FEDERAL UNIVERSITY OF SANTA CATARINA
TECHNOLOGICAL CENTRE
DEPARTMENT OF MECHANICAL ENGINEERING
Florianópolis – Santa Catarina - Brazil

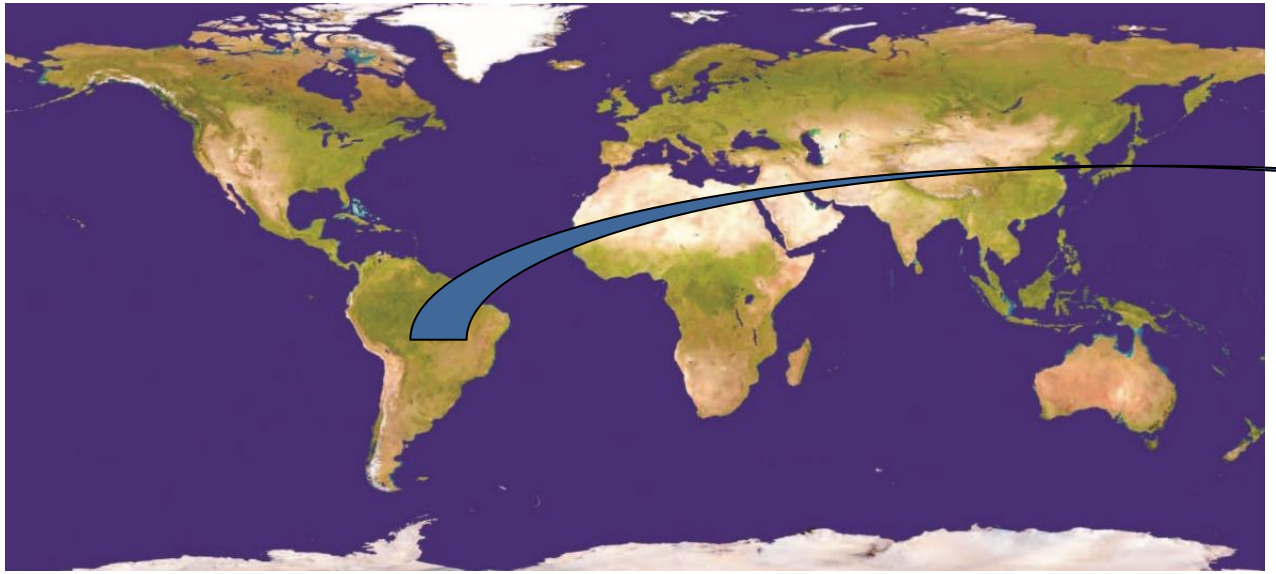
LASHIP - Laboratory of Hydraulic and Pneumatic Systems

Hydraulics and Pneumatics for Power Plants

Prof. Victor Juliano De Negri, D. Eng.

EMC - UFSC LASHIP HIDRÁULICA & PNEUMÁTICA

South America - Brazil



- Brazil:
  - Population (2022): 203.4 million people
  - Territorial area: 8,515,767 km^2
  - Seacoast: 7,491 km

Brazil – Santa Catarina

Camboriú

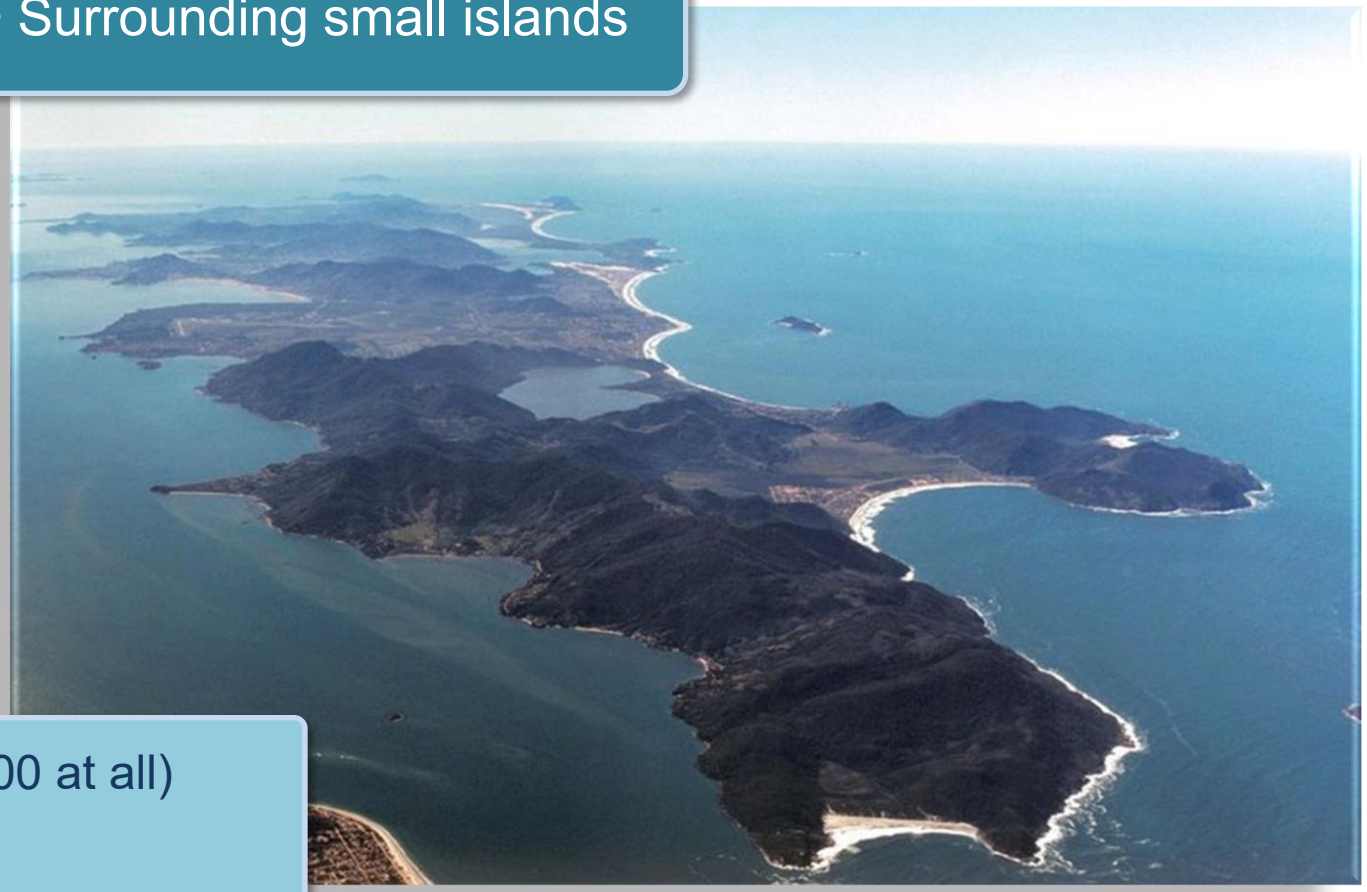
São Joaquim

Blumenau

- **Santa Catarina State:**
  - South of Brazil - 295 cities
  - One of the highest standards of living in Latin America (HDI ~ 0.8)
  - Population (2022): 7.6 million people

Santa Catarina Island - Florianópolis

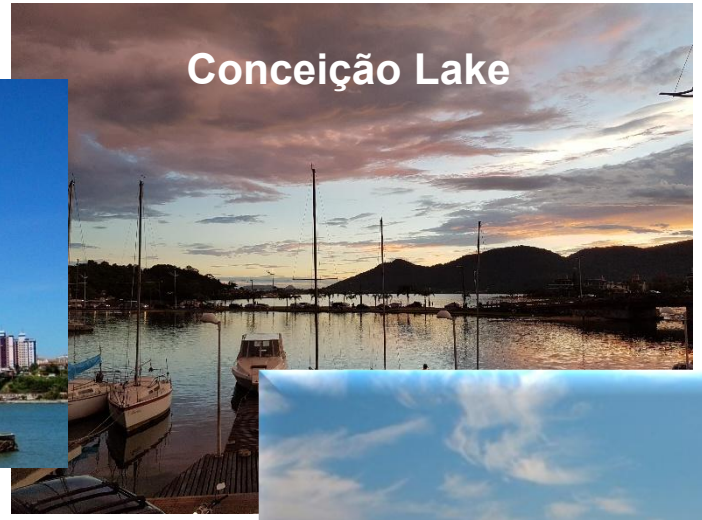
Capital of Santa Catarina State
(1726)
Main island (*Ilha de Santa Catarina*) +
Continental area + Surrounding small islands



- 42 main beaches (100 at all)
- 537,211 inhabitants

Santa Catarina Island - Florianópolis

Hercilio Luz Bridge



Praia Mole (“Soft Beach”)

Florianópolis: Innovation Ecosystem

More than 600 technology companies
National Capital of Startups (by Federal Law)
2 high quality public universities
4 Venture Capital funds

1st Brazilian capital in digital inclusion
One of the best 10 cities to work and live in the world *(Newsweek)*
The best Brazilian capital in life quality
The friendliest city in world ***(Condé Nast Traveler)***

Federal University of Santa Catarina

Founded: 1960

Faculty Staff: 2,600

Technical and Administrative Staff: 2,890

Students: 38,290 (2025)

Undergraduate courses: 120

Graduate courses (Master's & Doctorate): 90

Mechanical Engineering Department

- Created in 1962
  - Occupied area: 16,000 m^2
  - Expansion: 4,000 + 8,000 m^2
- People:
  - 66 academic staff
  - 1,400 students (undergraduate and graduate)
- Research:
  - 24 Research groups
  - 400 Assistants (undergraduate students)

- Undergraduate courses:
  - Mechanical Engineering (1962)
  - Material Engineering (1999)

enade
Exame Nacional de Desempenho dos Estudantes

5

- Graduate Programs (M.Eng. & D.Eng.)
  - Mechanical Engineering (1969)

6

  - Material and Sciences Engineering (1994)

7

CAPES

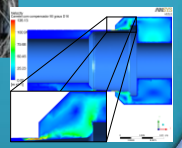
LASHIP: Infrastructure

Laboratories: 280 m²

Pneumatic Lab.

Hydraulic Lab.

Instrumentation, Software & Bibliography



Work Shops

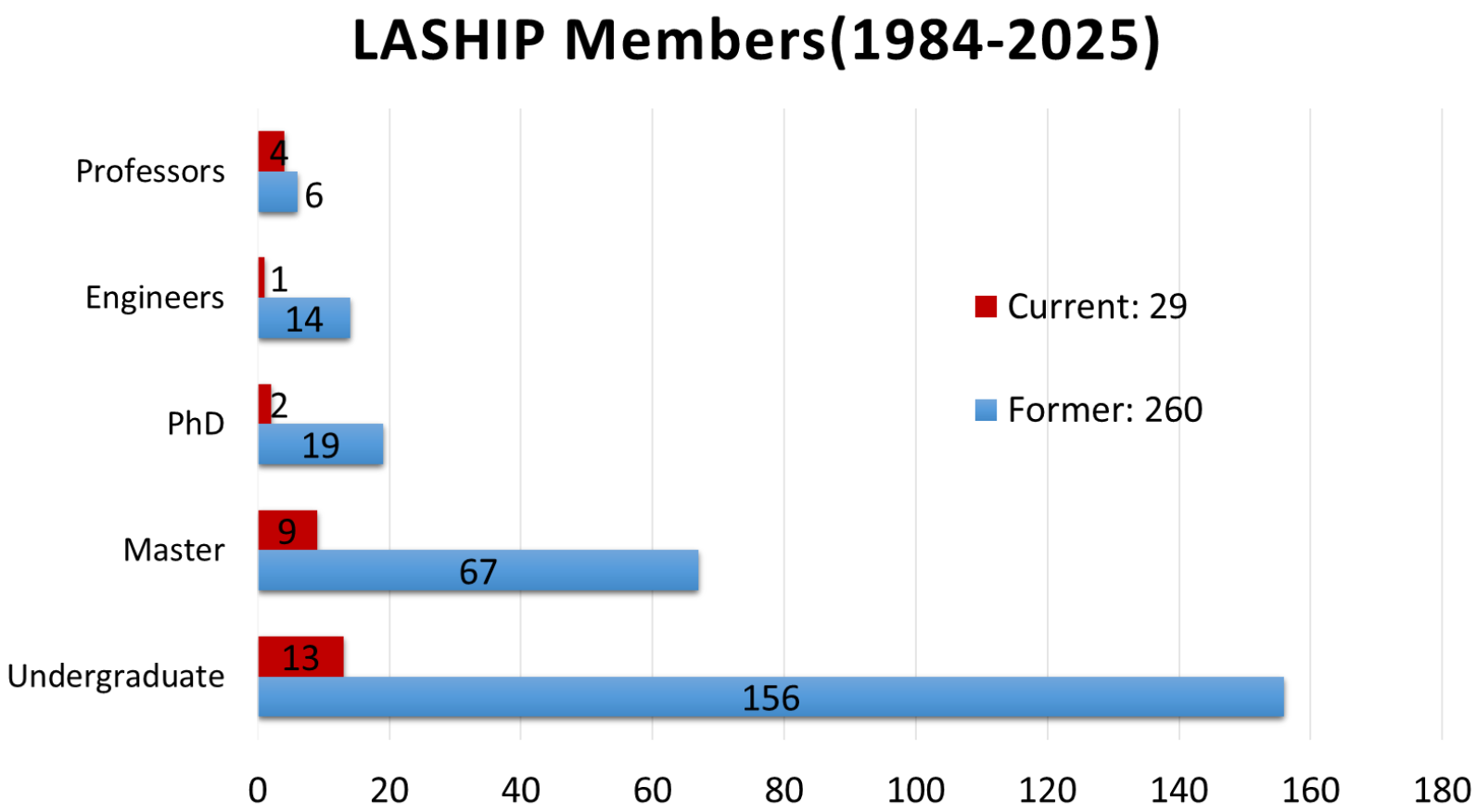
Staff: 170 m²

Offices

Meeting Room

Laboratory of Hydraulic and Pneumatic Systems

- Professors:
  - Antonio Carlos Valdiero
  - Jonny Carlos da Silva
  - Marcos Paulo Nostrani
  - Victor Juliano De Negri
- Technical Staff:
  - Keliene M. Sousa de Jesus
- Current Collaborations
  - Rodrigo B. Fernandes (NeDIP)
  - Amir Oliveira Jr. (LABCET)
  - Liselott Ericson (FLUMES, LiU)
  - Petter Krus (FLUMES, LiU)
  - Jürgen Weber (Fluidtronik,TUD)

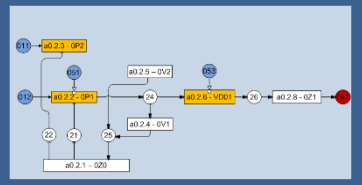


Research Areas and Application Sectors

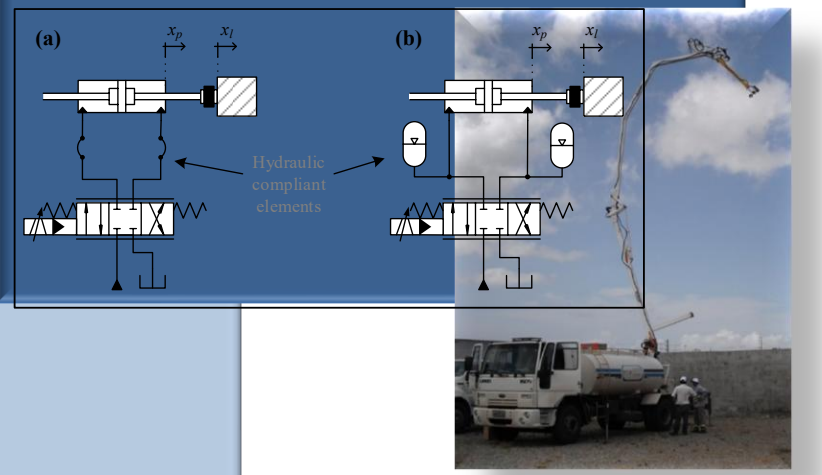
EMC - UFSC LASHiP HIDRÁULICA & PNEUMÁTICA

Methods and Intelligent Systems for Design, Control, and Operation of Mechatronic, Hydraulic, and Pneumatic Equipment

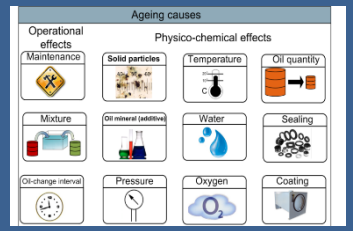
Design of automatic systems



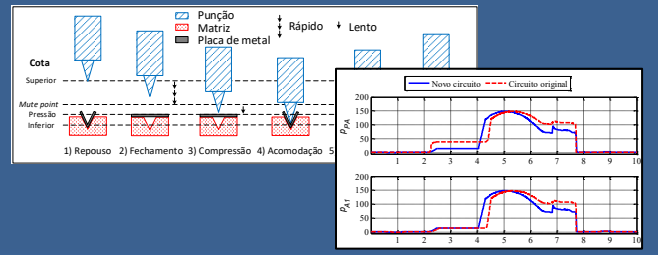
Robots and position and force control



Systems with biodegradable fluids



Machine design



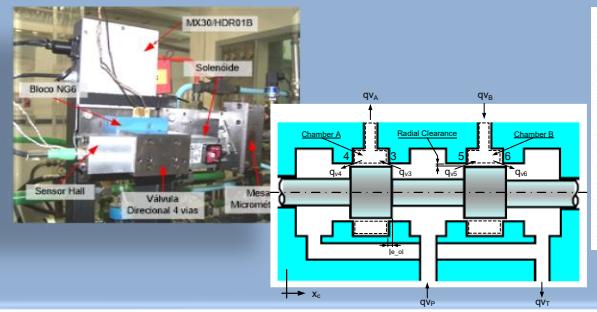
System dimensioning

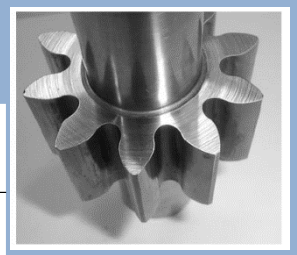
Research Areas and Application Sectors

EMC - UFSC LASHIP HIDRÁULICA & PNEUMÁTICA

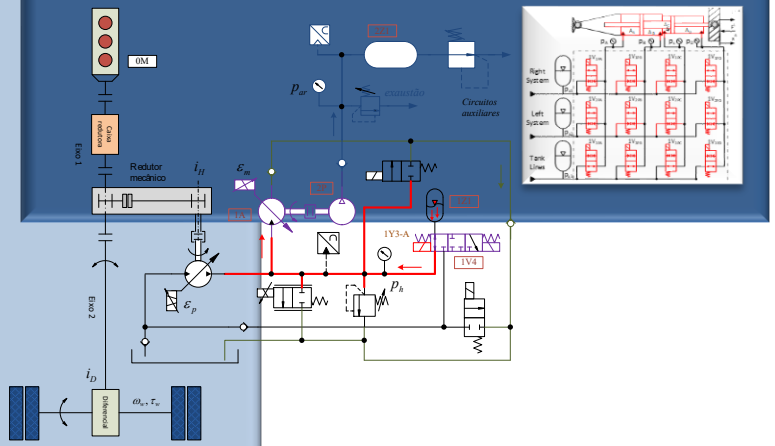
Development and Optimization of Hydraulic and Pneumatic Systems and Components

Fault analysis and design

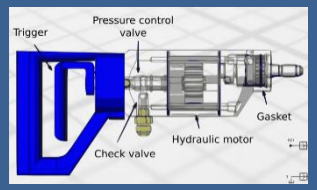




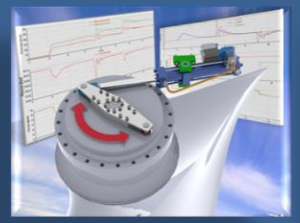
Mobile and aeronautical systems

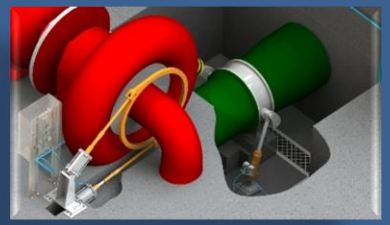


Component design

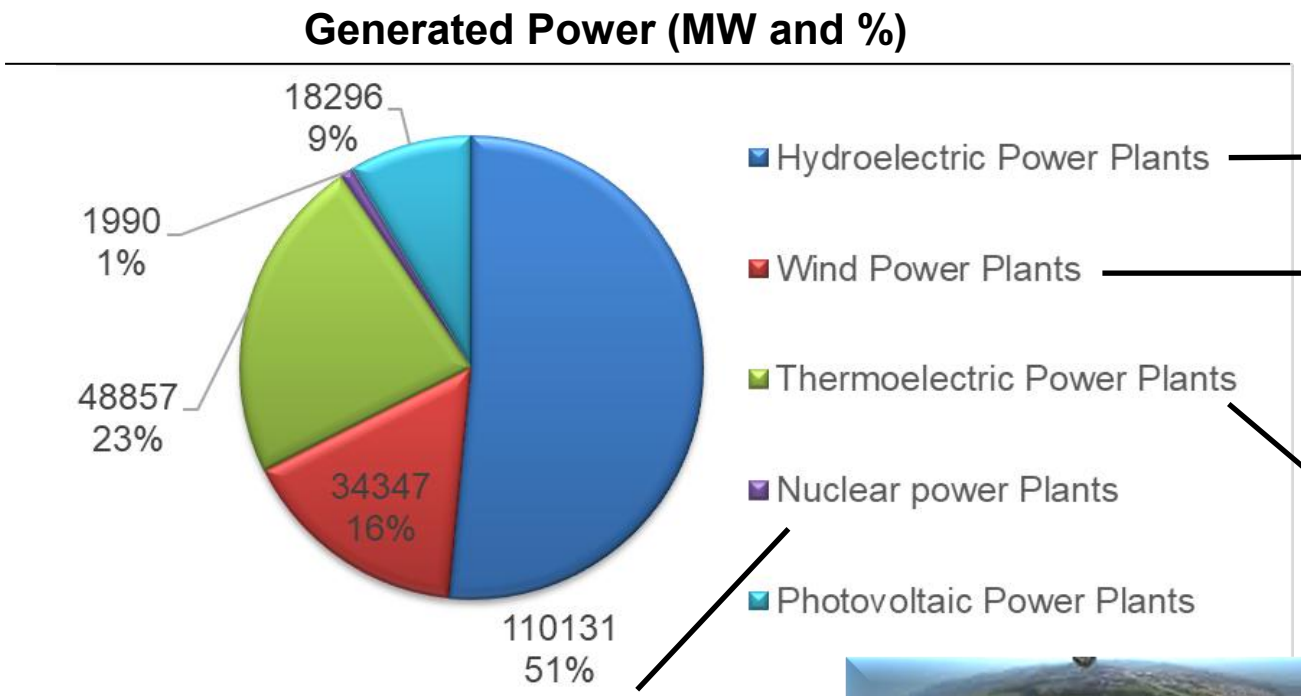


Speed and power governors





Electricity Generation in Brazil



ANEEL (2025)

Electricity Generation in Brazil

24,132 Power Plants in Operation:

213.6 GW of electrical power

1,345 Hydroelectric Power Plants:

110.1 GW of electrical power

1,132 Wind Power Plants:

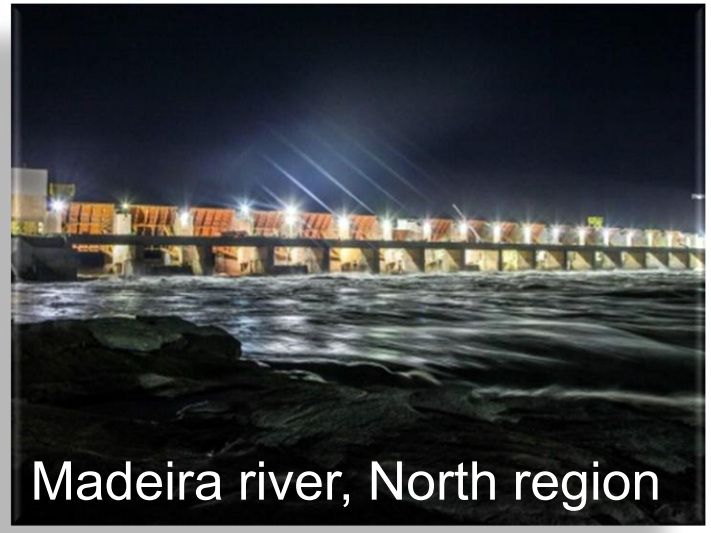
34.3 GW of electrical power

https://www.gov.br/aneel/pt-br/centrais-de-conteudos/relatorios-e-indicadores/geracao

Electricity Generation in Brazil

- Hydro Power Plants (2025):
  - In operation: 1,345 plants: 110,1 GW
  - Under construction: 25 plants: 0.37 GW
- Categories:
  - 701 Micro Power Plants (CGH) (< 5 MW)
  - 429 Small Power Plants (PCH) (5 MW to 30 MW)
  - 215 (Medium and Large) Power Plants (UHE) (> 30 MW)

Paraná river, South region

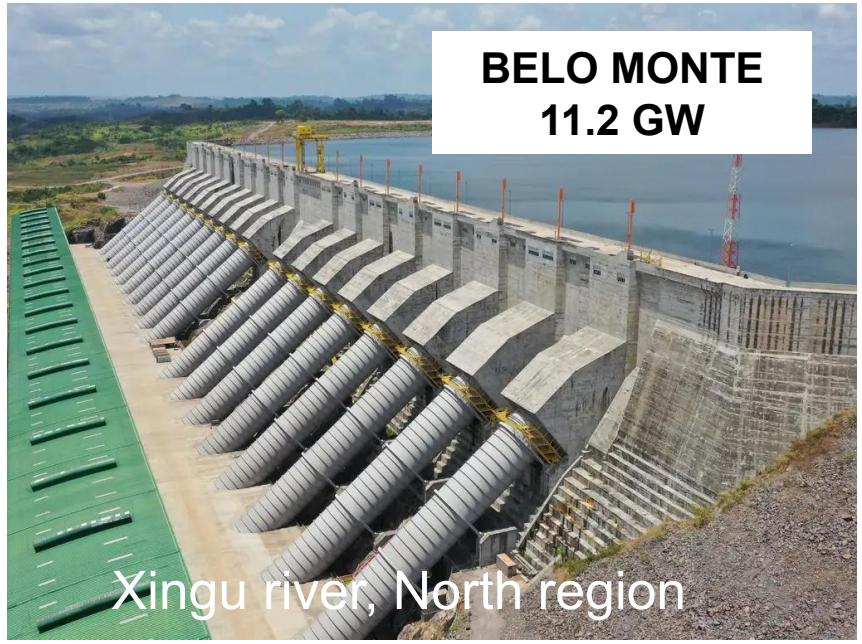


Madeira river, North region

JIRAU: 3.75 GW

Madeira river, North region

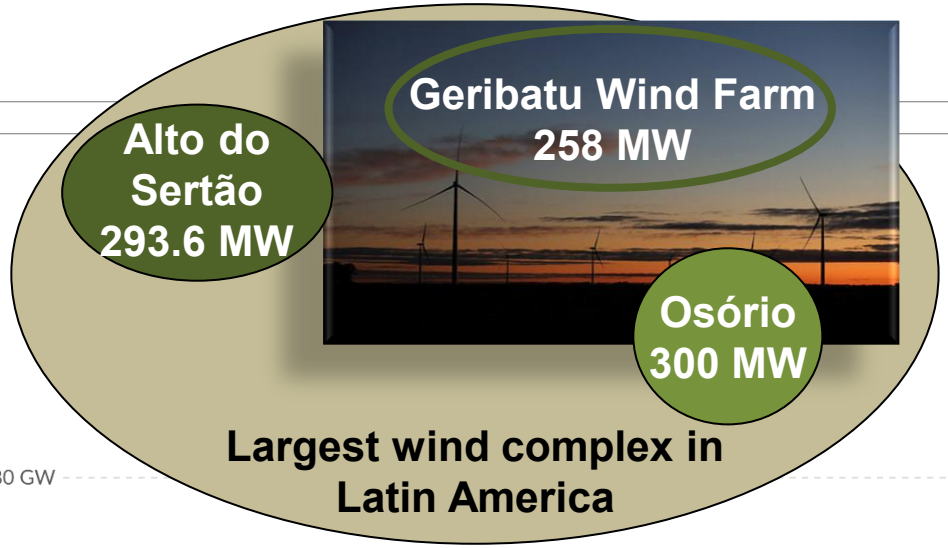
SANTO ANTÔNIO: 3.15 GW

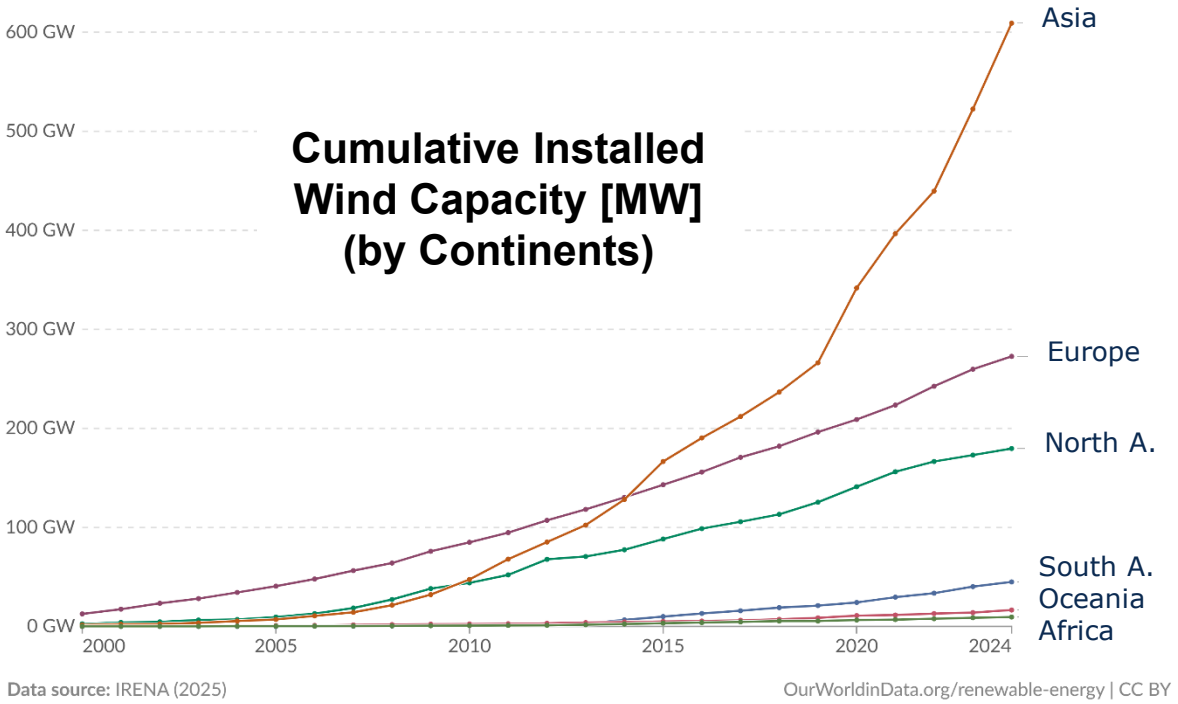


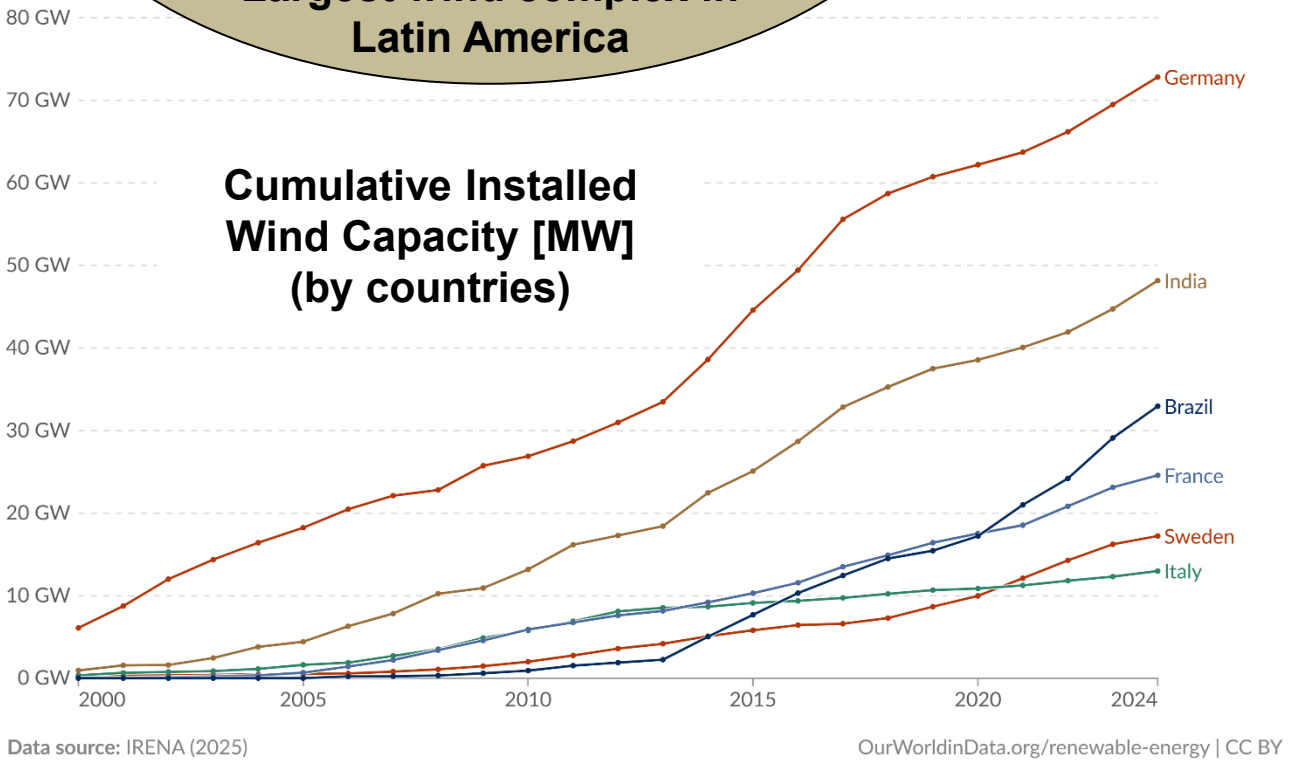
Xingu river, North region

Electricity Generation in Brazil

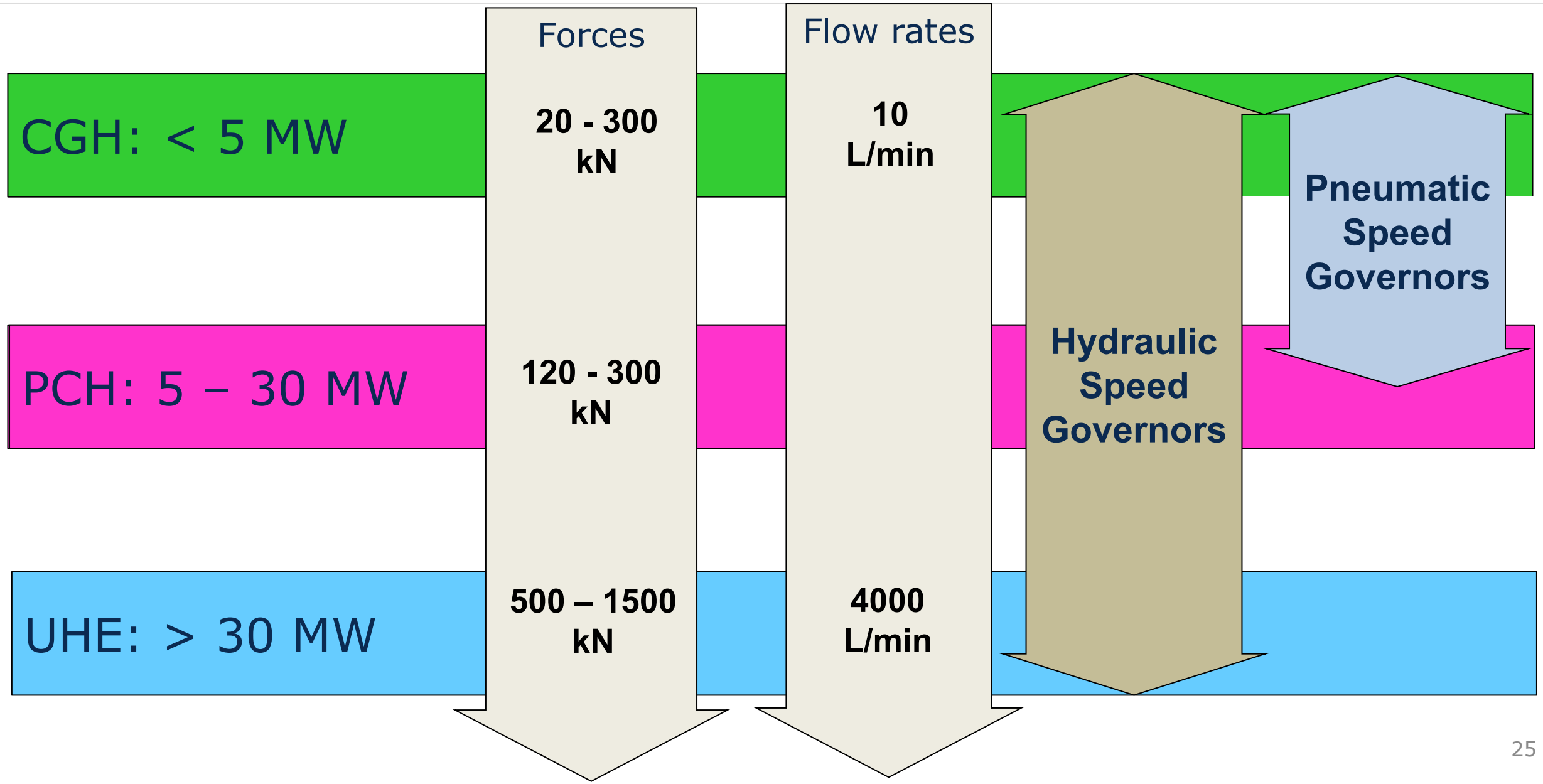
- Wind Power Plants (2025):
  - In operation: 1132 plants: 34 GW
  - Under construction: 52 plants: 1.7 GW





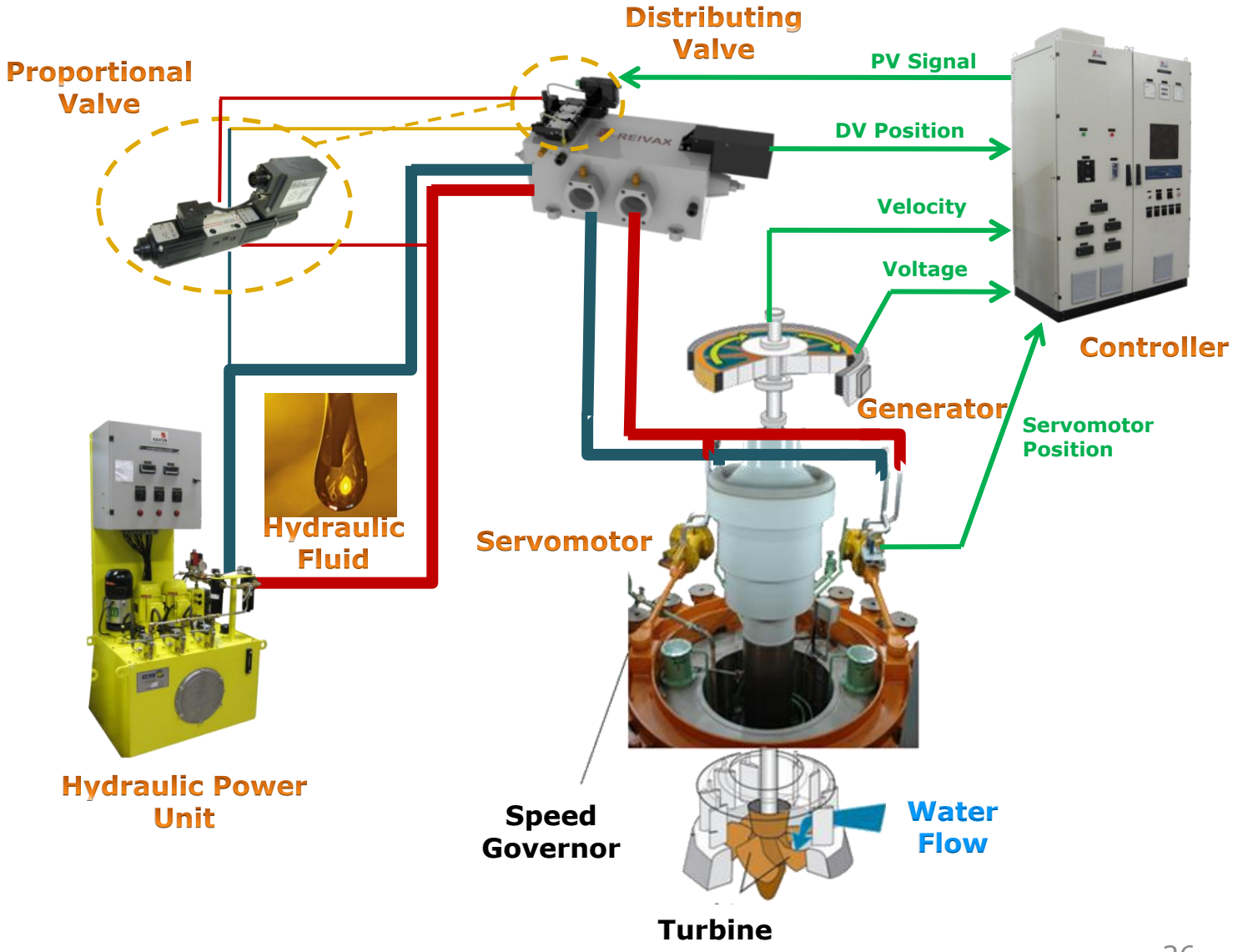


Hydroelectric Power Plants



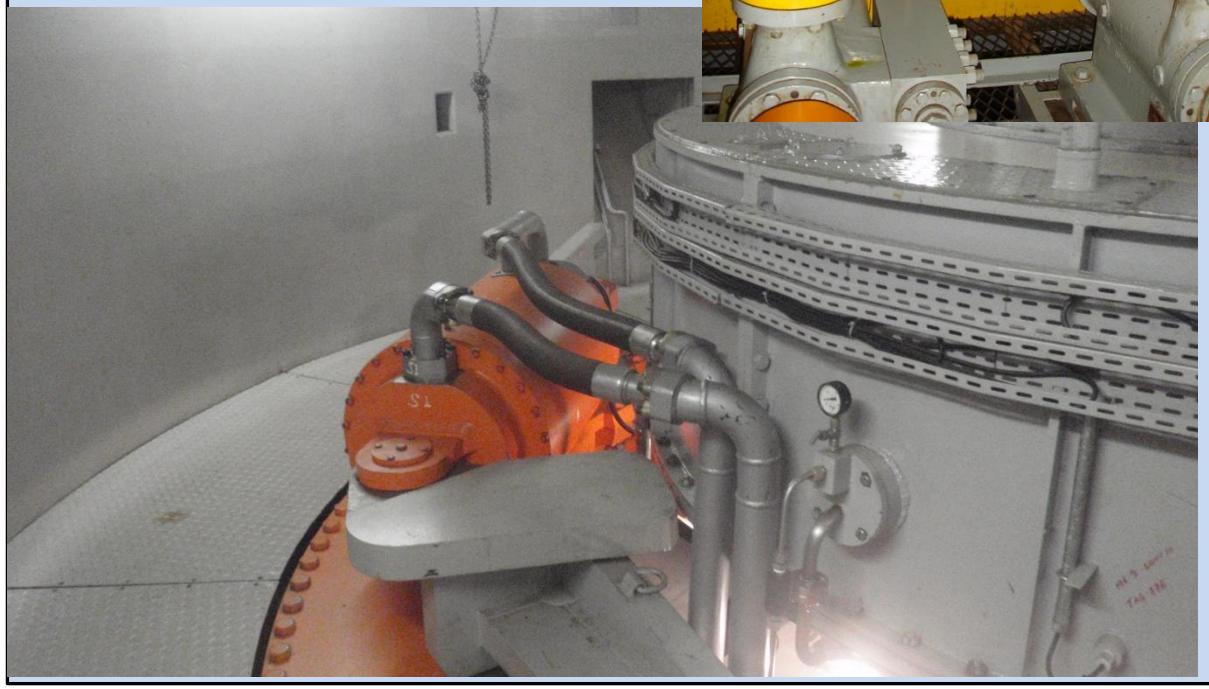
Hydraulic Speed Governors

- Conventional solution
  - Used worldwide in all types and sizes of Hydroelectric plants
- High service time:
  - Power plants from 1950s operated for more than 30 years without oil changes
- Intrinsic maximum force limits:
  - No damage on:
    - Blades (Kaplan and Francis)
    - Needle (Pelton)
    - Inlet valves (butterfly / spherical valves)
- Safety conditions:
  - Use of accumulators



Salto Grande
Kaplan
20 MW

Cachoeira Dourada
Kaplan
16.8 MW

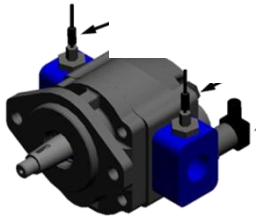


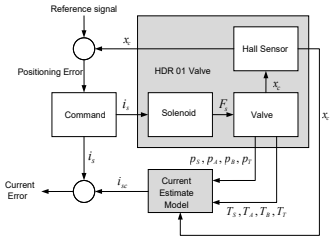
Hydraulic Technologies for Hydroelectric Power Plants

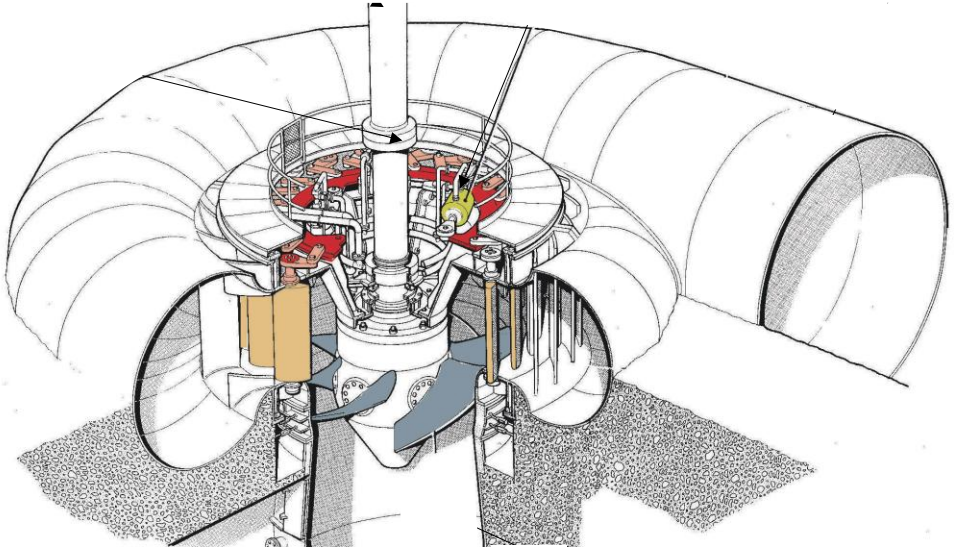
EMC - UFSC LASHiP HIDRÁULICA & PNEUMÁTICA

- Hydraulic component design:
  - Distributing valves

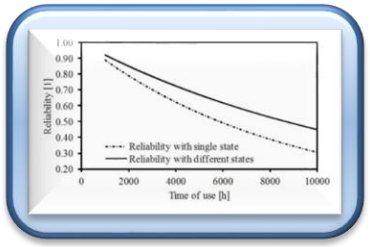
- Component fault detection:
  - Pumps
  - Proportional valves



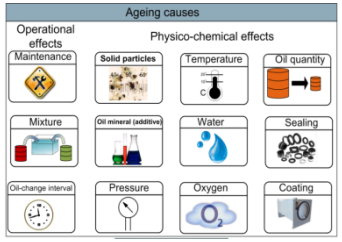




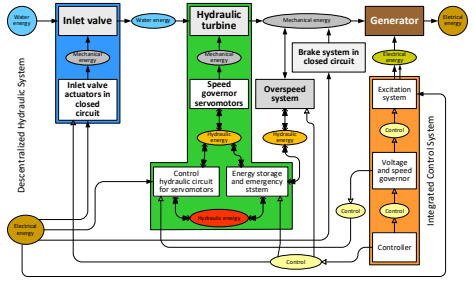
- System reliability analysis:
  - Design methodology



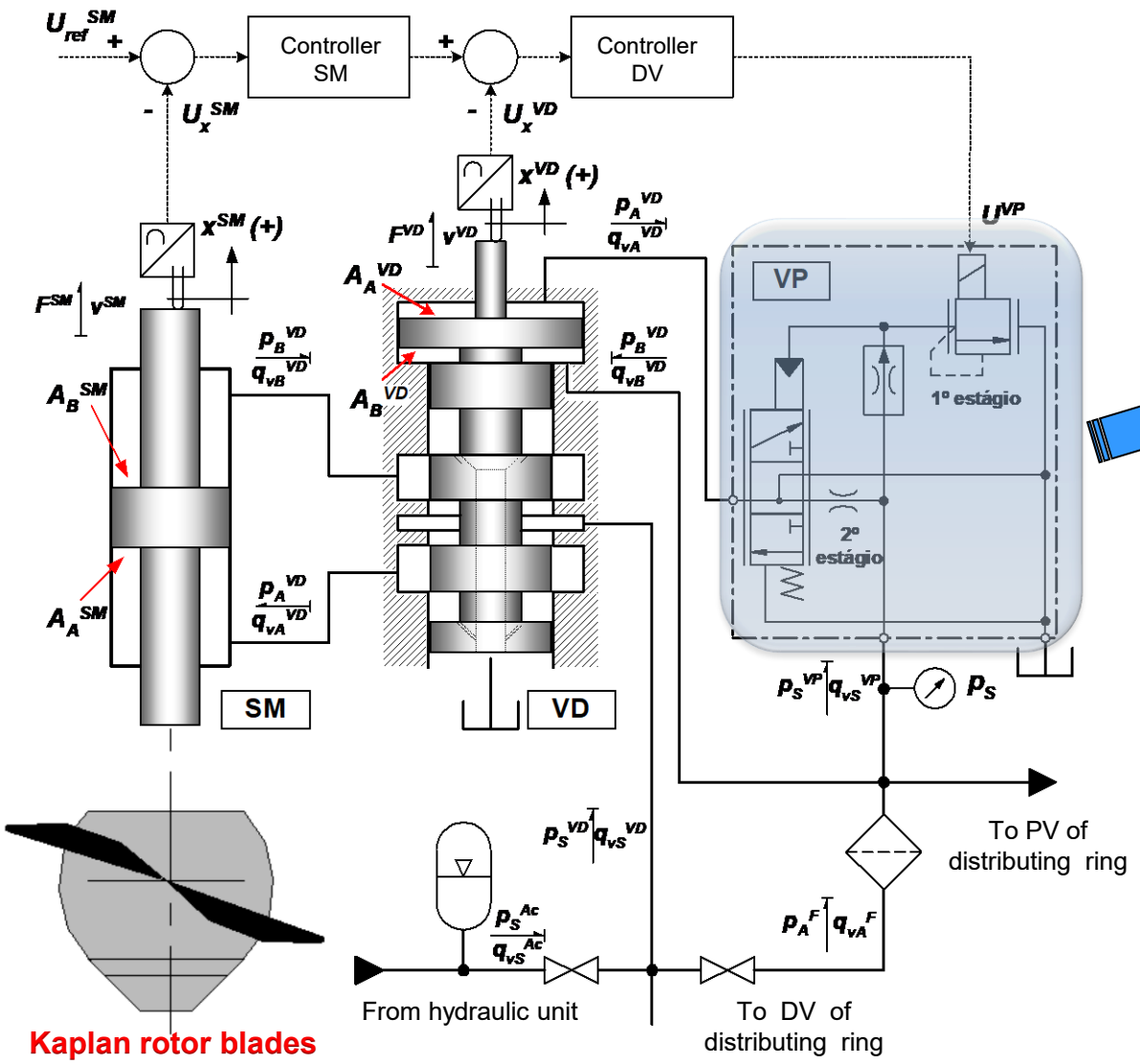
- Biodegradable hydraulic fluids:
  - Analysis of impact of contaminants
  - System design for bio-oils

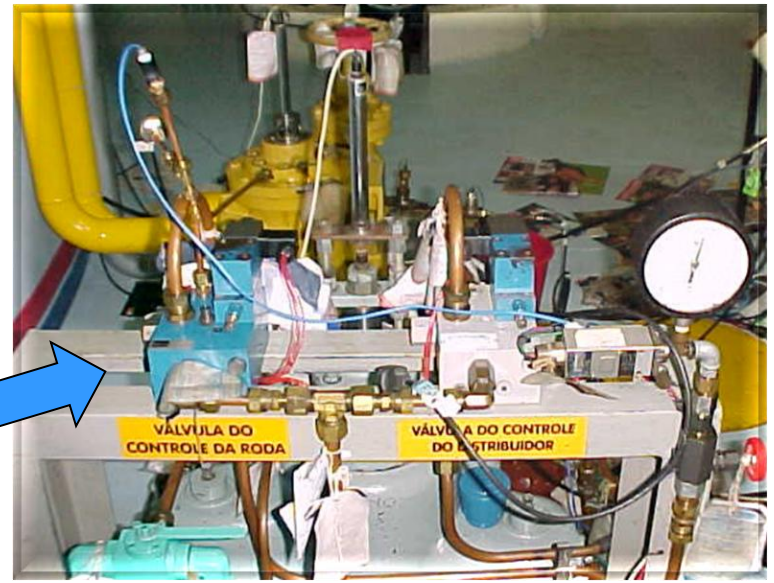


- Circuit architectures:
  - Proportional valves / Cartridge valves / EHAs
  - Decentralized hydraulic architectures



Industrial Proportional Valves for Speed Governors





1991:
Industrial Proportional Valves are Introduced into Speed Governors

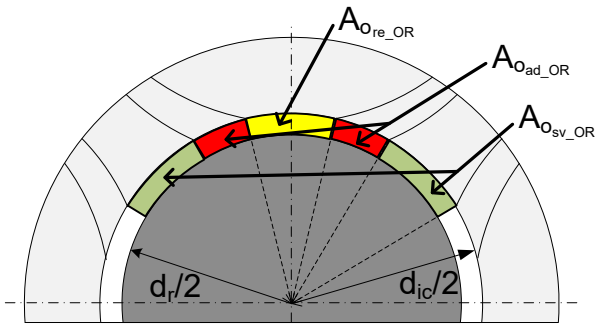
LASHIP EMC UFSC Hidráulica & Pneumática

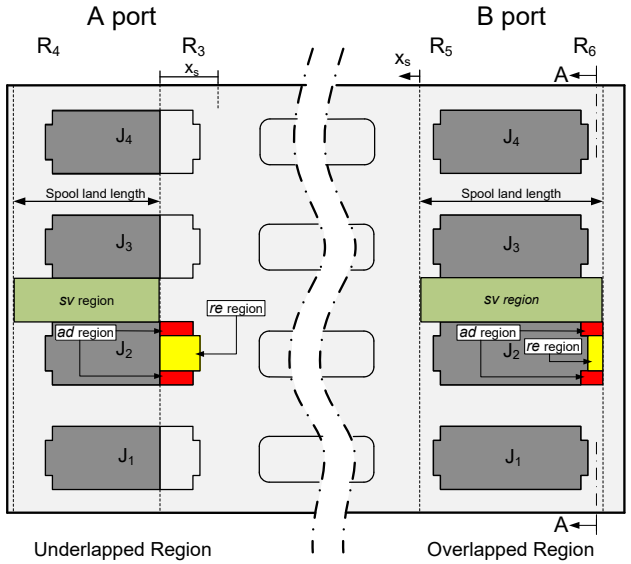
REIVAX

Distributing Valve: Desing and Performance Characterization

- Distributing valve:
  - **Hydraulically piloted 4-way directional continuous control valve**
  - **High flow rate: 1000 – 5000 L/min**
  - **Spool diameter: 80 – 120 mm**
  - **Spool maximum displacement: 6 mm**
  - **Spool control displacement: 1 mm**
  - **Radial clearance: 10 – 15 μm**
  - **Overlap: 0.2 mm**

350 MW Turbine
Tucurui Power Plant

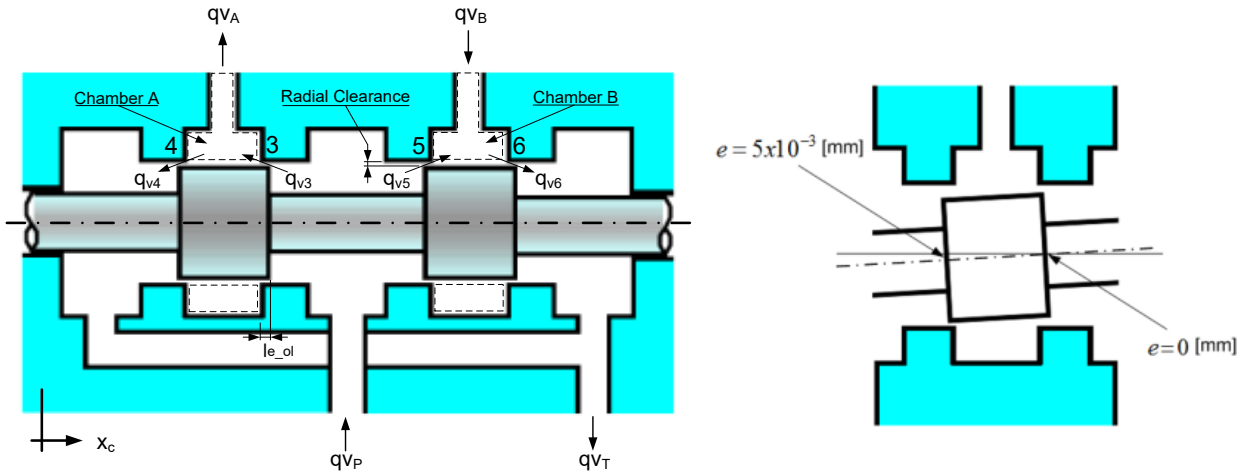




Distributing Valves: Desing and Performance Characterization

- Flow rate through the valve orifices
  - Flow rate under turbulent and laminar conditions
  - Discharge coefficient as a function of Reynolds number

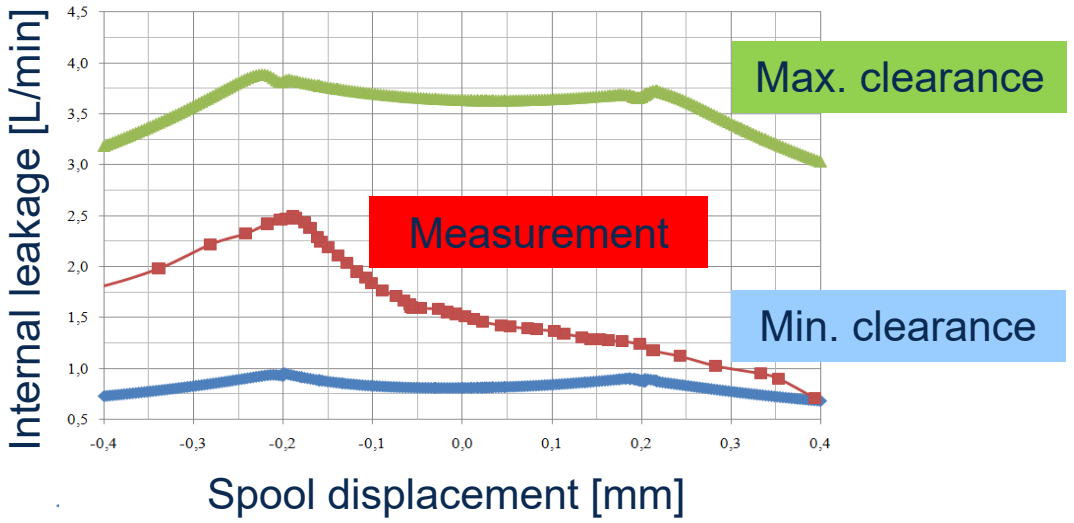
$$qv_{lam\_ol} = 0.01286 \cdot \frac{{D_{h\_ol}}^2 \cdot A_{0\_ol}}{\nu \cdot l_{ol}} \left(\frac{2 \cdot \Delta p}{\rho}\right)$$



- Tests according IEC 60308
  - High sensitivity with radial clearance and overlapping

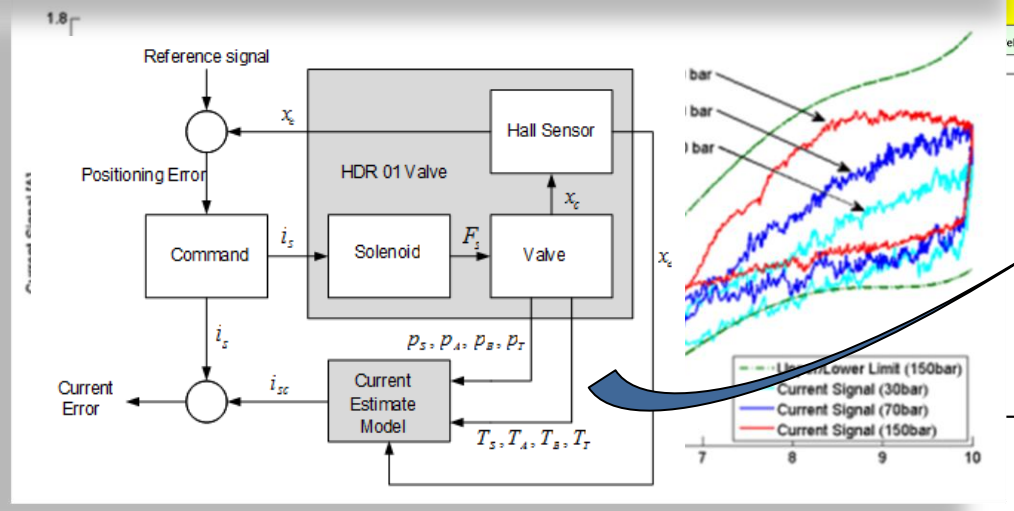
Measuring accuracy: 4 μm

Orifice	Min. clear. [μm]	Aver. clear. [μm]	Max. clear. [μm]
3	10.5	14.0	17.5
4	11.5	15.0	18.5
5	8.0	11.5	15.0
6	11.0	14.5	18.0



Fault Detection in Proportional Valves: From Proof of Concept to Industrial Prototype

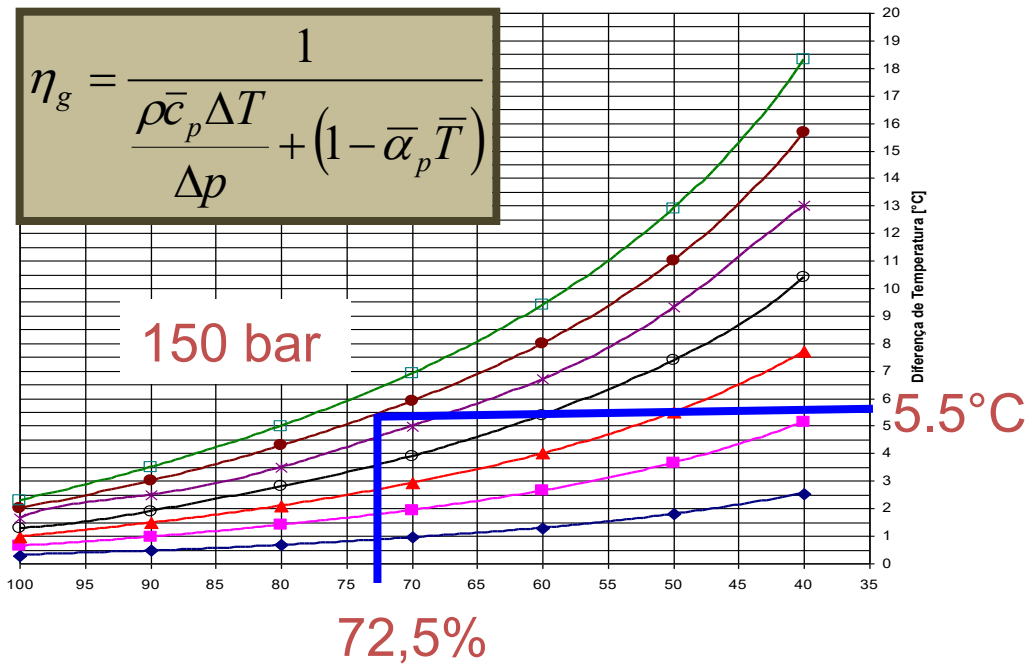
- Implementation of the fault detection in off-the-shelf valves
- Embedment in software/hardware of speed governors for hydroelectric power plants

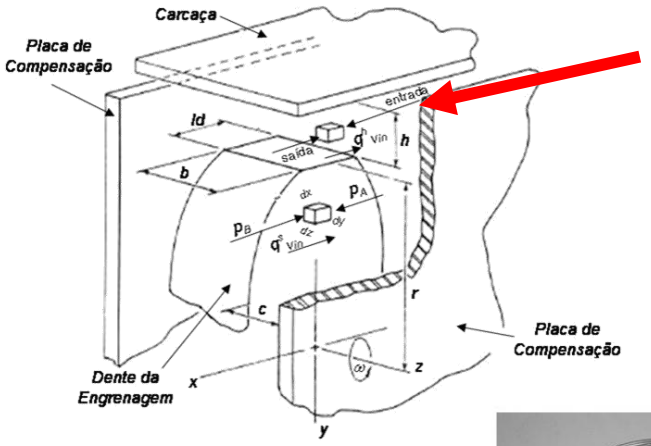


Fault Detection: Gear Pumps - On-Line Efficiency Estimation

- Global effciency determined by thermodynamics and fluid mechanics principles
- On-line estimation by measuring of
  - Inlet and outlet temperatures
  - Outlet pressure

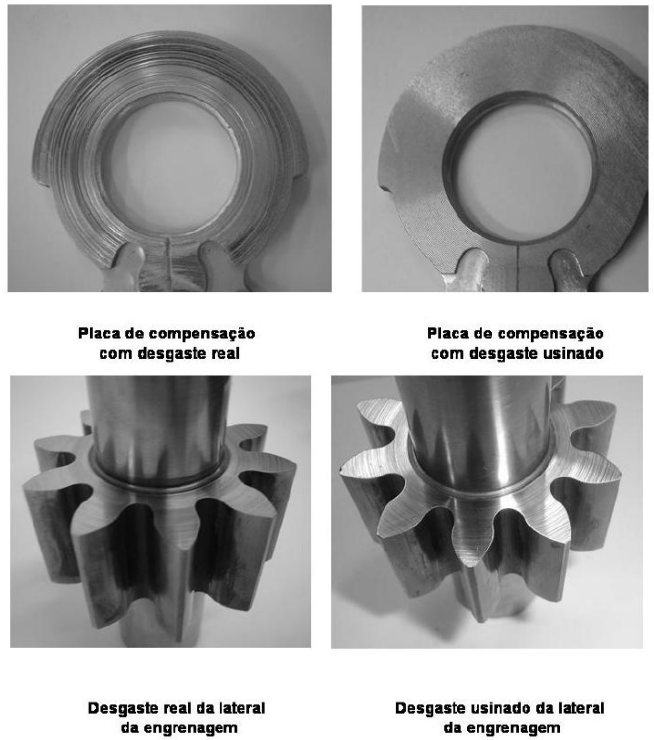
$$\eta_g = \frac{1}{\frac{\rho \bar{c}_p \Delta T}{\Delta p} + \left(1 - \bar{\alpha}_p \bar{T}\right)}$$





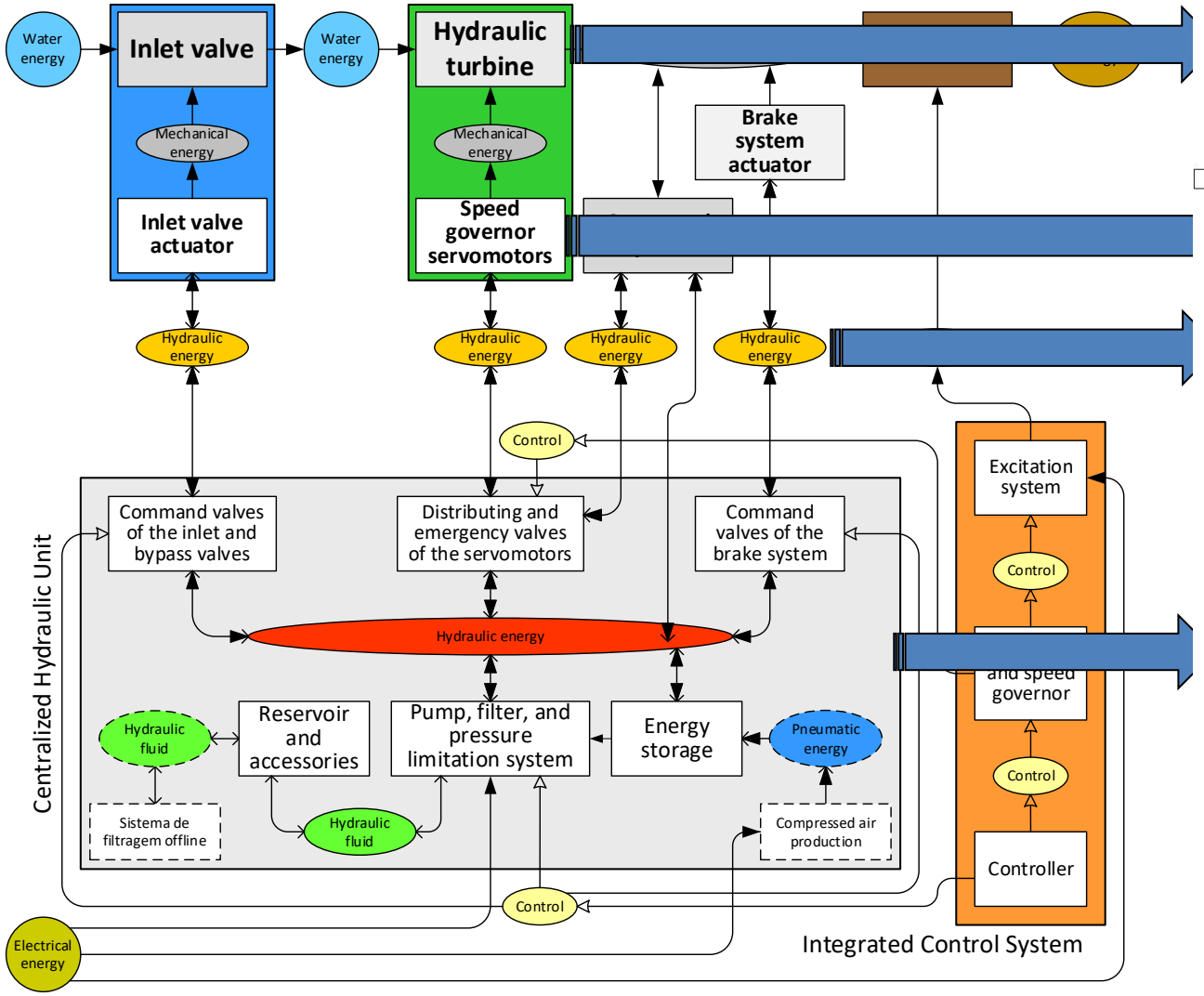
$$q_{V\,\mathrm{sin}}^{h} = \frac{ld.h^3}{12.\mu.b}.(p_B - p_A) - \frac{ld.h}{2}V$$

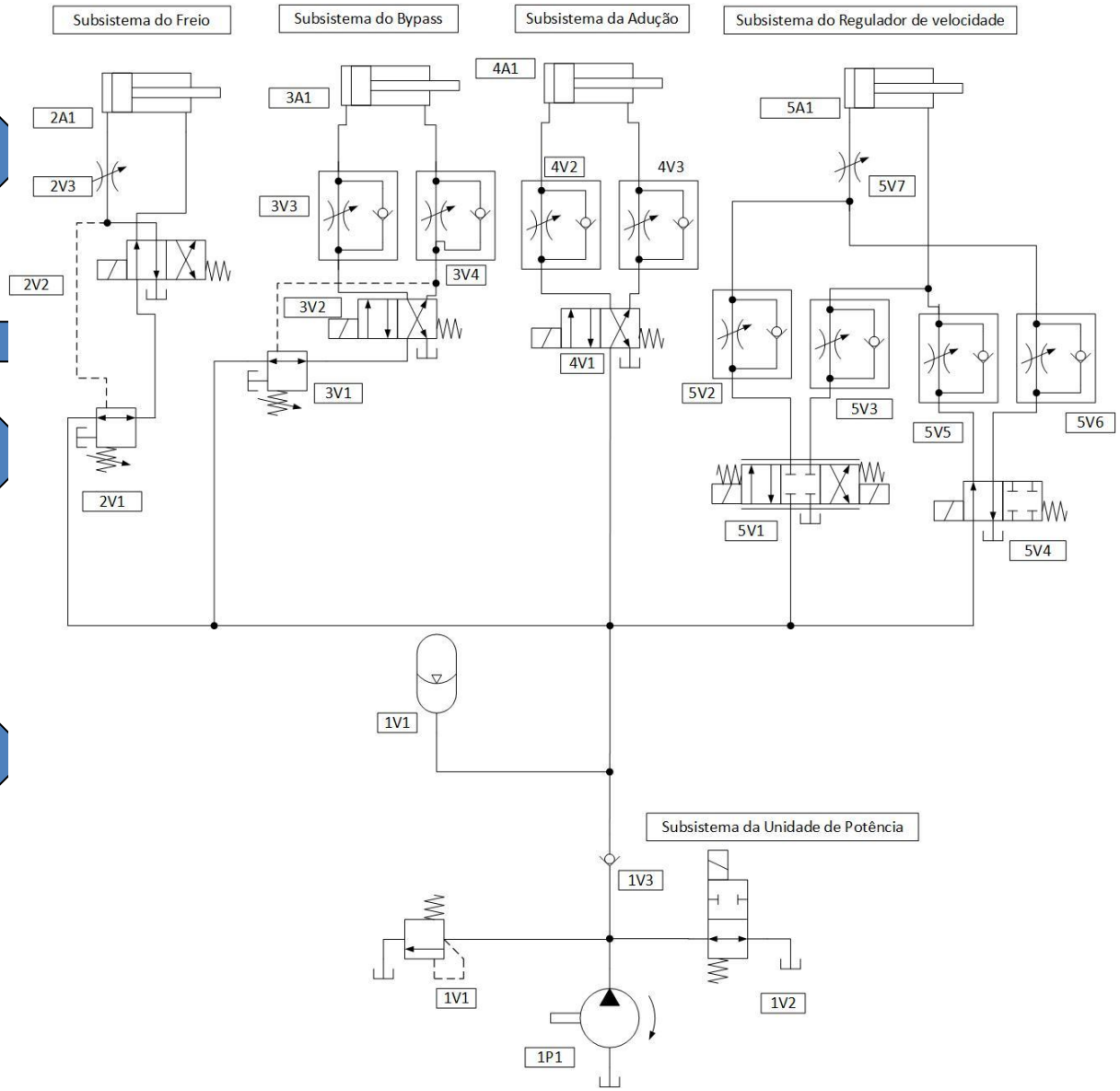
Fault reproducttions by milling



New Circuit Architectures

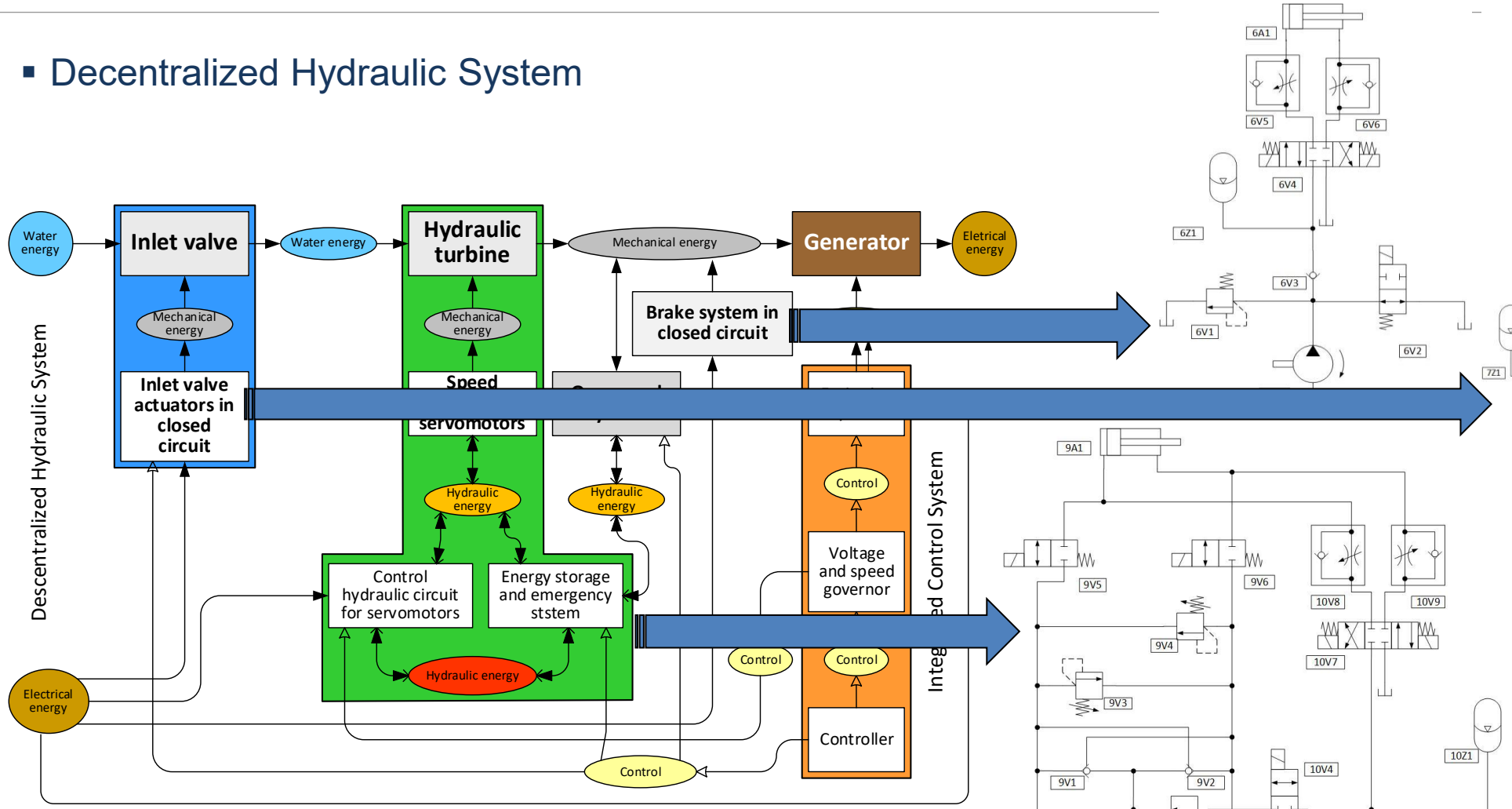
- Centralized Hydraulic Power Unit

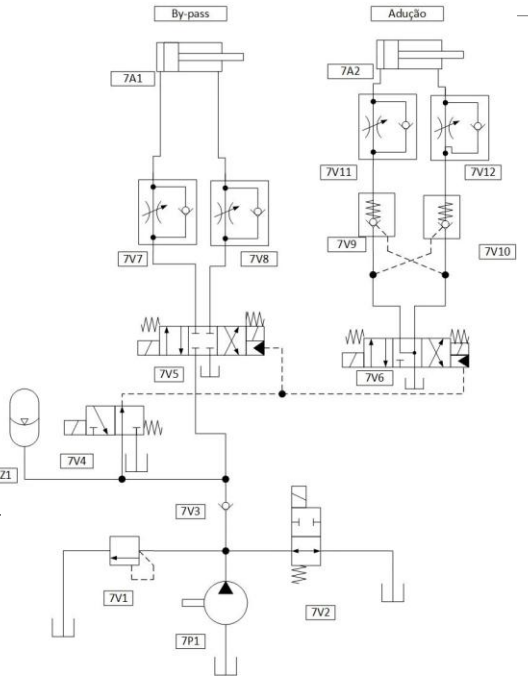




New Circuit Architectures

- Decentralized Hydraulic System



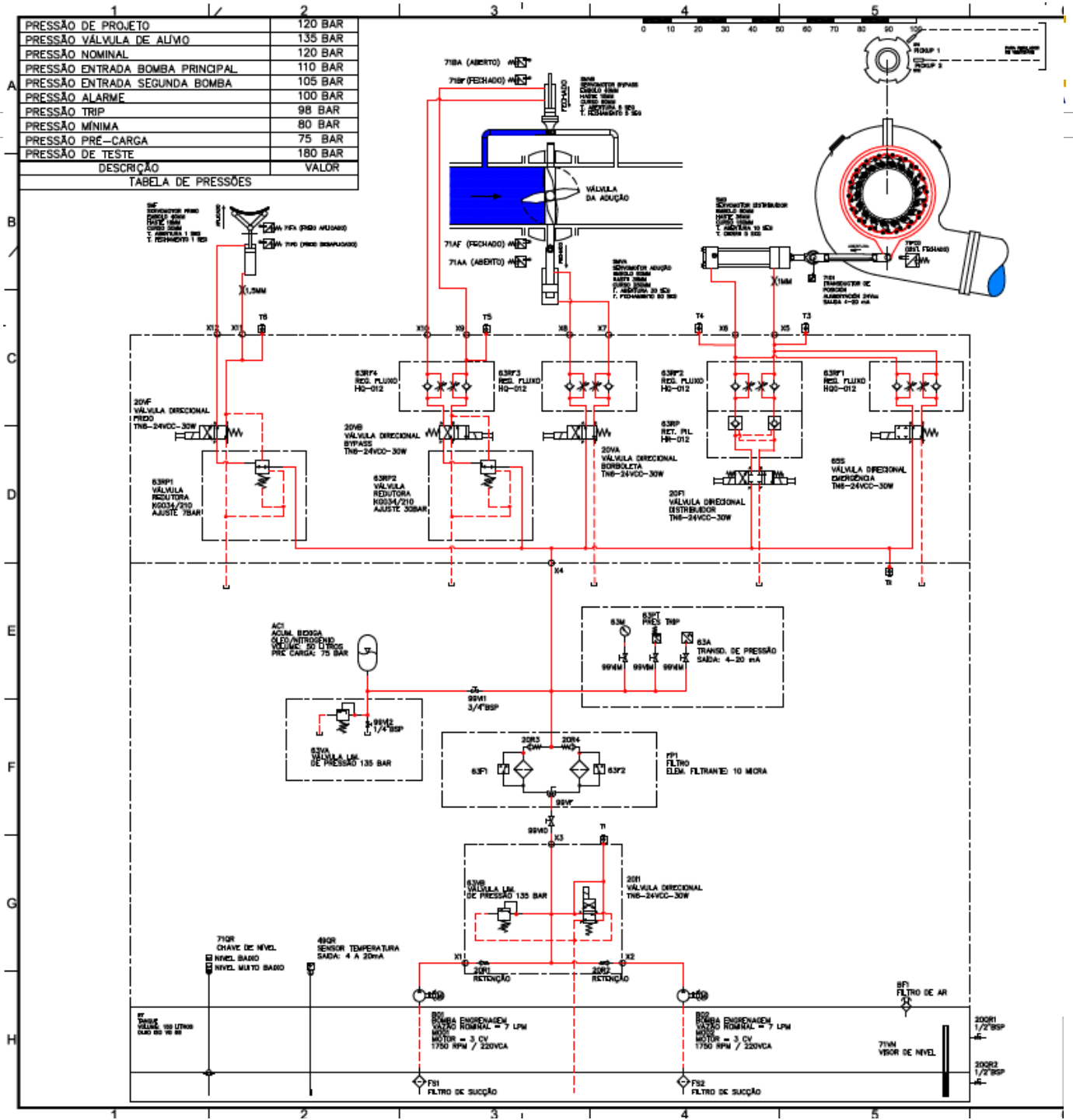


New Circuit Architectures

- Micro Power Plant (CGH)
  - Working pressure: 120 bar
  - Maximum flow rate: 9 L/min

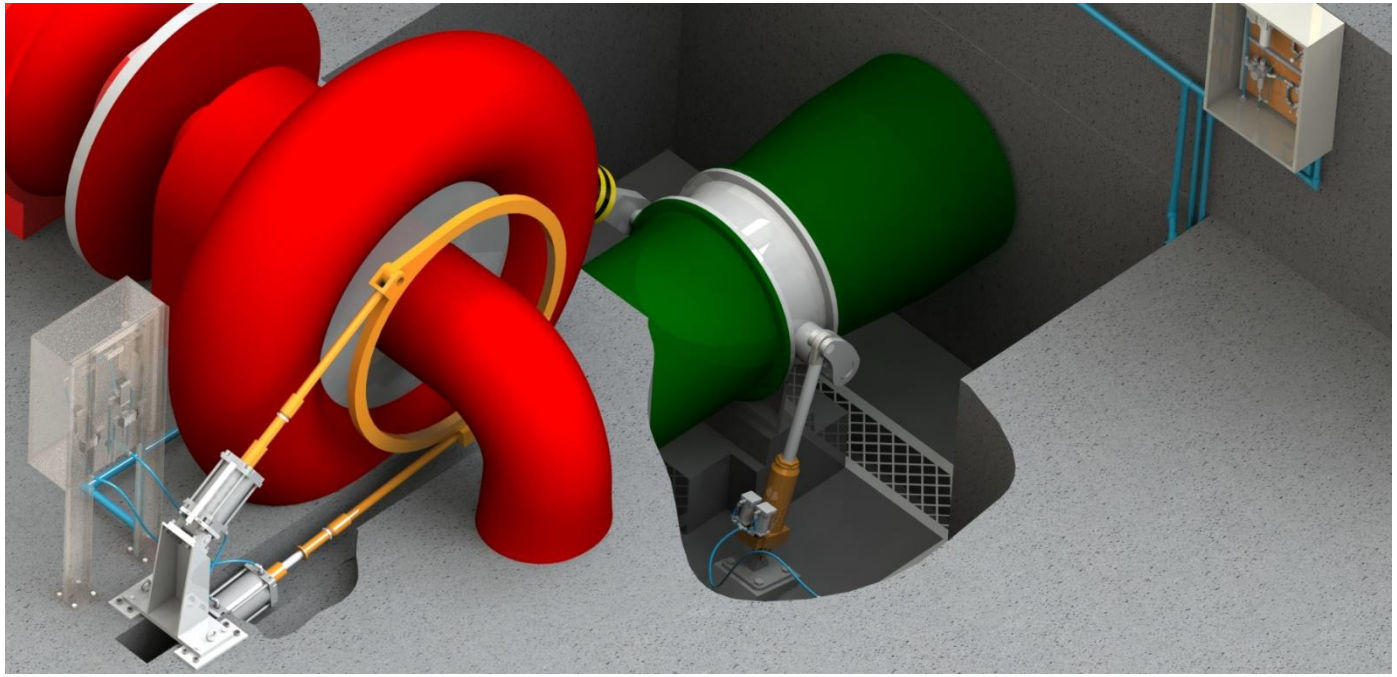
3 Saltos
Francis
1 MW

- **From Centralized to descentralized system:**
  - **69 % reduction in oil volume**
  - **25 % reduction in energy losses**



Hydraulic Speed Governors

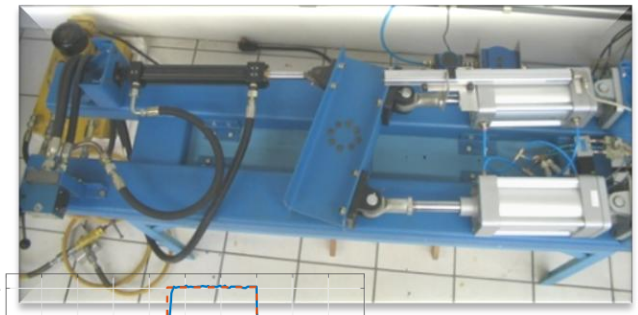
- Conventional solution
  - Used worldwide in all types and sizes of Hydroelectric plants
- High service time:
  - Power plants from 1950s operated for more than 30 years without oil changes
- Intrinsic maximum force limits:
  - No damage on:
    - Blades (Kaplan and Francis)
    - Needle (Pelton)
    - Inlet valves (butterfly / spherical valves)
- Safety conditions:
  - Use of accumulators

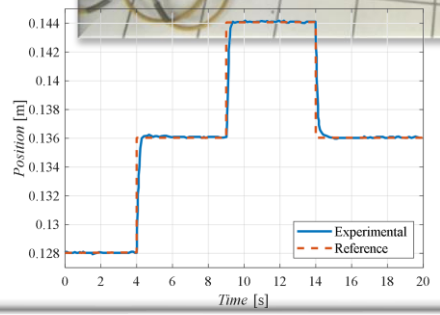


Pneumatic Speed Governor: Developing Steps

Desing and Proof-of-Concept

- Circuit design, modeling, simulation
- Prototype in lab. with load
- Step response tests according to IEC/IEEE Standards

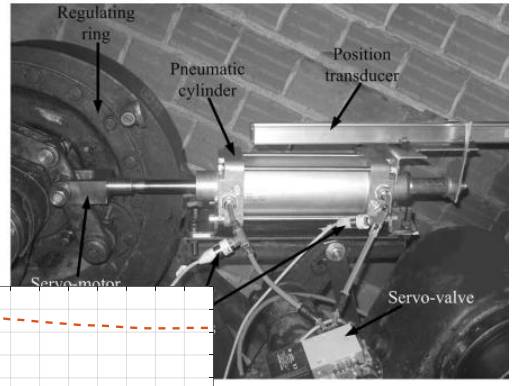


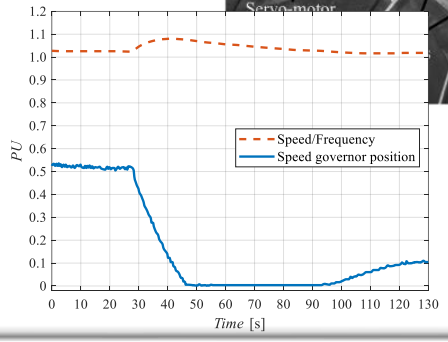


TRL 4

Small Scale Prototype

- Francis turbine (35 kVA)
- Tests according to IEC/IEEE:
  - Step response
  - Load rejection

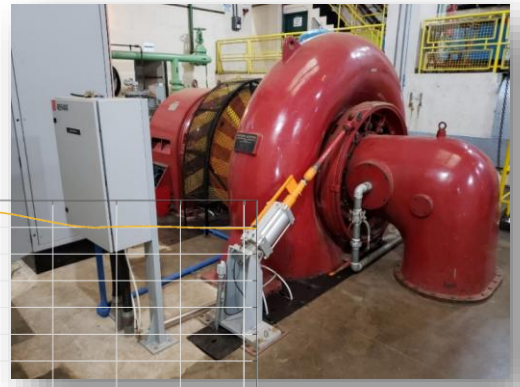


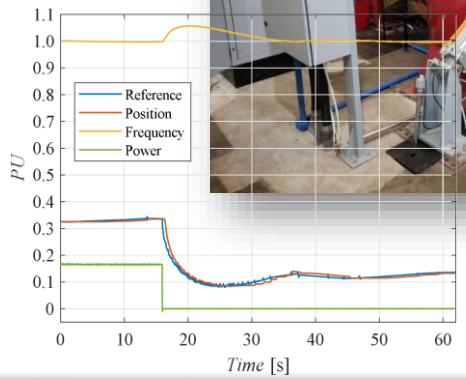


TRL 5

Pilot System

- Francis Turbine (438 kVA)
- Full automation:
  Speed governor+ Inlet Valve + Brake
- Tests according to IEC/IEEE:
  - Step response
  - Load rejection





TRL 7

2006 2008 2021

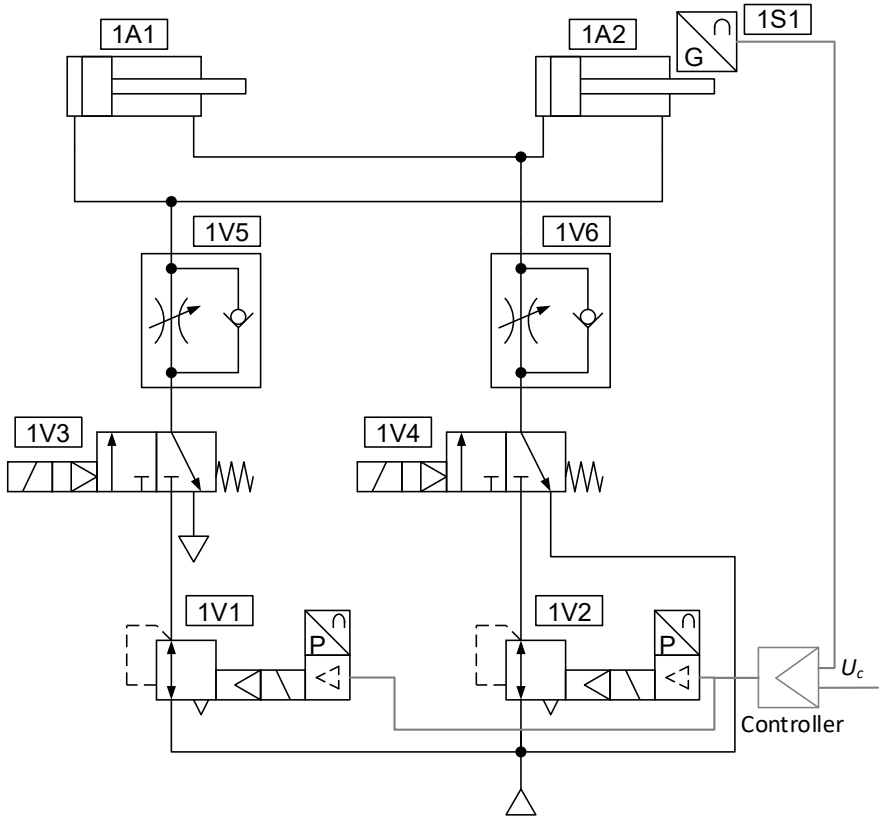
Pneumatic Speed Governor: Pilot System

- Francis Horizontal Turbine:
  - Nominal power: 438 kW
  - Head: 18.5 m
- Speed governor:
  - Emergency closing
  - Minimal opening and closing times: 300 – 600 ms
  - Positioning error: 1% (1.3 mm)
  - Maximum force: 26 kN
- Inlet valve:
  - Emergency closing
  - Nominal diameter: 900 mm
  - Opening force: 153 kN
  - Minimal opening and closing times: 80 to 160 s

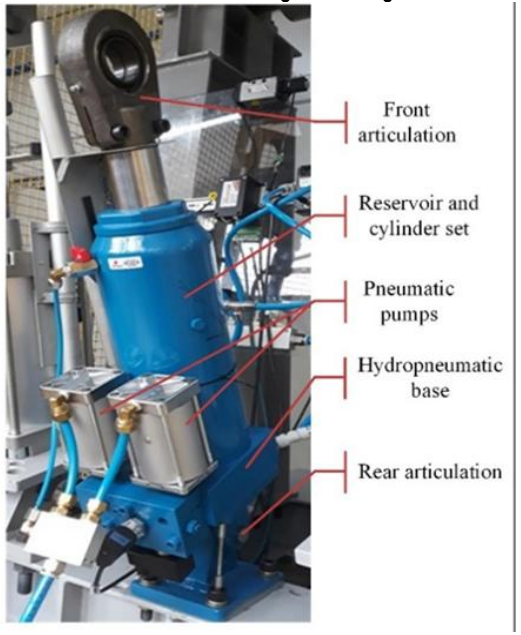
a)

Pneumatic Speed Governor: Pilot System

- Speed governor
  - Control by proportional pressure reducing valves



- Inlet valve
  - Actuator based on hydropneumatic jack
  - Forces up to 300 kN @ 5 bar pneumatic pressure

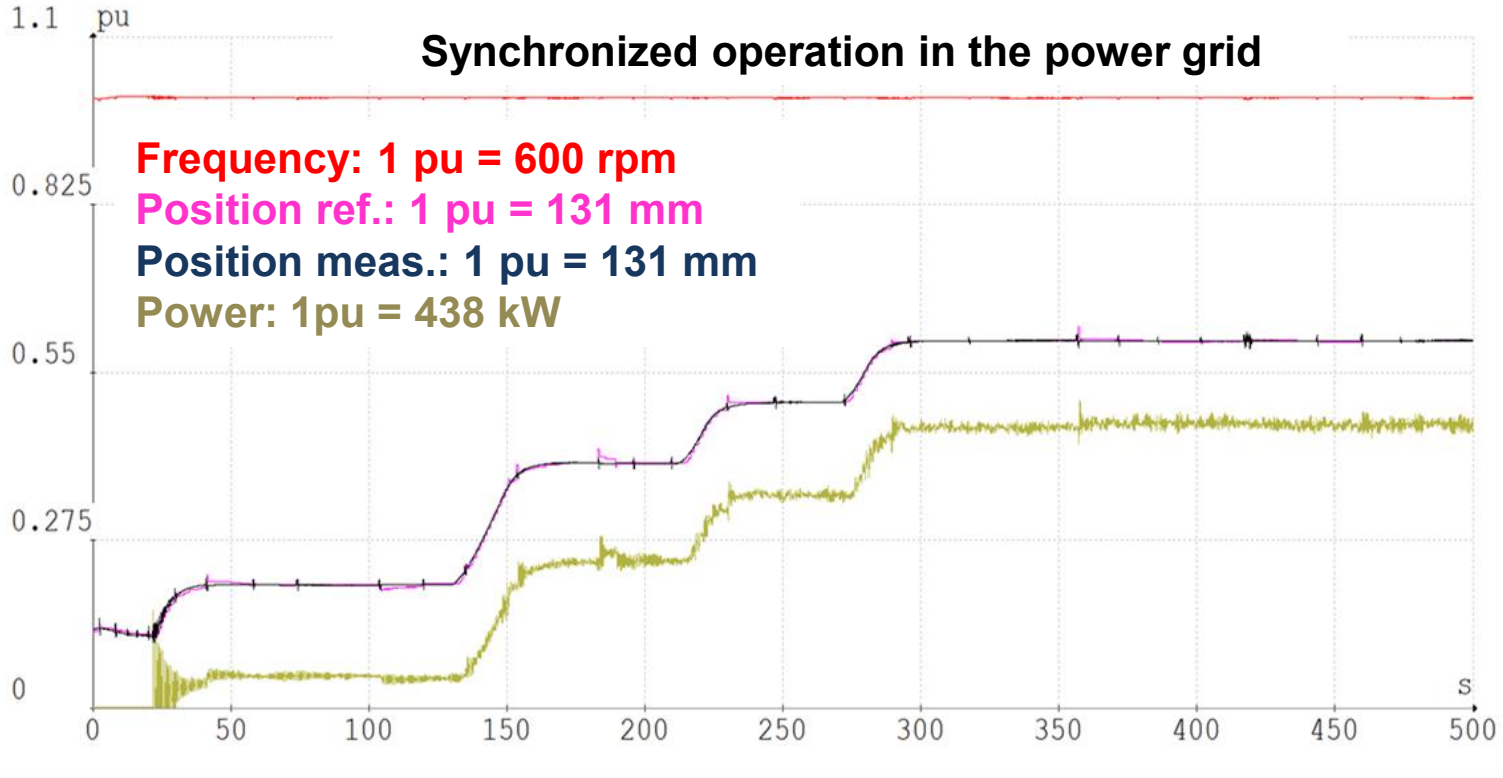


Pneumatic Speed Governor: Main Results

- Robust components
- 43% lower acquisition cost
- 50% reduction in installation cost
- Easier installation and maintenance
- Clean solution: Compressed air instead of mineral oil

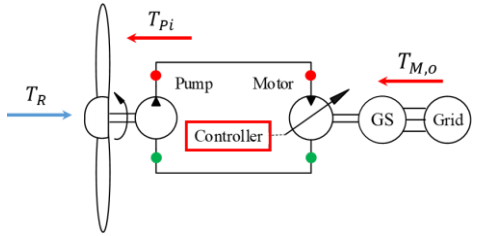
- Francis turbines up to 10 MW
- Pelton turbines up to 30 MW

- Pilot system under operation since December 2021
  - **Position error:**
    - **IEEE/IEC: 1% of stroke = 1.3 mm**
    - **Effective position error: 0.13 mm**

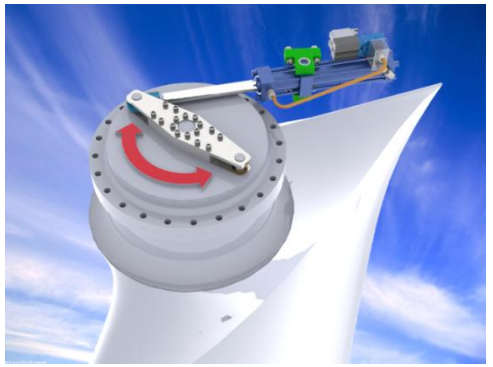


Hydraulic Technologies for Wind Turbines

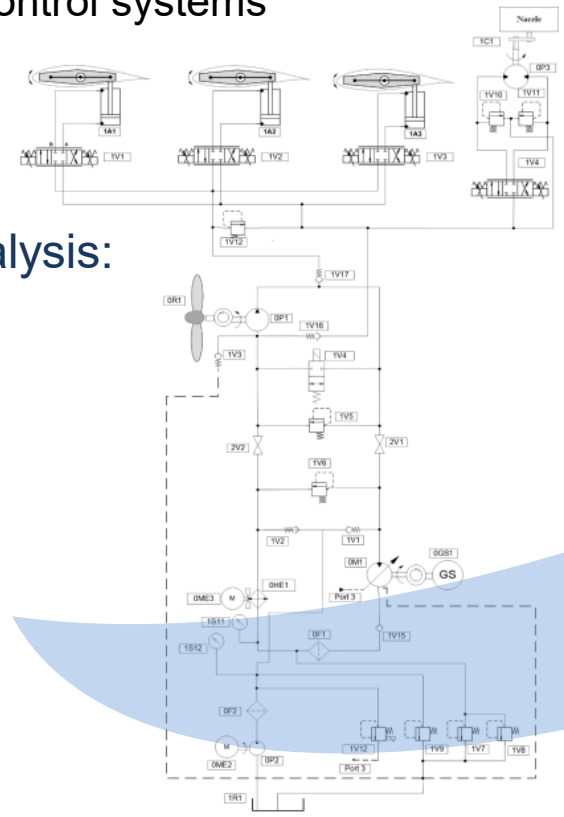
- Rotor-generator coupling
  - Hydrostatic transmission

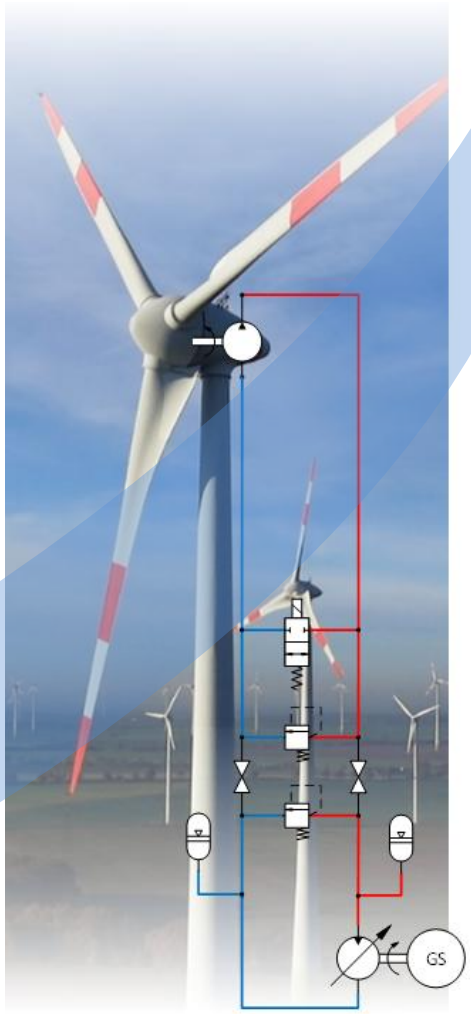


- Pitch control:
  - Analysis of hydraulic control systems
  - Aerodynamic forces



- Integrated system analysis:
  - Pitch control
  - Power transmission
  - Yaw control





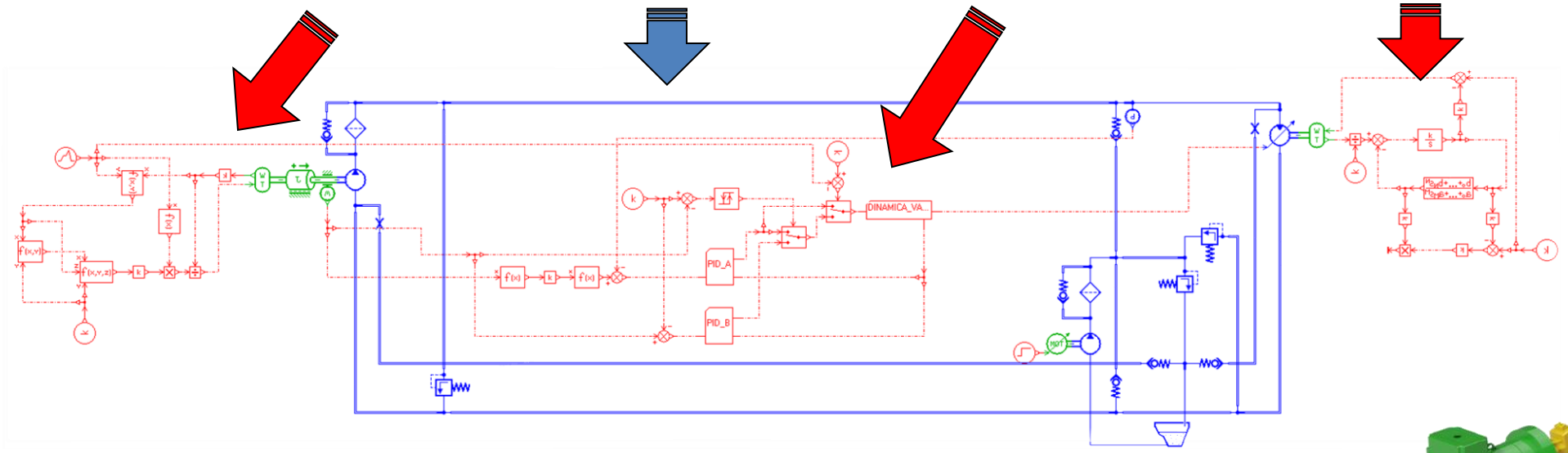
Hydrostatic Transmission for Rotor – Generator Coupling

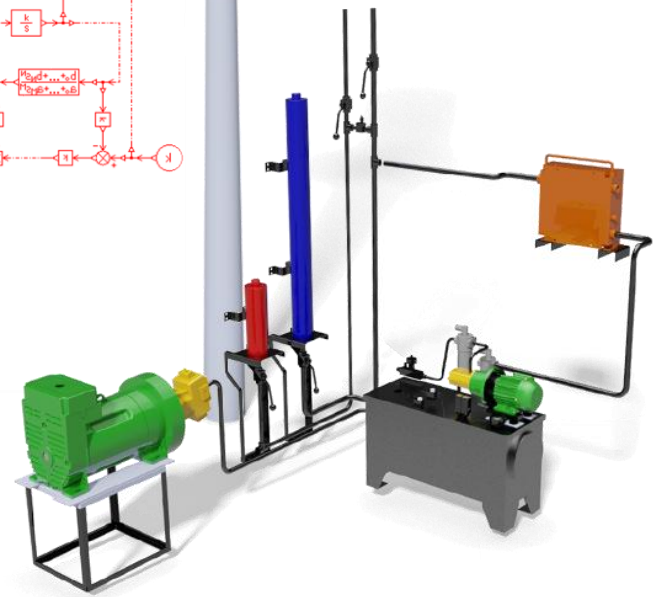
- Test rig for proof of concept evaluation
  - 8.5 m high to include the effects of height difference;
  - 28 kW; Off-the-shelf components;
  - System connected to the grid;
- Improve the overall efficiency
- Achieve a cost effective solution
  - Synchronous generator
  - Most components installed on the ground

Hydrostatic Transmission for Rotor – Generator Coupling

- Test rig for proof of concept evaluation
  - 8.5 m high to include the effects of height difference;
  - 28 kW; Off-the-shelf components;
  - System connected to the grid;

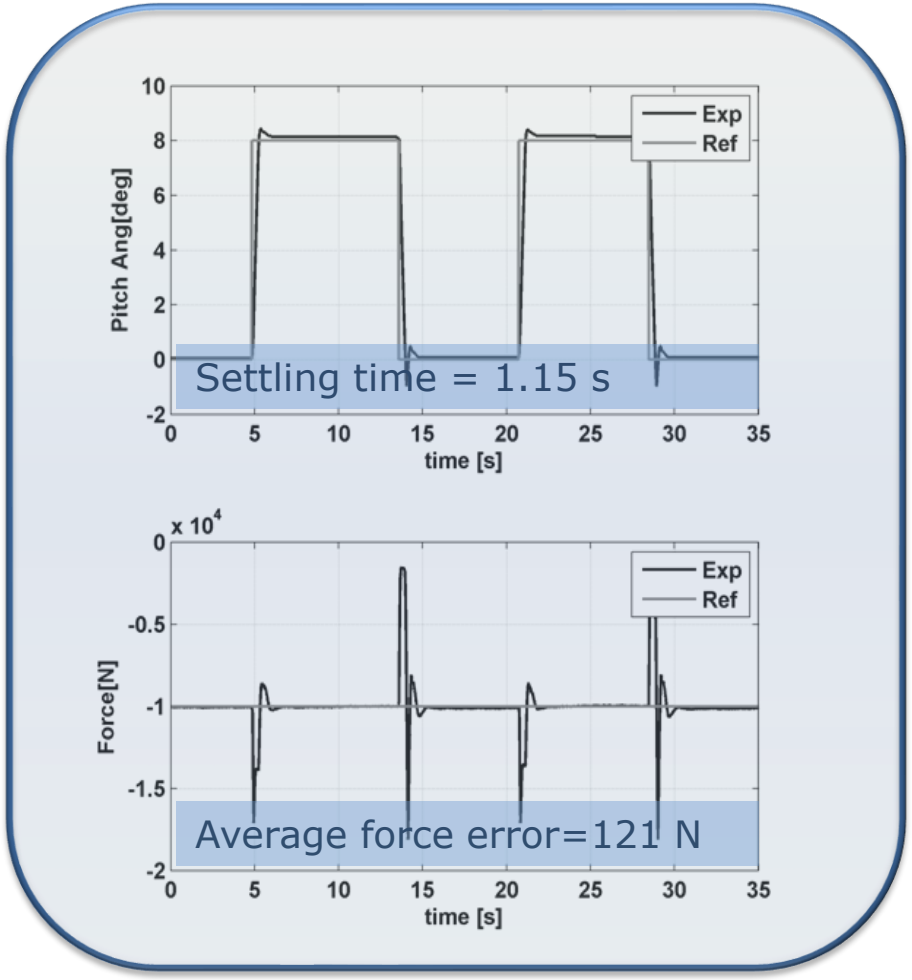
Wind torque; Hydraulic circuit; Control System; Electrical grid

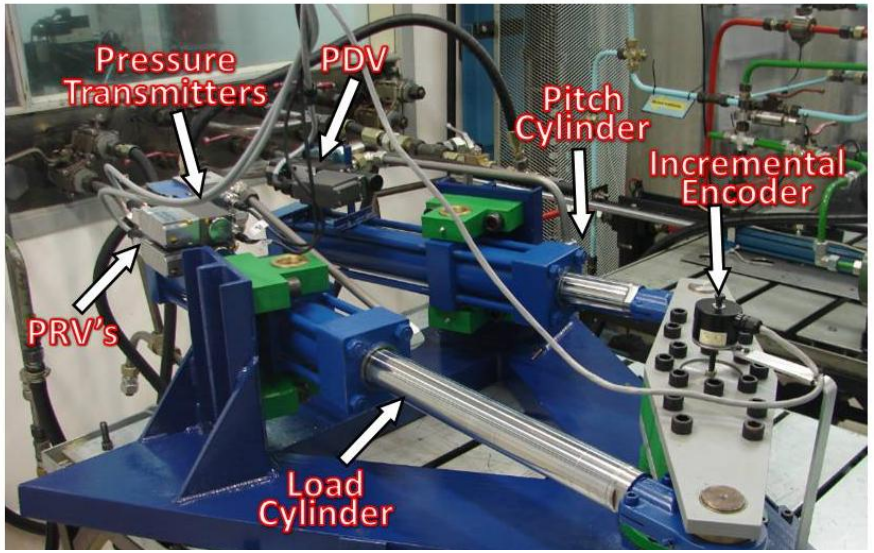


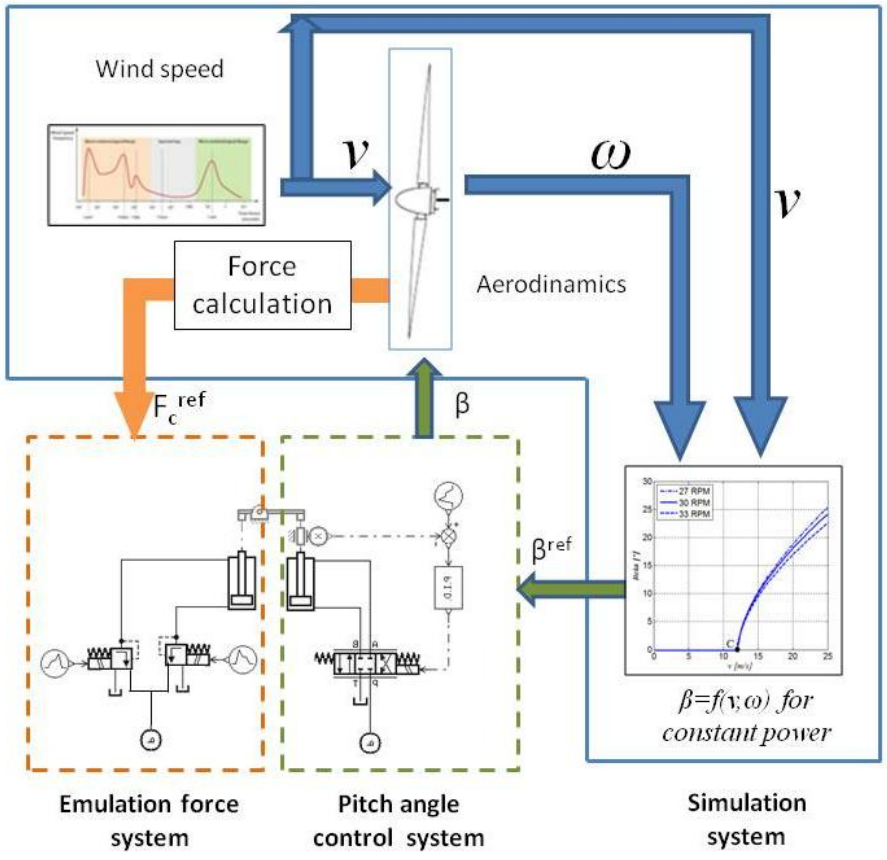


Wind Turbine Pitch Drives

- Hardware in the loop
- Emulation of load forces (10 kN)
- Proportional hydraulic control system



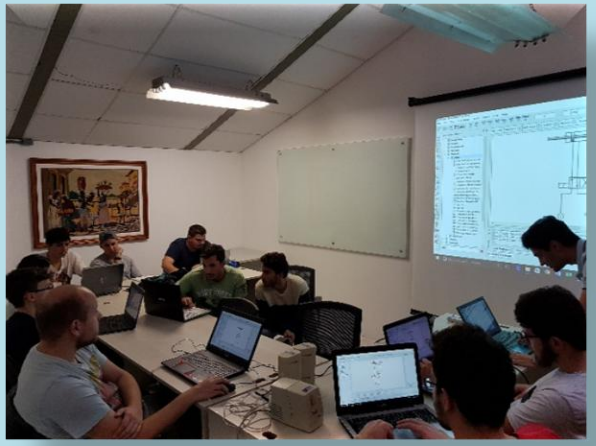




Master's and Doctorate at UFSC

- POSMEC – Graduate Program in Mechanical Engineering
  - Master's: 2 years: Subjects (18 credits) + Thesis
  - Doctorate: 4 years: Subjects (36 credits) + Thesis
- No fees charged
- Eligible for scholarships
  - From governmental programs / research projects

CAPES 6



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