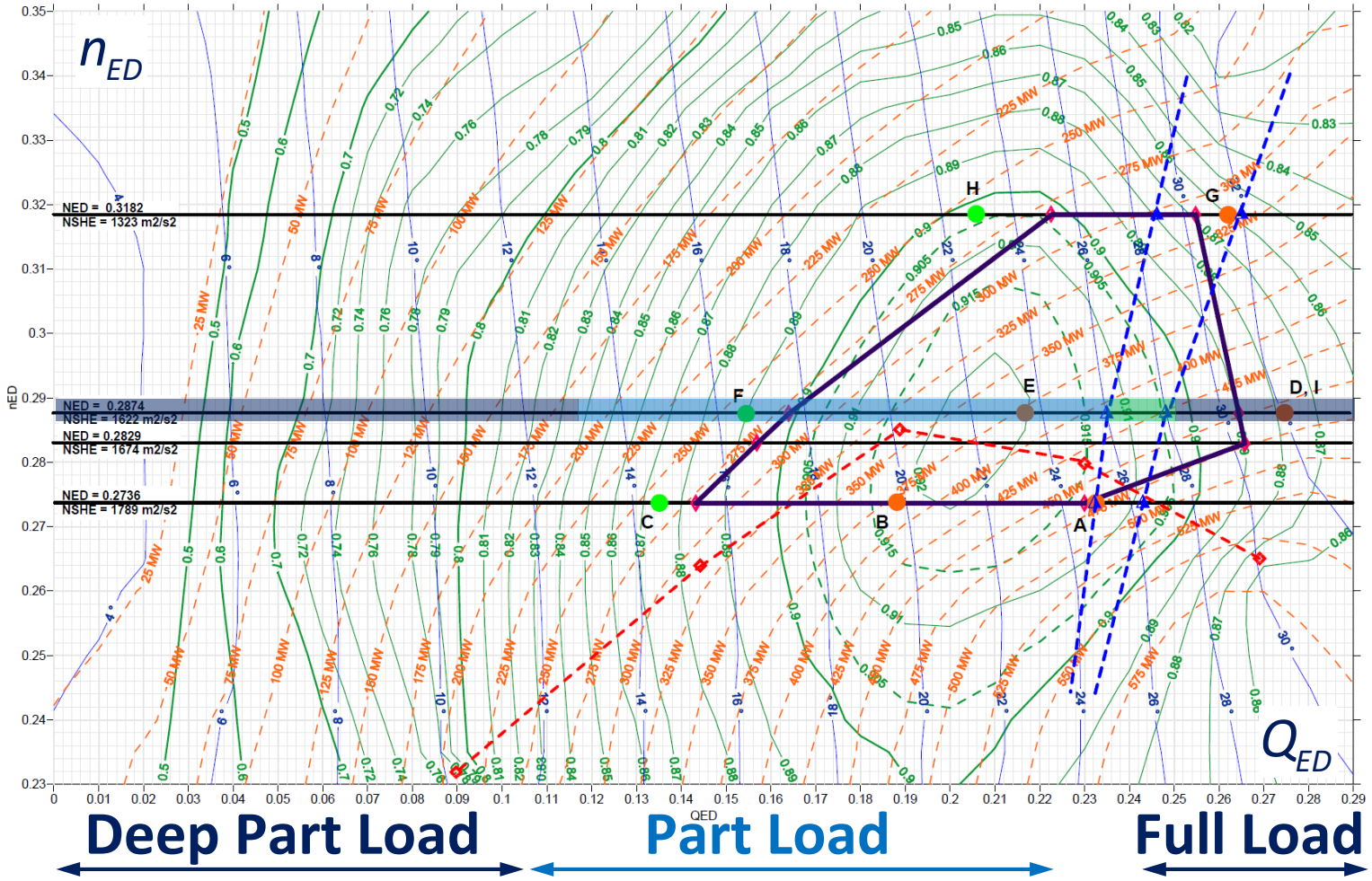
ERC/FP7-ENERGY-2013-1-Grant 608532

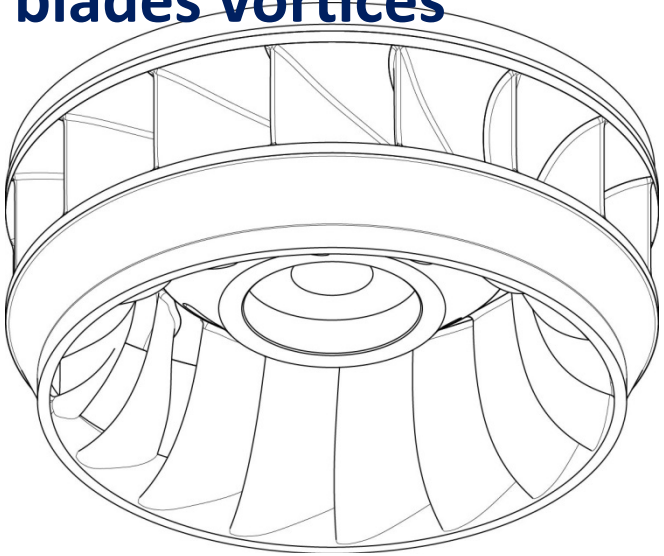
Existing Turbine hill chart and operating range

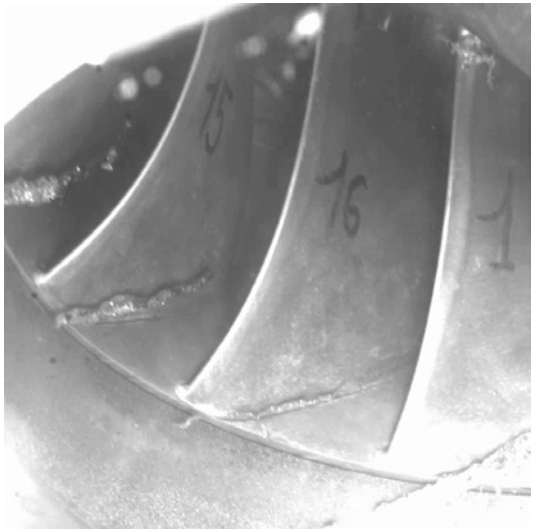
HYPERBOLE

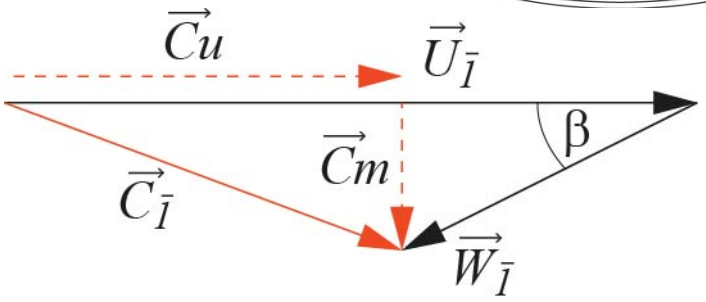


HYPERBOLE Deep part load operating conditions Q << QBEP

- Inter blades vortices







Keita Yamamoto et al., "Guide vanes embedded visualization technique for investigating Francis runner inter-blade vortices at deep part load operation", 6th IAHR International Meeting of the Workgroup on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, Ljubljana, Slovenia, 09/2015; .

Keita Yamamoto et al., "Experimental method for the evaluation of the dynamic transfer matrix using pressure transducers", Jo. Hydraulic Research, 07, 2015; DOI:10.1080/00221686.2015.1050076.

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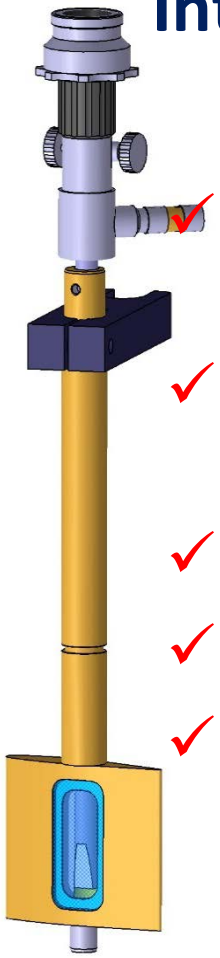
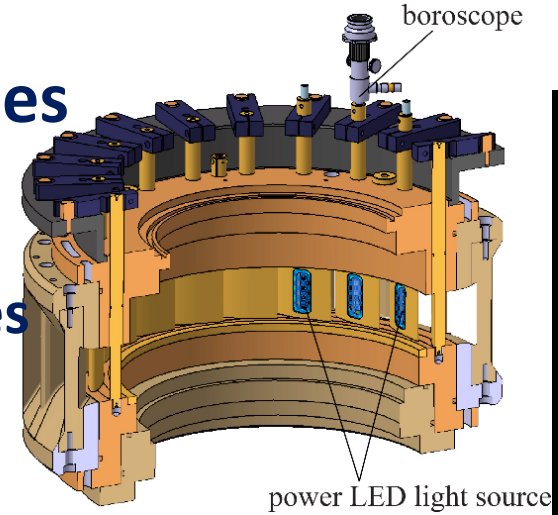
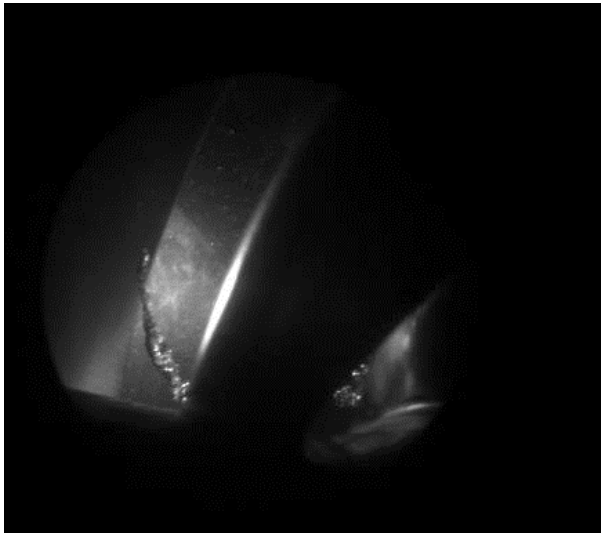
Deep part load
Inter blades vortices



Visualization

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

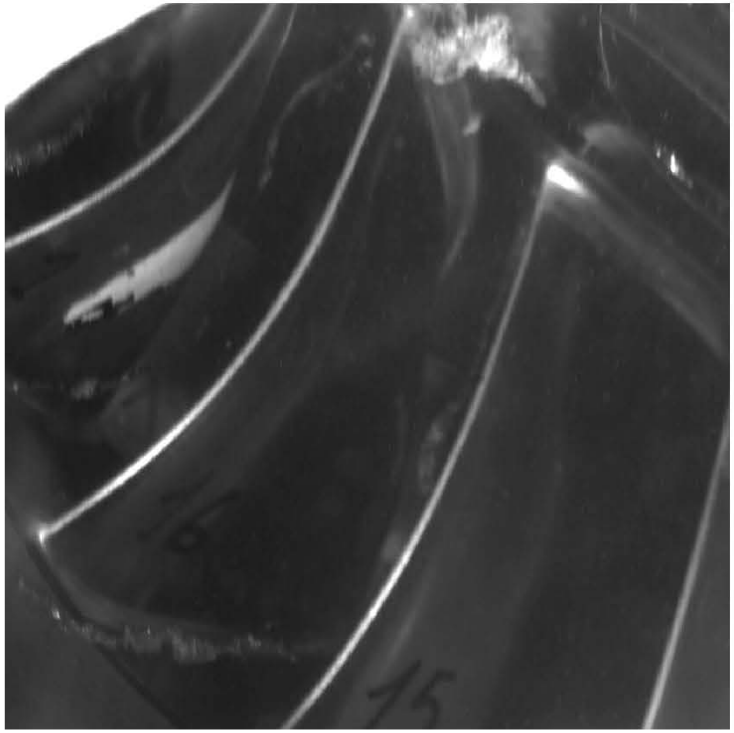


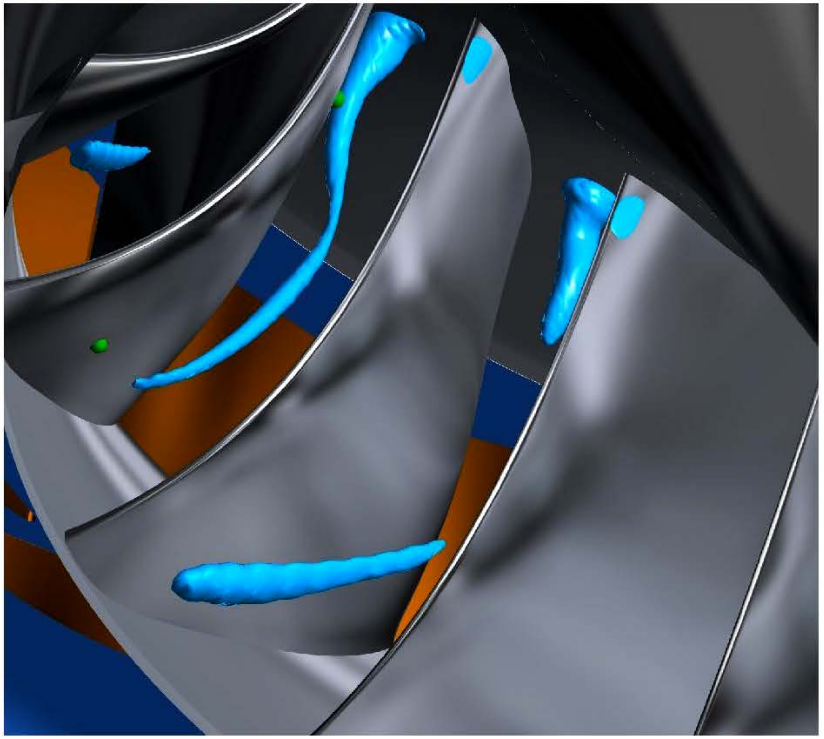


HYPERBOLE

Deep part load
Inter blades vortices

- Flow Numerical Simulations





Assessment of Hydropower Station Dynamics

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Actual practice

Model Testing (IEC 60193)

Test Results (Reduced Scale Turbine Model)

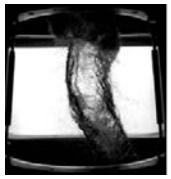
Clouds of Unknowns Prediction Quality

+/-30% ... +/-200%

Full Size Operating Conditions

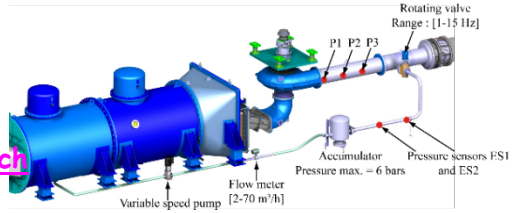
Goal: prediction quality +/-20%

Reduced-scale physical model



SIMSEN

http://simsen.epfl.ch



Draft Tube modelling

Natural Frequency Identification

Dimensionless Hydro-acoustic Parameters

Full-scale turbine

Power Unit Dynamics Simulation

Hydropower Station SIMSEN Model

Transposition to Prototype

$$a^P = a^M \left(\frac{D^P_{ref}}{D^M_{ref}}\right)\left(\frac{n^P}{n^M}\right) \qquad \mu''^P = \mu''^M \left(\frac{D^P_{ref}}{D^M_{ref}}\right)^2 \left(\frac{n^P}{n^M}\right)^2 \left(\frac{f^M_{natural}}{f^P_{natural}}\right)$$

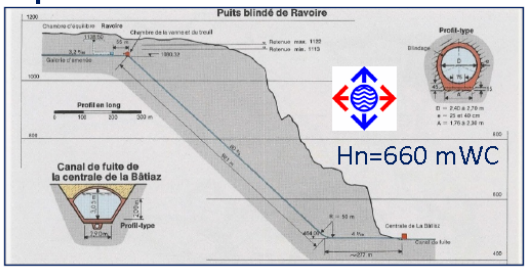
Christian Landry et al., "Part load cavitation vortex rope in Francis turbines: Experimental determination of local wave speed and second viscosity", Jo. Hydraulic Research, Volume 54, Issue 2, March 2016, pages 185-196

Power Station Digital Twin

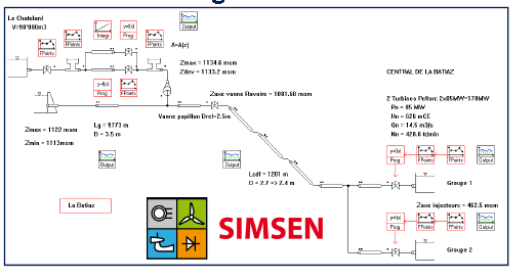
- Example of HYDRO-CLONE®

Case Study EMOSSON SA: 2x85 MW La Bâtiaz Power Plant

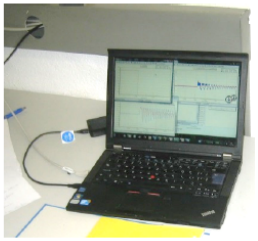
Input data



SIMSEN modeling and validation



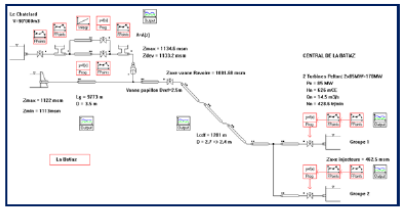
On-Site installation of Hydro-Clone
Acquisition, Simulation, Comparison



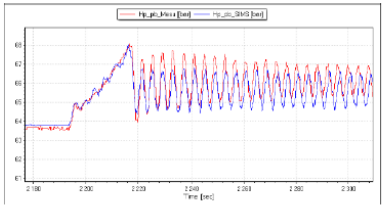
Data (Modbus)

f_{sample}=10Hz

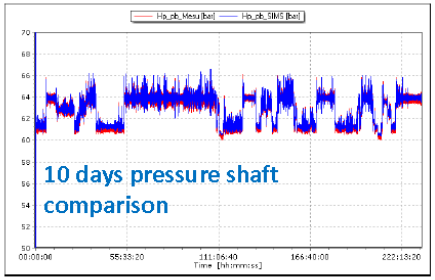
SCADA

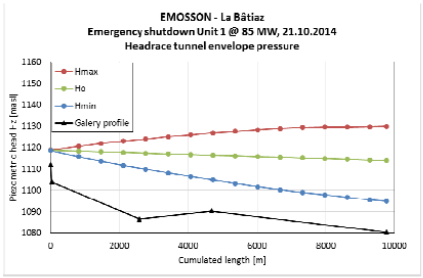


Comparison Simulation-Meas.



Long term transient survey and analysis





European Patent EP 2 801 879 A1, "Hydroelectric power plant real-time monitoring system and method", 7.5.2013

C. Nicolet et al., " Hydro-Clone: Innovative Real-Time Simulation Monitoring System for Hydropower Plant Transient Survey", Proc. of HYDRO 2015 Conference, Bordeaux, October 26 -28, 2015.

Conclusions

- To achieve safe and optimum operation complying new power generation paradigms
  - ✓ Energy vs. Services to the Grid
  - ✓ Environmental Requirements.
- Technology breakthrough to meet the market needs and to ensure and enhance the reliability, availability, maintainability and safety of the hydropower plants
- Modernization of hydropower scheme requires advanced risk analysis
- Is our knowledge and model accurate enough to develop a digital twin of generating units, hydropower plants and power transmission system??

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HYPERBOLE Consortium Convenes Porto Conference, Portugal February 2-3, 2017

Large scale integration of new renewable energy sources in Europe is demanding for an increased role of hydro-power plants in order to contribute to energy balance and to mitigate its stochastic nature. Simultaneously, preserving the global system stability is also a key contribution where hydro power is expected to play a major role, exploiting both generation and pumping operation modes. The flexibility of these new technologies will demand for a new regulatory framework to foster its wide adoption.

Therefore, this international conference will be a forum for researchers and practitioners to present the latest research results, ongoing developments, best practices and applications related to the complex environment of hydro power technology, including:

1. **Hydro technology: hydraulic, mechanical and electrical systems dynamics of several hydraulic machines configurations under an extended range of operations**
2. **Electric power systems: hydropower plants contribution to enable new renewable energy integration and opportunities to contribute to pump hydro participation in reserve markets**
3. **Energy regulation: future regulatory frameworks and market structures, the value of flexibility in deregulated power systems**

http://www.hyperbolesymposium.eu/

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