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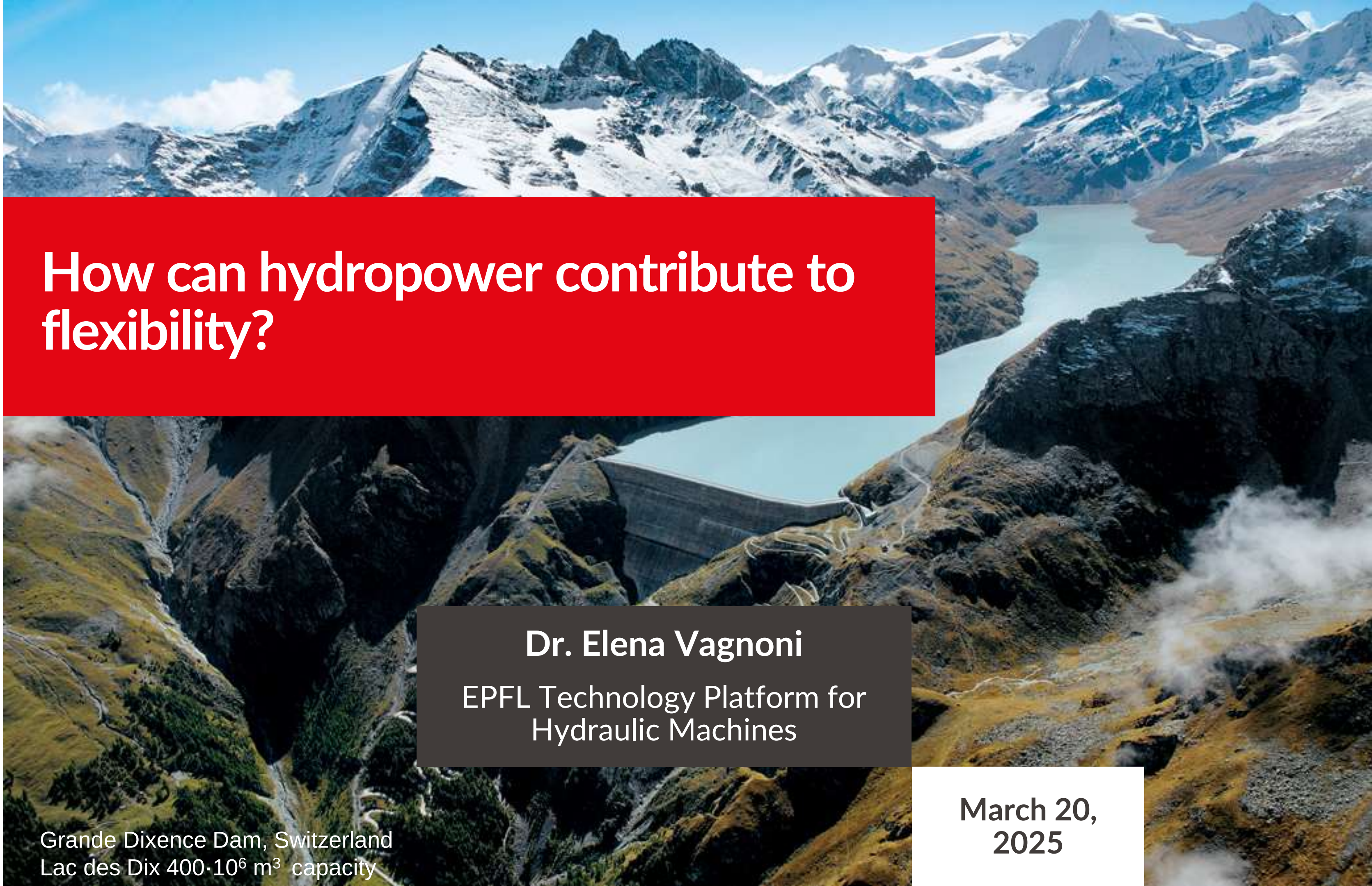

How can hydropower contribute to flexibility?

Dr. Elena Vagnoni

EPFL Technology Platform for Hydraulic Machines

March 20, 2025

Grande Dixence Dam, Switzerland
Lac des Dix $400 \cdot 10^6$ m^3 capacity

École polytechnique fédérale de Lausanne

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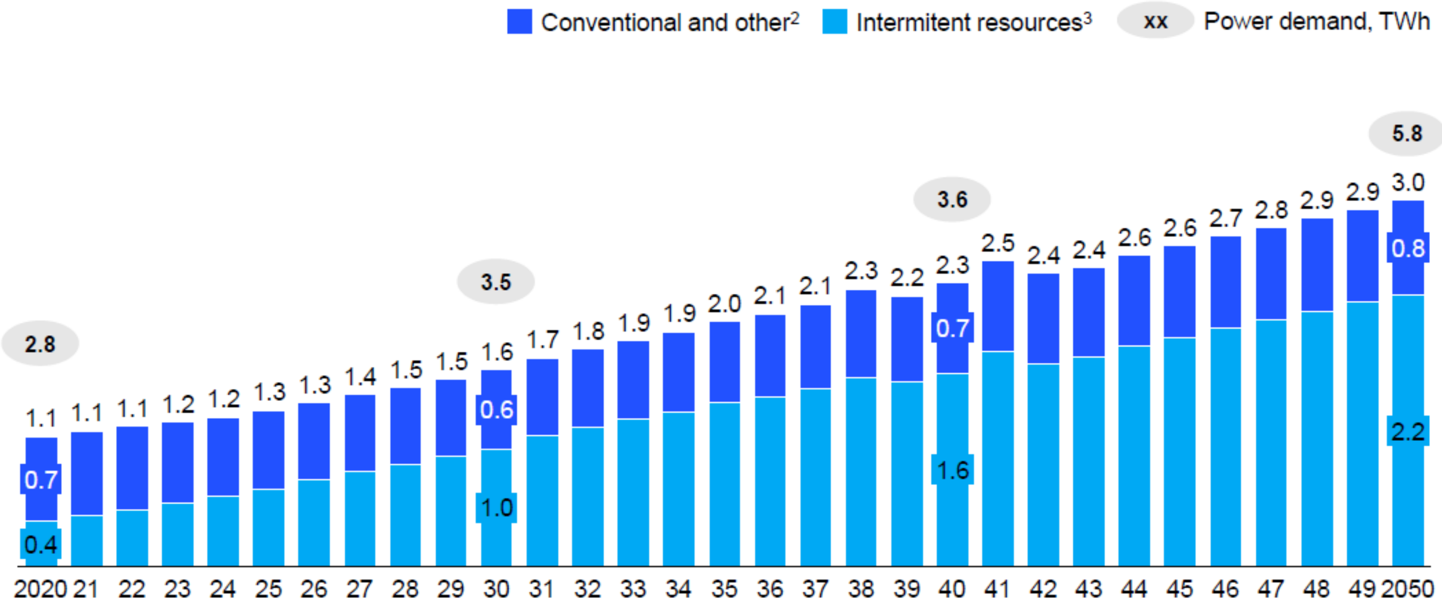
Context

Wholesale decarbonisation of electricity is happening: paradigm changes in the power system

European power installed capacity[1], TW



2x

Increase of electricity demand by 2050 (vs. 2020)

5x

Increase of intermittent generation capacity by 2050 (vs. 2020)

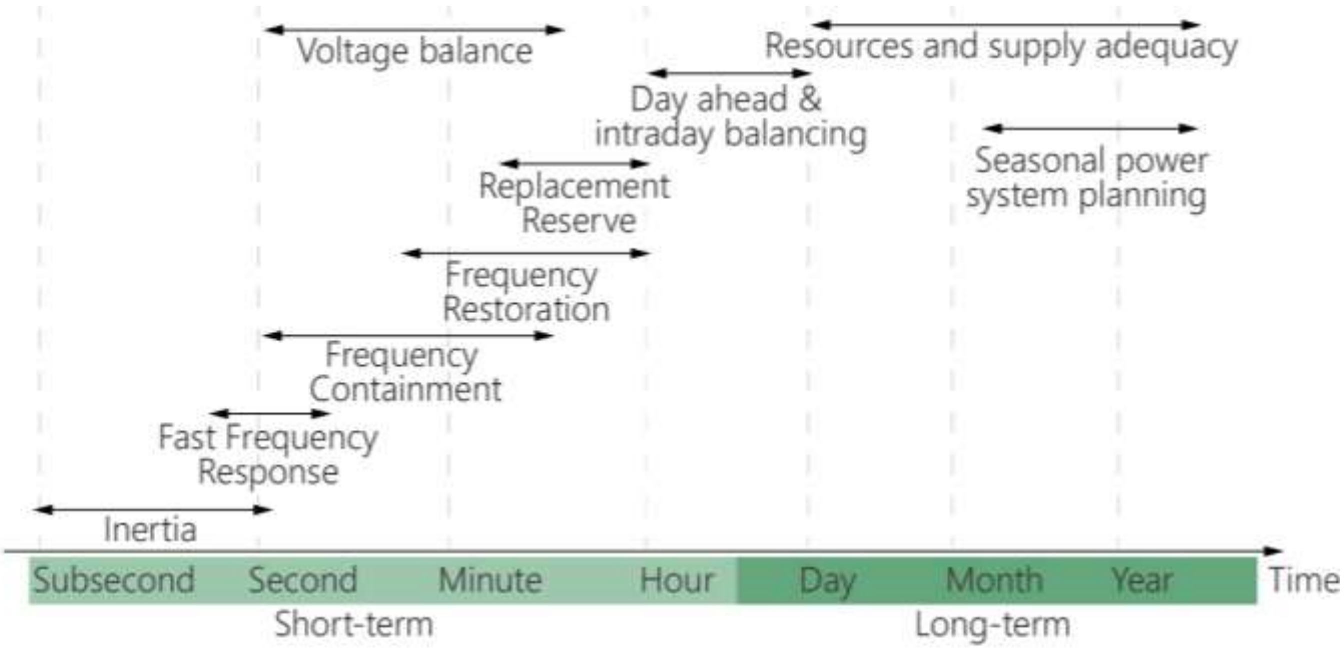
1. EU27+UK, 2022 Current Trajectory scenario
2. Gas, nuclear, oil, coal, biomass, hydrogen, geothermal, storage
3. Solar PV, CSP, wind onshore and offshore

Endorsement of flexibility and **reliability** from dispatchable energy sources is necessary

Context

Why Flexibility?

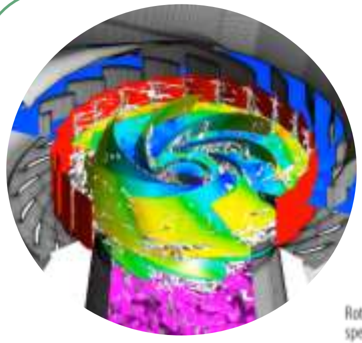
International Energy Agency (IEA) (2021). Hydropower Special Market Report. Analysis and forecast to 2030.



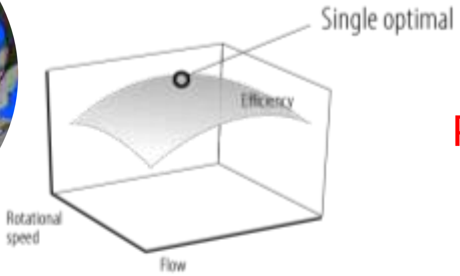
Hydropower is key in providing these grid services over all time scale

Context

Flexibility implications on hydropower operations



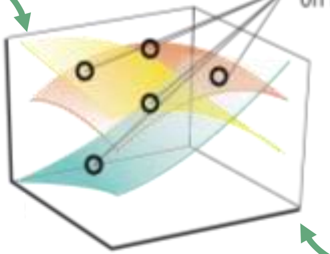
Design condition



Paradigm shift

Flexible operation

Multiple operating points depending on needs



Sustainable operation and resilience to climate change

New operational requirements:

- Extended operating range
- More frequent transient operations, i.e. start-up and stops
- Efficient water management

Industrial needs:

- Optimisation of power plants operation, monitoring and maintenance taking into consideration multiple factors: *Efficiency, wear & tear, water management, vibrations…etc*
- Novel technologies, designs and materials

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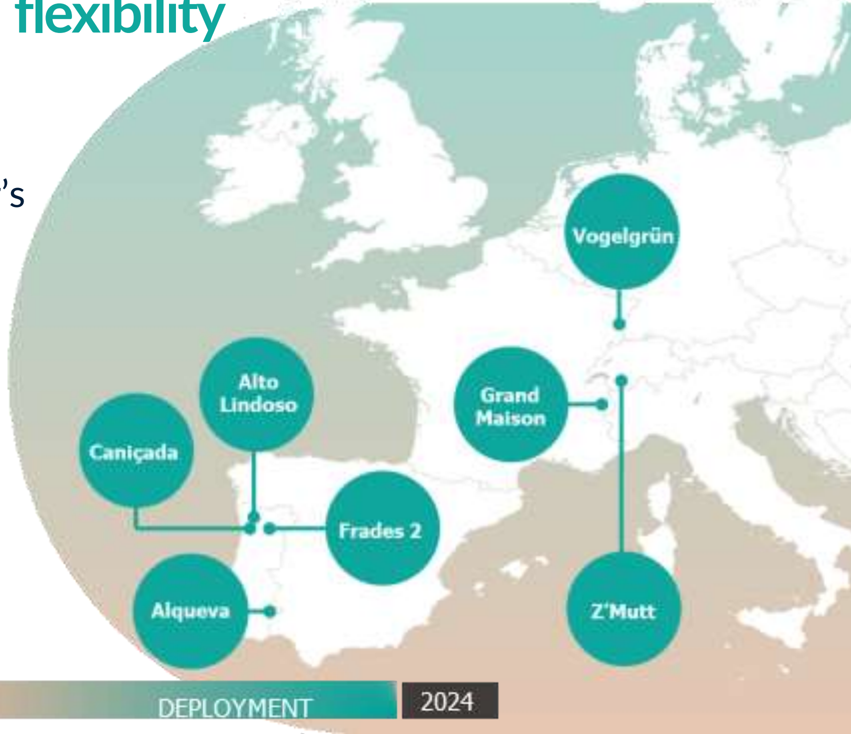
XFLEX HYDRO

XFLEX HYDRO

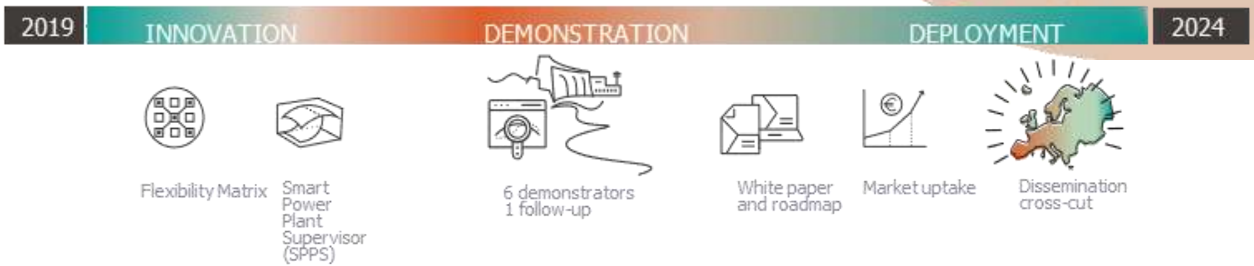
Hydropower extending power system flexibility

With increasing levels of variable renewables in the energy system, a consortium of partners collaborate on a four-year EU-funded project (XFLEX HYDRO) to enhance hydropower’s flexibility services and potential impact in modern power markets.



19 project partners

ALPIQ, ANDRITZ, ARMINES, CEA, EPFL, PSL, EDF, EDP, NEW, HES-SO, INESC TEC, IHA, POWER VISION ENGINEERING, GE, SuperGrid Institute, Universität Stuttgart, UPC, VOITH, zabala



INNOVATIVE FLEXIBLE TECHNOLOGIES:
HYDRAULIC SHORT CIRCUIT

Benefits

- Extended operating range and regulations in pump mode
- Provision of frequency control services in pump mode
- Faster switch from Pump mode to Turbine mode

Grid Services provision

Improved

- Synchronous inertia

Enabled

- Primary, secondary and tertiary frequency control while pumping

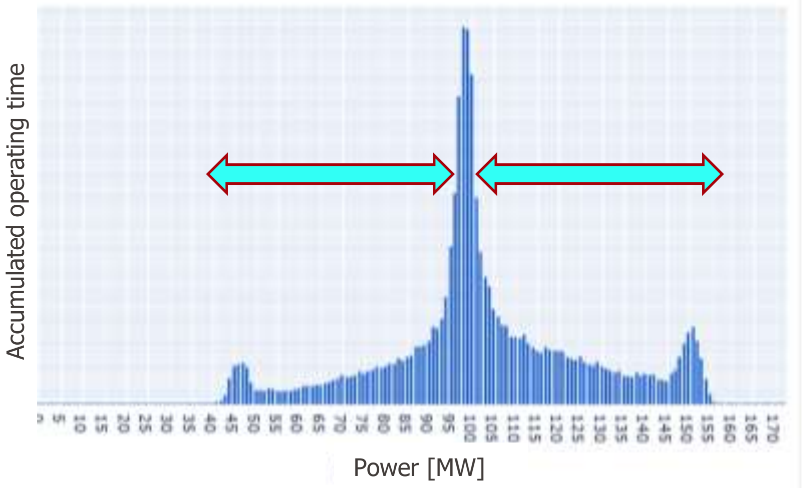
Demonstrated at Grand Maison (France), Frades and Alqueva (Portugal)

DEMONSTRATOR: Grand Maison

PUMPED STORAGE | 1986

x8 150MW x4 150MW

Plant Operation: range extension thanks to HSC



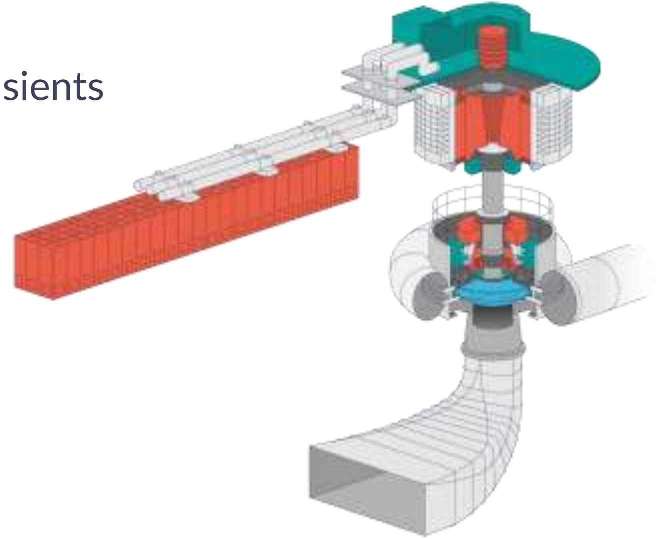
- ✓ Since Sept 2021, demo is operated daily
- ✓ Full remote operation and automatic selection of units to be started
- ✓ Balancing power up to +/-57MW
- ✓ HSC mode accounts for 55% of pumping time

INNOVATIVE FLEXIBLE TECHNOLOGIES:
VARIABLE SPEED

Demonstrated at Z'Mutt and Frades pumped-storage plants

Benefits

- Extended operating range and regulations in pumping mode
- Faster regulation
- Improved operations at partial load
- Minimized fatigue accumulated during start-up transients



Grid Services provision

Improved

- Primary frequency control (FCR)
- Blackstart capabilities
- Voltage/VAR control

Enabled

- Primary, secondary and tertiary control in pumping

DEMONSTRATOR: Z'Mutt

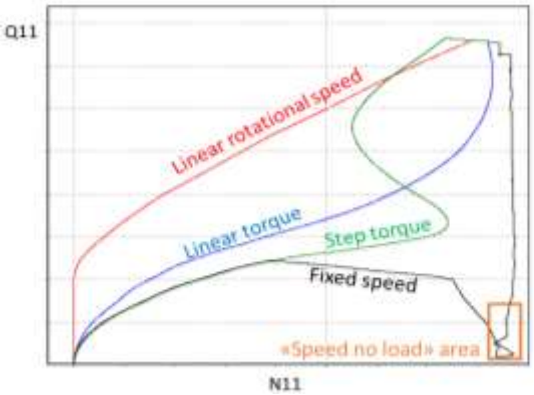
x1 5MW

PUMPED STORAGE 1964

Key Outcomes:

- **Optimized use of a 5 MW variable speed pump-turbine**, equipped with full size frequency converter (FSFC).
- **New start-up trajectories** for damage reduction thanks to the variable speed technology: up to **15 time damage saving** while shortening **three times the start-up duration**

Start-up trajectories



INNOVATIVE FLEXIBLE TECHNOLOGIES:
HYBRIDISATION WITH BATTERY

Benefits

- Reduced wear & tear on hydraulic components
- Fast provision of frequency control services
- Enhanced regulating margin

Grid Services provision

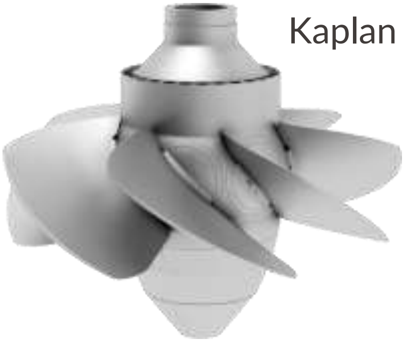
Improved

- Primary & secondary frequency control (FCR, a/mFRR)
- Blackstart capabilities

Enabled

- Synthetic inertia
- Primary control (FFR)

Demonstrated at Vogelgrun RoR in France



Kaplan unit

\+ Battery Energy Storage System (BESS)

DEMONSTRATOR: Vogelgrun

RUN-OF-RIVER 1959

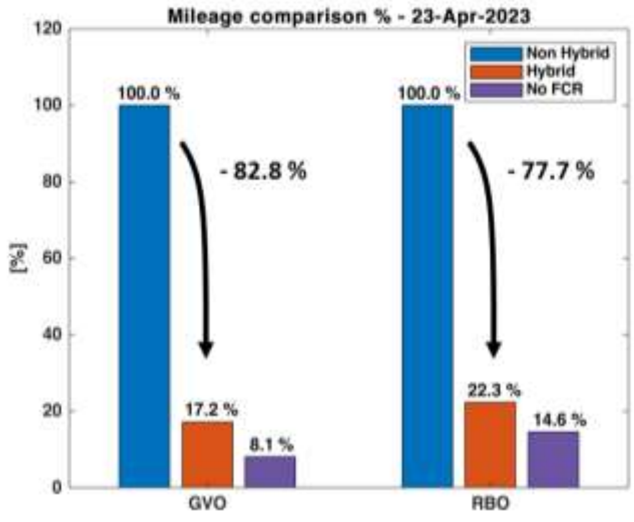
XFLEX HYDRO

x4 39MW

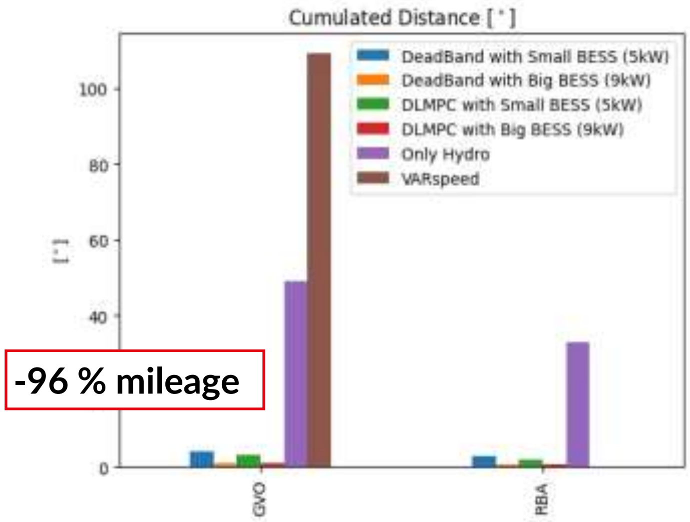
Key Outcomes:

- **Hybridisation of the turbine unit with a battery** improves **fast and dynamic frequency response** of the combined system and **reduces turbine wear and tear.**
- **Battery hybridisation CAPEX** payed back in **4 years** thanks to revenue from FCR, reduced maintenance costs and reduced risk of turbine failure (and consequent lower operational losses).

Mileage of the regulating mechanical components steered by fuzzy logic controller



Mileage of the regulating mechanical components steered by model predictive control (MPC)



INNOVATIVE FLEXIBLE TECHNOLOGIES:
Smart Power Plant Supervisor SPPS

The SPPS brings the turbine dynamics and conditions knowledge into advanced control unit operation and predictive maintenance

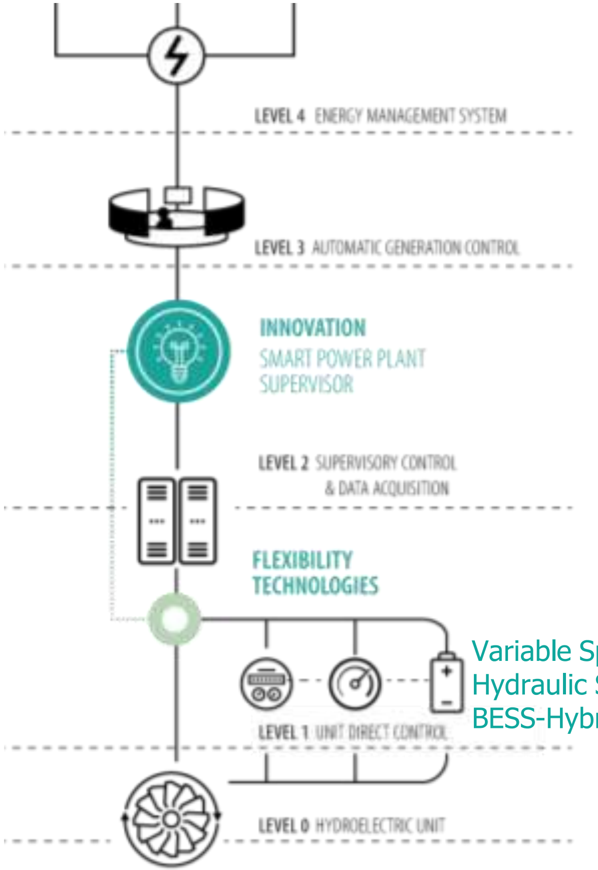
Benefits

- Real time optimisation of power plants operations taking into consider multiple factors: *Efficiency, wear & tear, water consumption optimisation, unit start and stop…etc*
- Optimised integration of other technologies
- Extended operating range
- Extended components life

Grid Services provision

Improved

- Primary frequency control (FCR)
- Secondary frequency control (FRR)
- Tertiary frequency control (RR)



Variable Speed
Hydraulic Short Circuit
BESS-Hybridization

Extension of the operating range and optimal dispatch

Demonstrated at Alto Lindoso and Alqueva

RESERVOIR STORAGE

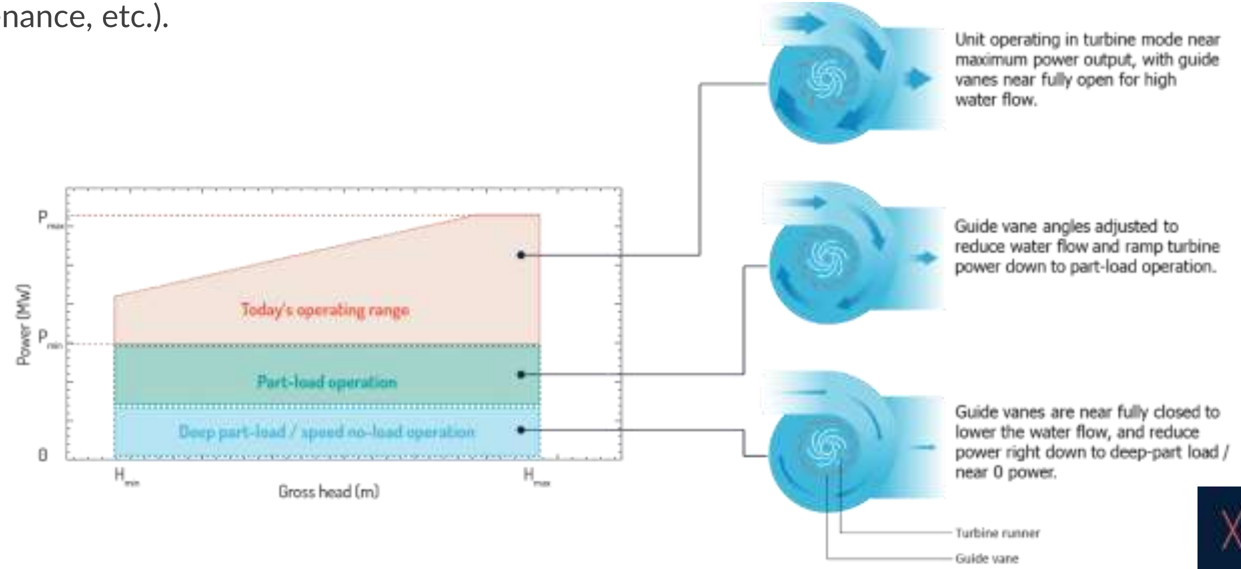
1992

x2

317MW

Key Outcomes:

- **Low CAPEX solution** to enhance services at an existing reservoir storage plant with high head Francis turbines. In particular, **extend the operating range** targeting an almost continuous power output from near zero to rated power.
- Use **advanced control** to adapt and **optimise plant dispatch** under various criteria (efficiency, wear and tear, maintenance, etc.).



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XFLEX HYDRO

Optimization of operations including HSC

Demonstrated at Grand Maison PSP

How to optimally steer operation of multiple units considering power dispatch plan and reserve to maximise efficiency and minimize start-up/stop cycles?

Results

Algorithm	Efficiency (%)	SUSD	Computational Time (s)		
			Mean	Std	Max
Measurement	85.75	15508	-	-	-
Algorithm (No Cost)	86.36 (+0.61%)	16809 (+8.3%)	0.93	0.88	6.00
Algorithm (Cost)	86.30 (+0.55%)	14651 (-5.5%)	1.02	0.86	7.02

Pre-Filtering

$2^4 \cdot 3^8 \approx$ 105'000 combinations.
Without smart filtering the problem would be computationally infeasible.

Main contributions:

- Multi-parameter modeling method for multi-units PSP.
- Low computational time algorithm for real-time operations optimization.

CONSESUS software licensing

IEEE Transaction on Power System

*F. Gerini, **E. Vagnoni,** R. Cherkaoui, M. Paolone, "Optimal Short-Term Dispatch of Pumped-Storage Hydropower Plants Including Hydraulic Short Circuit".*

Optimization of start-up sequences

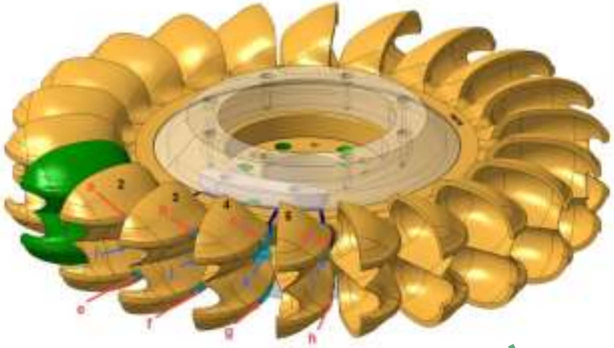
Demonstrated at Veytaux PSP

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Office fédéral de l'énergie

Predictively model and minimize the structural damage in Pelton runners and multistage pumps during start-up acceleration

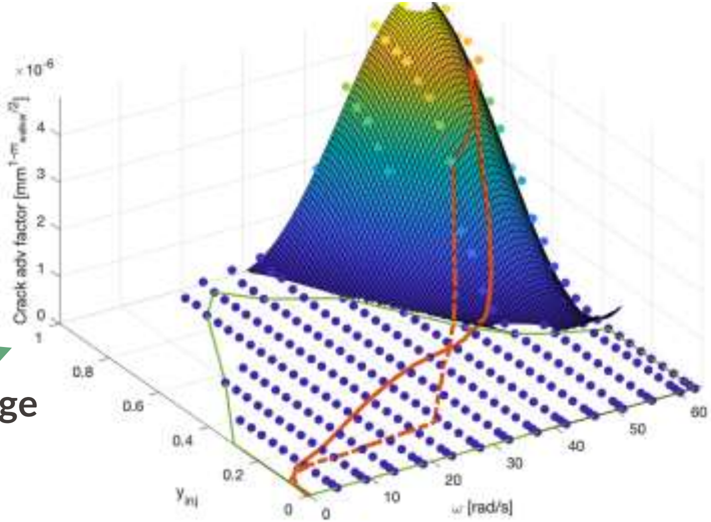
Ternary group

Experimental investigation



Fatigue-induced damage modelling

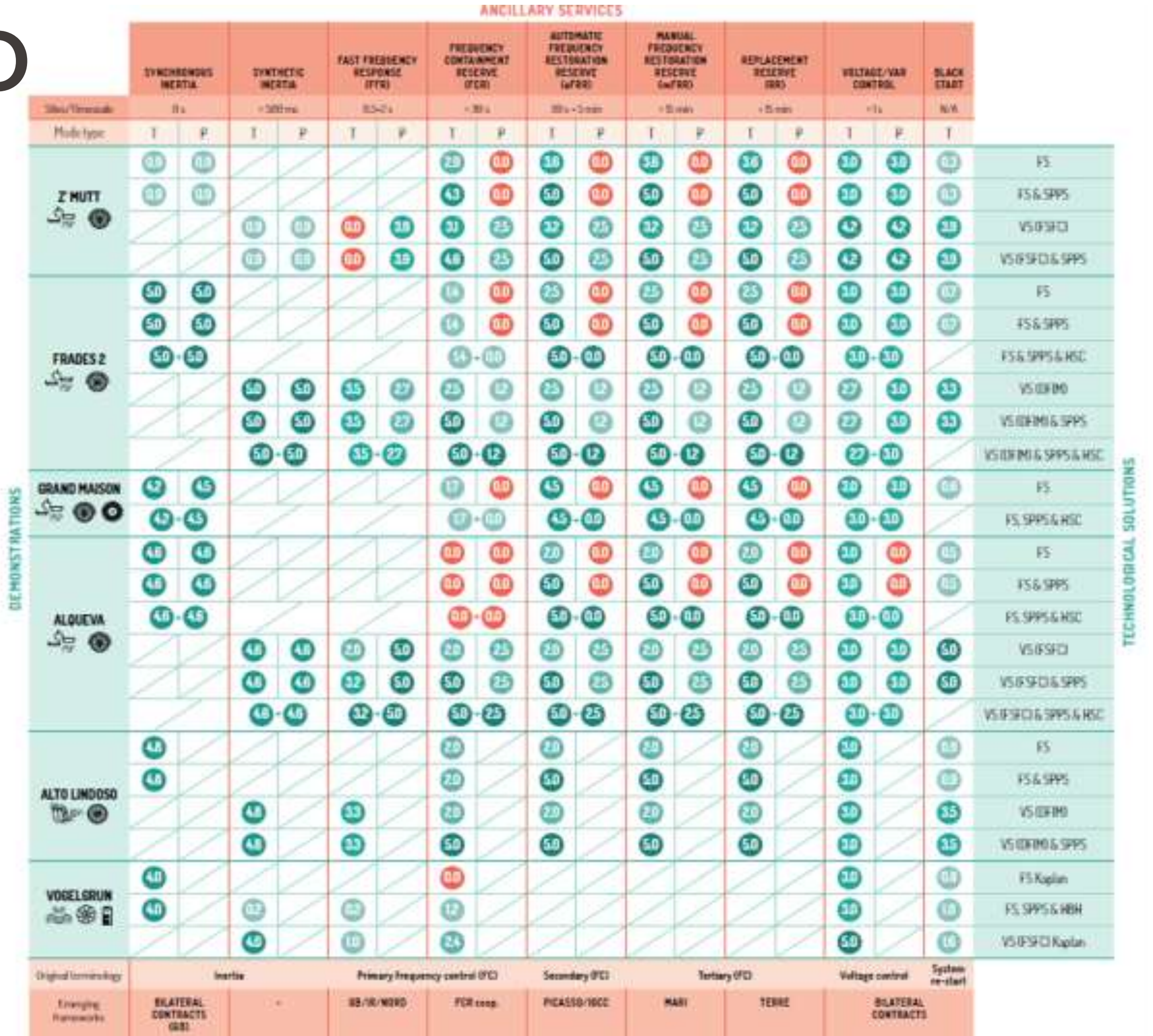
Optimization framework



XFLEX HYDRO

Hydropower flexibility matrix

- ✓ Detailed study of the today and future ancillary services markets
- ✓ Simulations including grid codes requirements
- ✓ Extensive 1D simulations for all hydropower plants for technical flexibility assessment



XFLEX HYDRO

CONCLUSION AND OUTLOOK

- **Flexibility and digitalization** are keys to boost the role of hydropower in the energy transition.
- **Flexibility technological solutions** rely on the optimal implementation, advanced control methods and monitoring systems.
- **Innovative technologies for refurbishments** are needed:
    - Increasing operating range of the units considering also harsh operations (sediments-laden flows, waste water)
    - Optimized management of water resources
    - New and improved pumped-storage capacity and installations
    - Innovative electro-mechanical equipment, hybrid solutions and new hydraulic machines design to overcome the existing challenges: premature aging, performance degradation, reaction time

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THANK YOU!

XFLEX HYDRO

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