University of Stuttgart
Institute of Fluid Mechanics
and Hydraulic Machinery

Hydropower Plants

Carbon Neutral Electricity Generation

07.12.2022

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IHS

Electricity Generation for our Society

Our society requires electricity …

… if wrong, then …

… return to basic principles of the past …

Electricity Generation for our Society

Our society requires electricity …

… if true, then …

… we require power plants …

… and transmission lines

Electricity Generation for our Society

The only remaining question:

> Which of the available power plant technologies
> do we want to deploy?

All power plant solutions affect the environment.

- Air
- Rivers
- Ocean
- Soil
- Plants
- Animals
- Humans

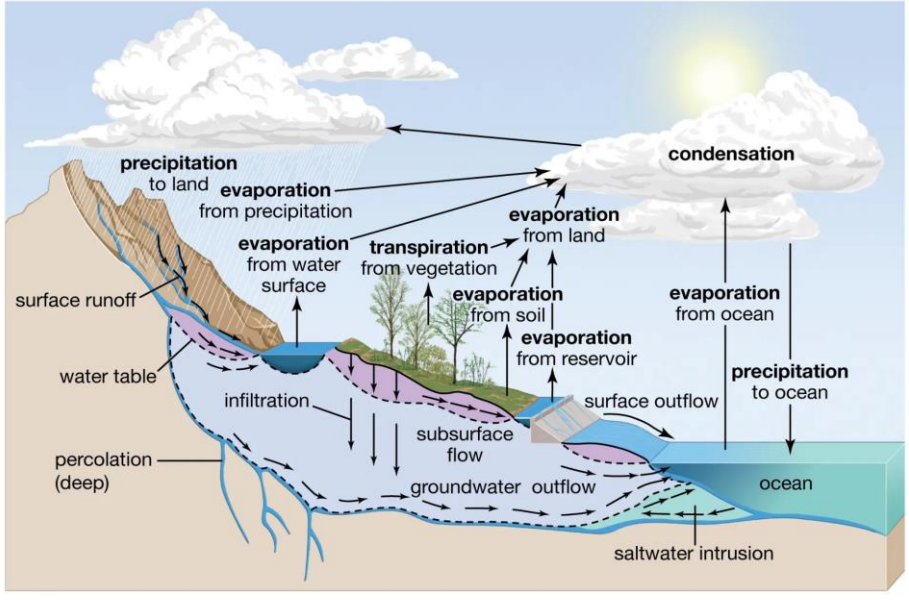
Here comes a plea for the utilization of hydropower technology.

Water Cycle driven by Solar Radiation

Solar radiation generates weather on earth, as a consequence

- Water is lifted to higher than sea level altitudes
  → potential energy
- Water surface runoff
  → kinetic energy

Hydropower plants convert potential and / or kinetic energy



Source: Encyclopædia Britannica, Inc.

Hydropower is driven by solar power - sustainable and renewable energy

Renewable energy is energy that is collected from renewable resources that are naturally replenished on a human timescale.

Hydropower Plants - Potential Energy

Carbon Neutral Electricity Generation - net-zero carbon dioxide emissions

- Different types for Hydropower electricity generation are available, examples:

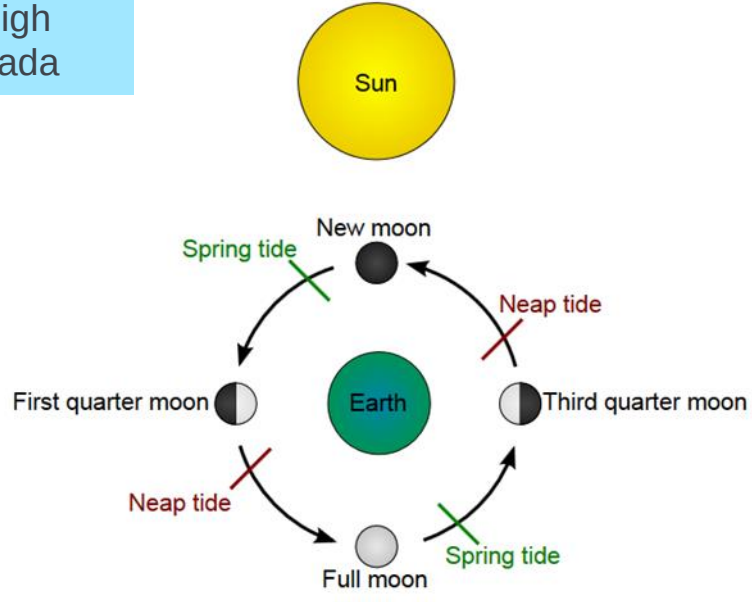
Pumped storage plant	Pumped storage plant	Base and peak load
Raccoon Mountain, USA	Limberg 2, Austria	Cana Brava, Brasil

- Conversion of energy without thermal processes allow
  - Continuous electricity generation – base load
  - Very fast power changes to support stability of electrical grid – key advantage

Gravitational Forces between Sun, Earth and Moon

- Gravity forces generate tidal currents

Bay of Fundy at high and low tide, Canada

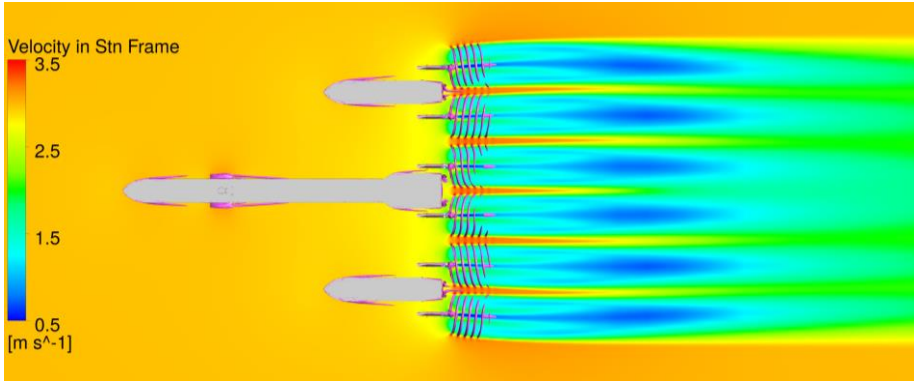


- Advantage: Tidal currents are very well predictable and thus, the electricity generation
- But, relatively low flow speed from a technical perspective

Conversion of tidal energy

- Conversion of kinetic energy

- Flow simulation and performance assessment



Gefördert durch:
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aufgrund eines Beschlusses des Deutschen Bundestages

Hydropower Plants - Kinetic Energy

Carbon Neutral Electricity Generation - net-zero carbon dioxide emissions

- Different types for Hydropower electricity generation are available, examples:

tidal current

propeller turbine

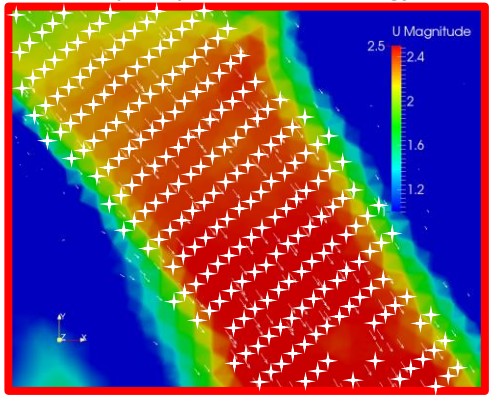
river current

hydrokinetic turbine

simulation tidal currents

performance prediction project area

EMEC (European Marine Energy Center)



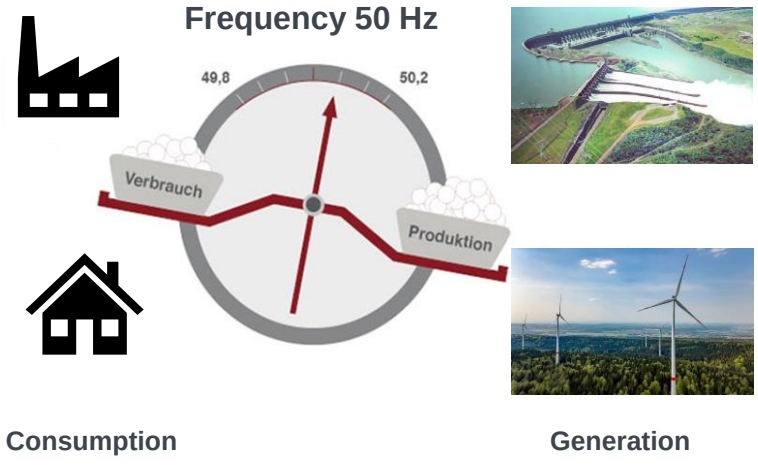
- Continuous electricity generation for river currents – base load
- Tidal currents created by gravity forces between earth, sun and moon - renewable resources

Electrical Grid

Properties and Requirements

- Power demand is constantly changing
- No storage of electricity in the electrical grid, only energy conversion

➢ Prompt generation of electricity required



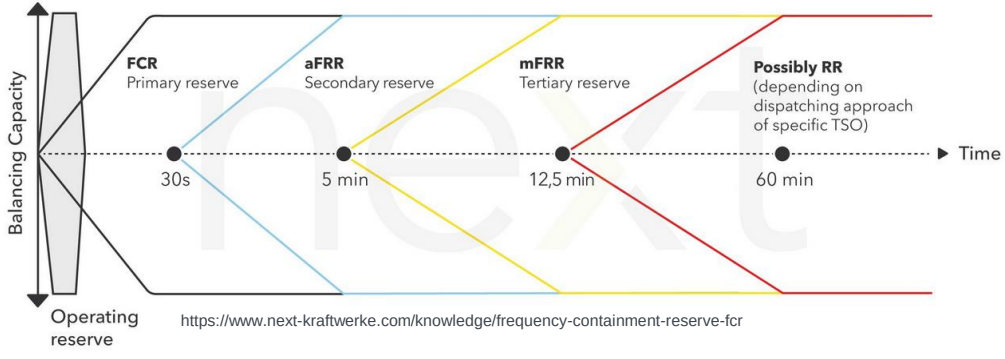
- Grid frequency is a **measure for grid stability**
  → **balance** between generation and consumption
  → continuous power control by power plants necessary

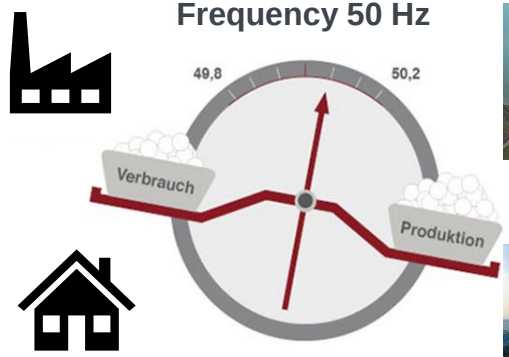
- Grid frequency may vary depending on country

Electrical Grid

Properties and Requirements - Balancing Services

- FCR – Frequency Containment Reserve - primary control reserve
- aFRR – Automatic Frequency Restoration Reserve - secondary reserve
- mFRR – Manual Frequency Restoration Reserve - tertiary reserve
- RR – Replacement Reserve





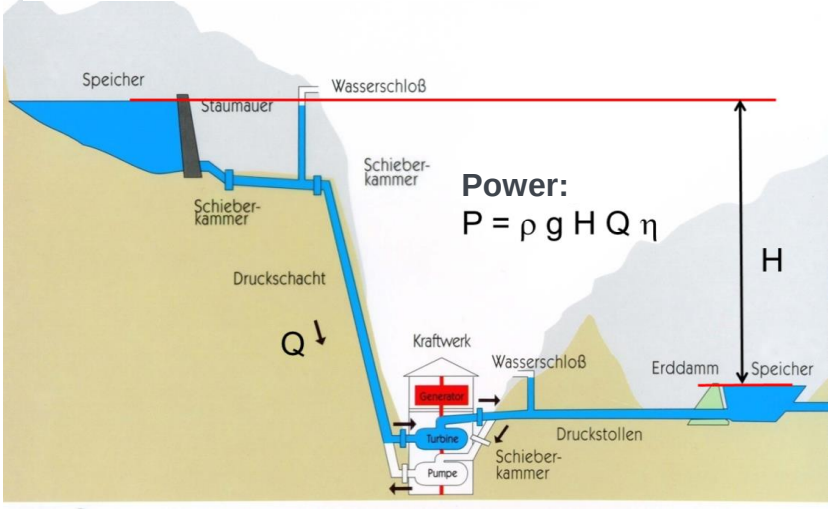
Generation

- **Hydropower plants** are ***ideally suited*** for this fast control task due to their physical function

Hydropower Plants - Advantages

Schematic pump storage plant

Pump Storage Hydroelectric Plant

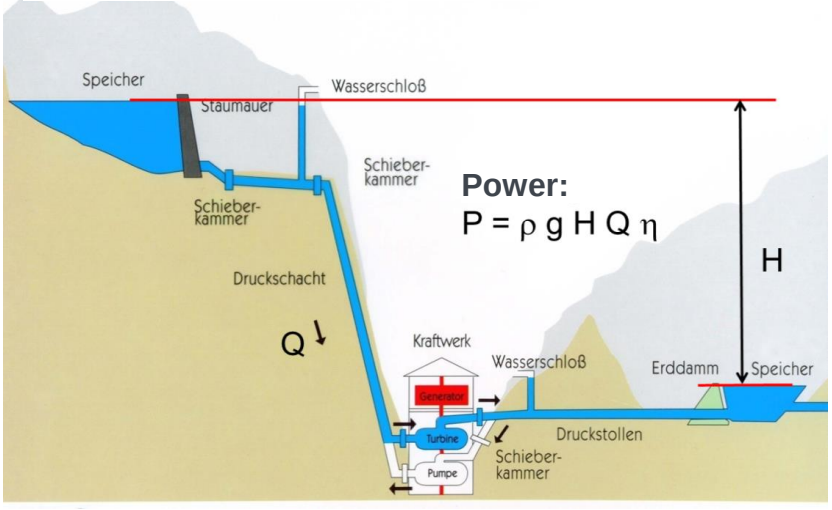


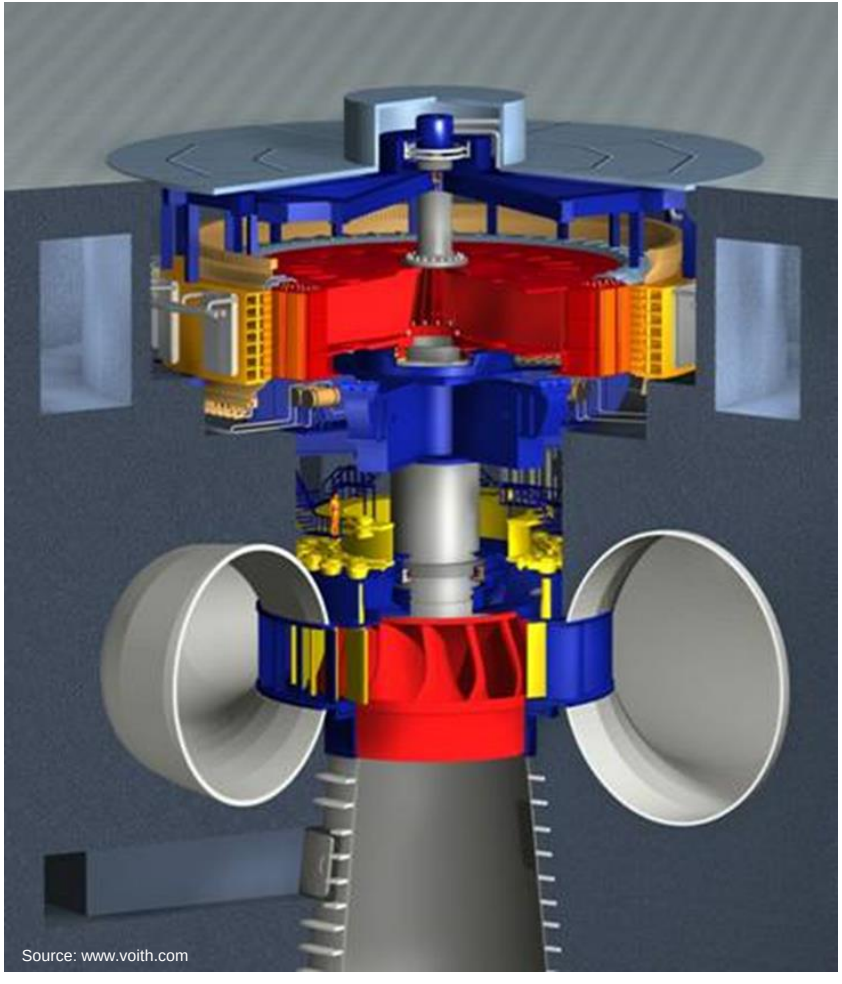
- Generate electricity from stored energy reservoir
- Consume electricity to build up an energy reservoir again
- High efficiency of overall system

Hydropower Plants - Advantages

Schematic pump storage plant

Pump Storage Hydroelectric Plant



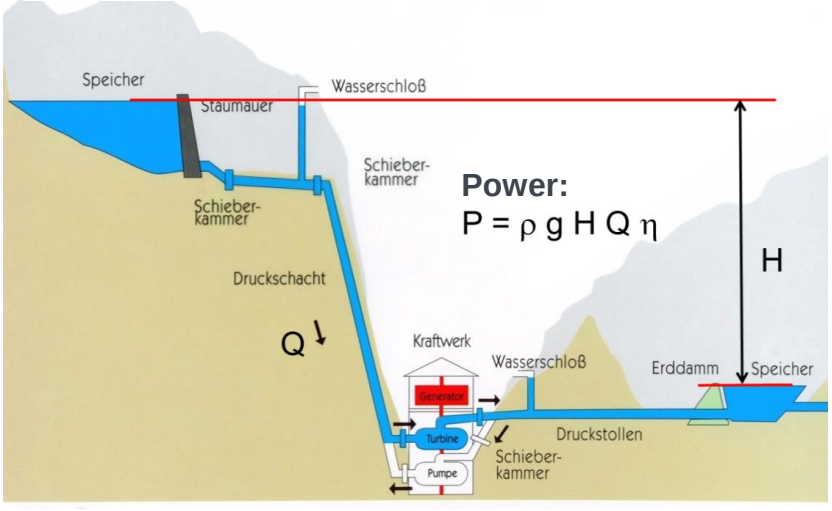


Francis turbine

Hydropower Plants - Advantages

Schematic pump storage plant

Pump Storage Hydroelectric Plant



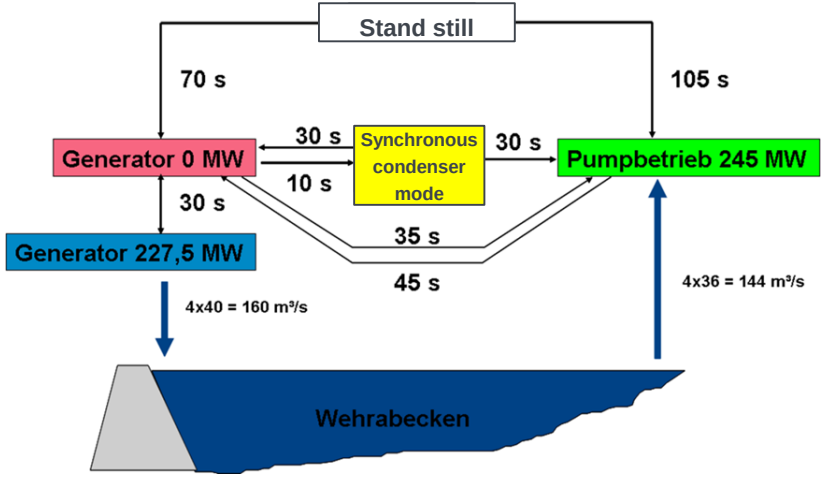
Very fast reaction times of Hydropower:

→ Operational transition times

Generate electricity from stored energy reservoir

Consume electricity to build up an energy reservoir again

High efficiency of overall system



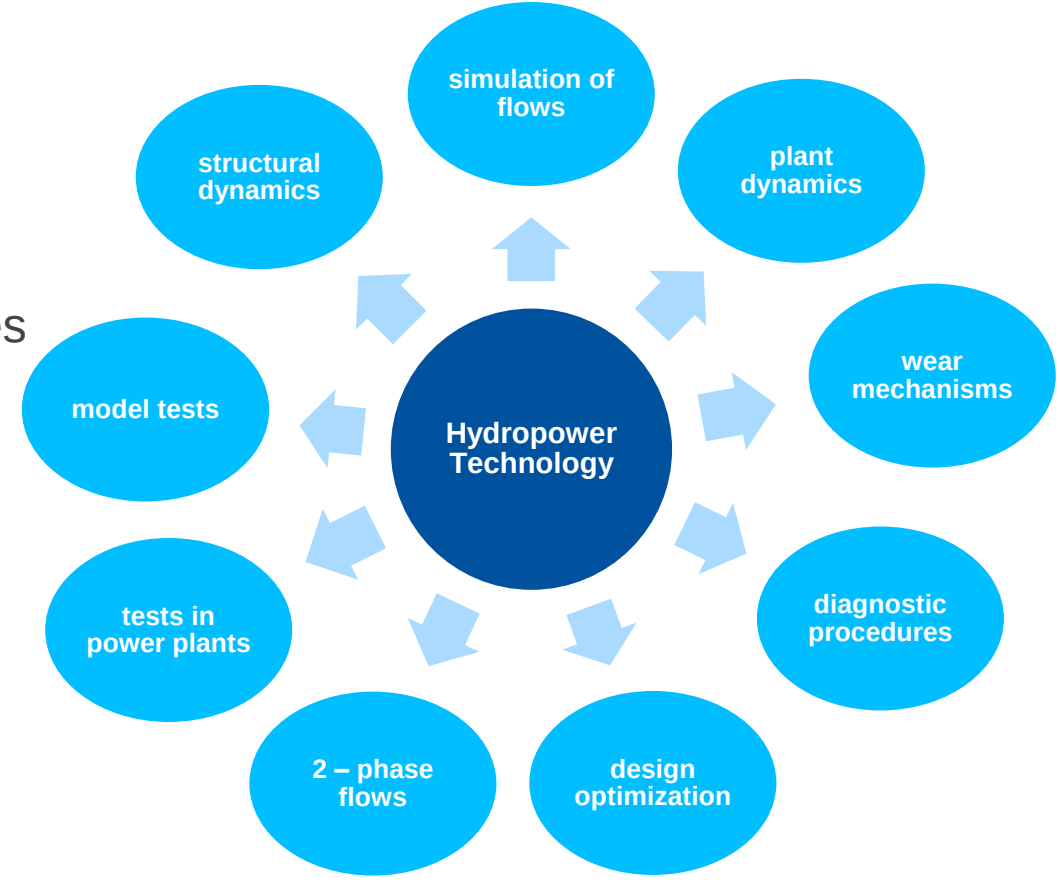
Source: Schluchseewerk AG

Research activities related to Hydro Power Technology

Interdisciplinary methods and topics

Research requirements

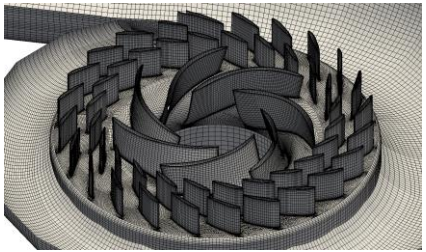
- for high flexibility
- fast operational changes

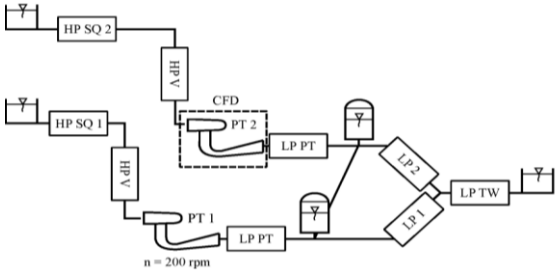


Research activities

Examples related to Hydropower technology

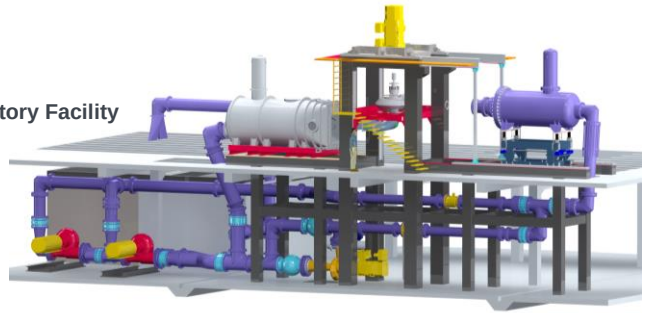
- Operational transients of turbomachinery including piping system
  - Computational Fluid Dynamics plus plant dynamics as well as experiment
  - Assessment service life





Hydroelectric Powerplant

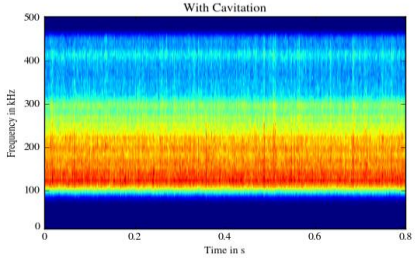
Laboratory Facility



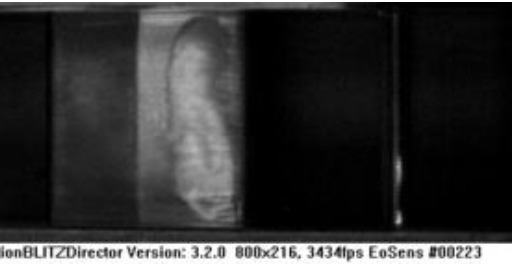
Research activities

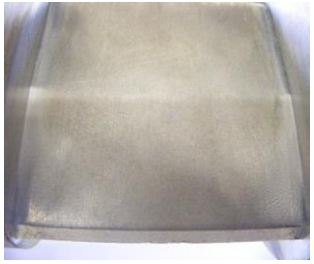
Examples

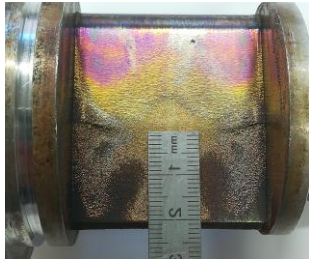
- Predictive damage assessment
  - Detection of cavitation using Deep-Learning methods



  - Assessment of cavitation erosion



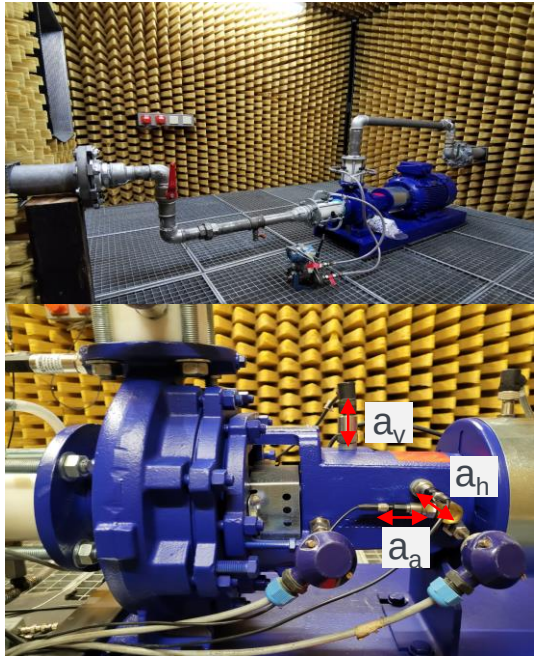


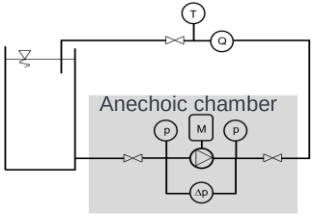


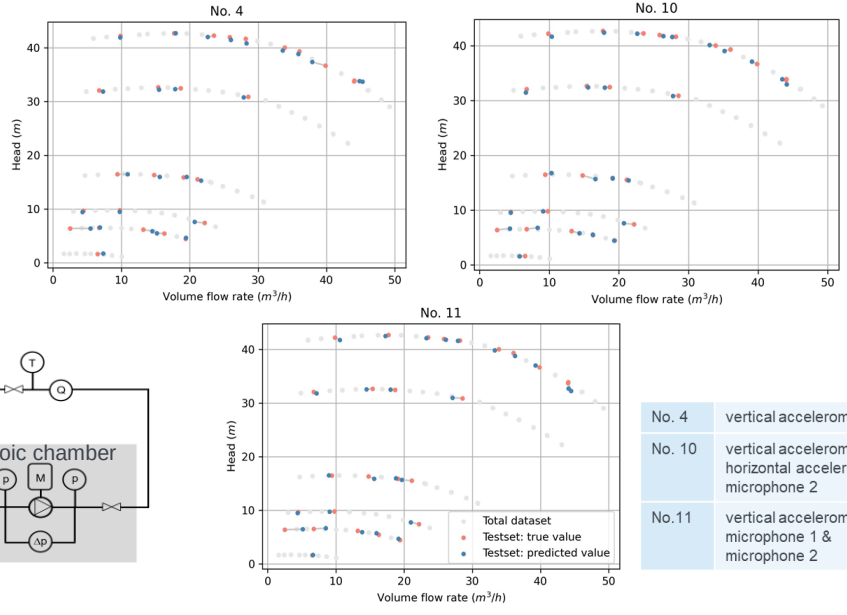
Research activities

Examples

- Predictive damage assessment
  - Operating point estimations of pumping units applying Deep-Learning methods
  - to be expanded towards power plants





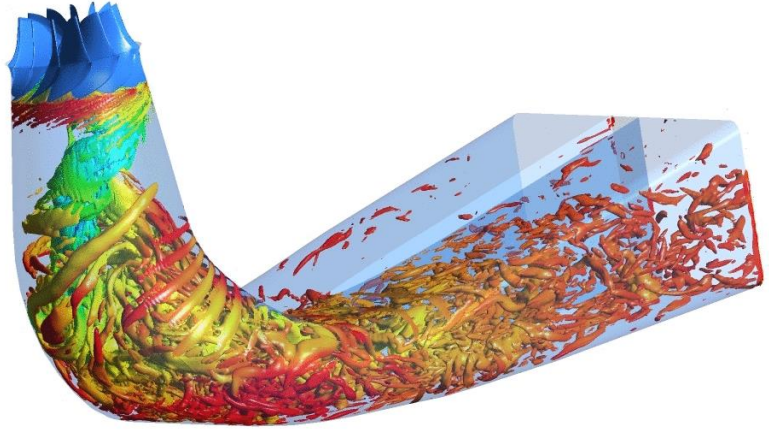


No. 4	vertical accelerometer 3
No. 10	vertical accelerometer 3 & horizontal accelerometer 2 & microphone 2
No.11	vertical accelerometer 3 & microphone 1 & microphone 2

Research activities

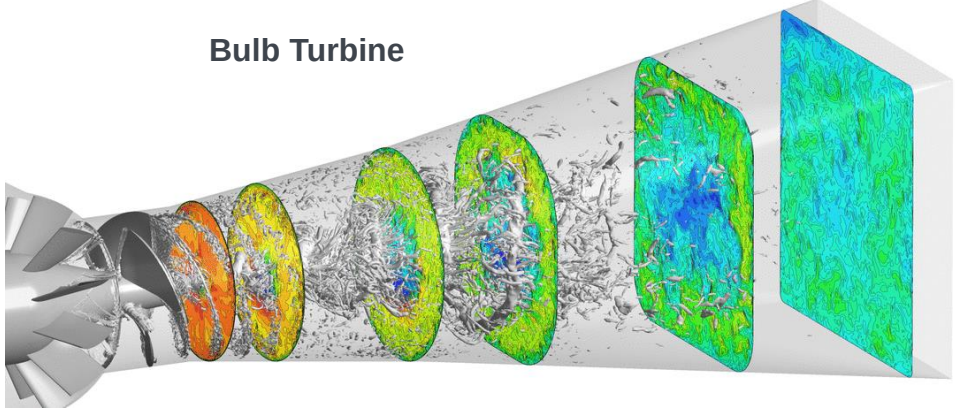
Examples

- Accurate prediction of flows in turbomachinery for wide off-design operating range



Francis Turbine

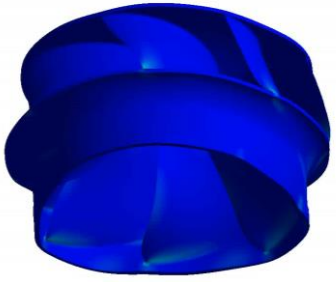
Bulb Turbine



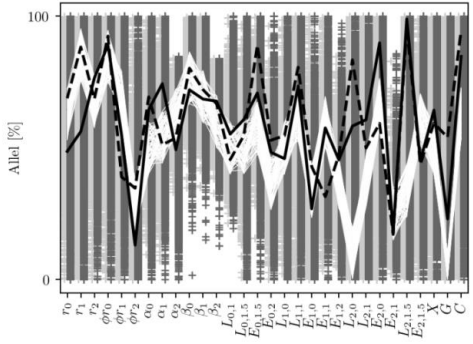
Research activities

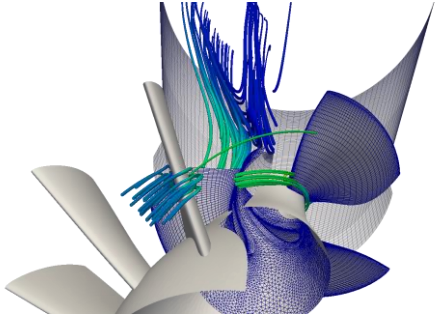
Examples

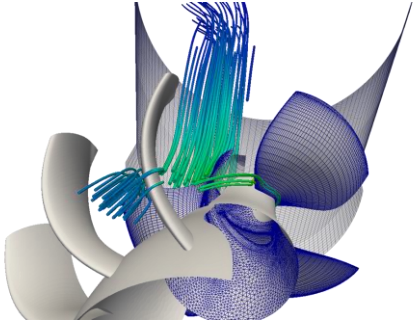
Pumpturbine runner



- Fluid Structure Interaction - CFD coupled with FEM
  - Forced vibration in turbomachinery
  - Assessment service life for extreme off-design and operational transients
- Design - Framework for turbomachinery
  - Fully automatic geometry optimization based on CFD



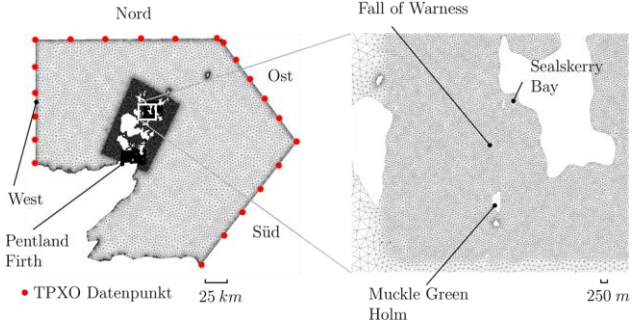


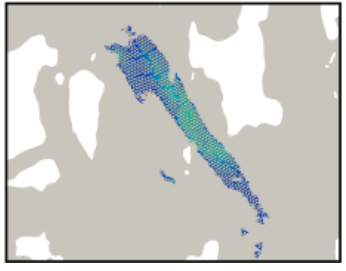


Research activities

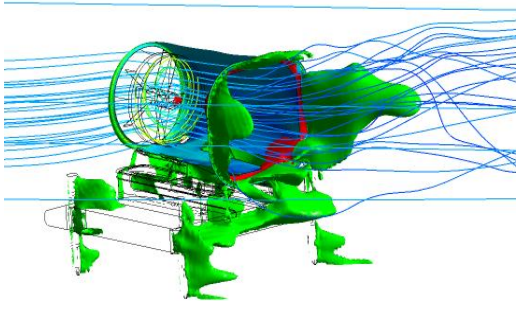
Examples

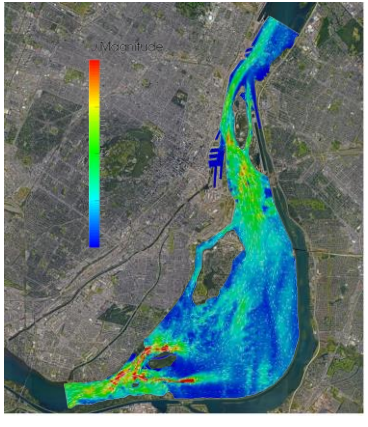
- Extraction of energy from tidal currents and river currents
  - Performance prediction of project area with turbine array - EMEC





  - Site evaluation at rivers for hydrokinetic turbines





Hydropower Technology

Pathways to Carbon Neutrality

- Hydropower Plants
  - Very high efficiency level of energy conversion
  - Very high flexibility and capability for fast and very fast power output changes within one minute and less due to non-existent thermal processes
  - Excellent for stabilizing electrical grids with a high share of volatile renewable energies such as wind and photovoltaics

- Multipurpose plants
  - Reservoir for drinking water
  - Recreational space for people
  - Habitat for plants and animals
  - Flood Control and others

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Research work with excitement and fun factor - Hydropower Technology

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Acknowledgement
Many thanks to all my scientific assistants for the achievement of the presented results during my time as Director of the Institute IHS.

Electrical Grid - Frequencies in different countries

Properties and

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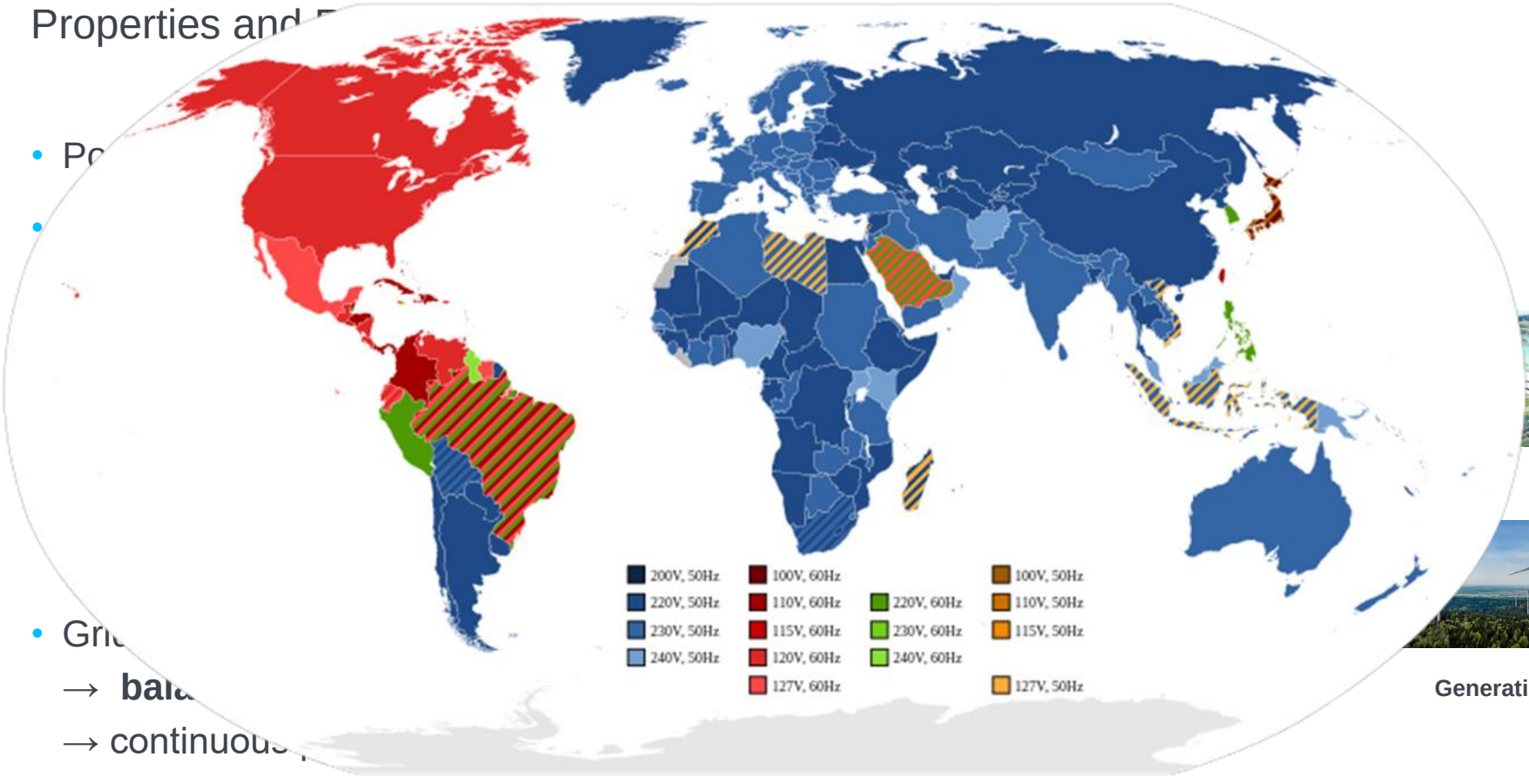
-
- Gri
  → **bala**
  → continuous



Source: http://de.wikipedia.org/wiki/Netzspannung#mediaviewer/Datei:Weltkarte_der_Netzspannungen_und_Netzfrequenzen.svg

Generation