XFLEX HYDRO

EPFL

XFLEX HYDRO
HYDROPOWER EXTENDING POWER SYSTEM FLEXIBILITY

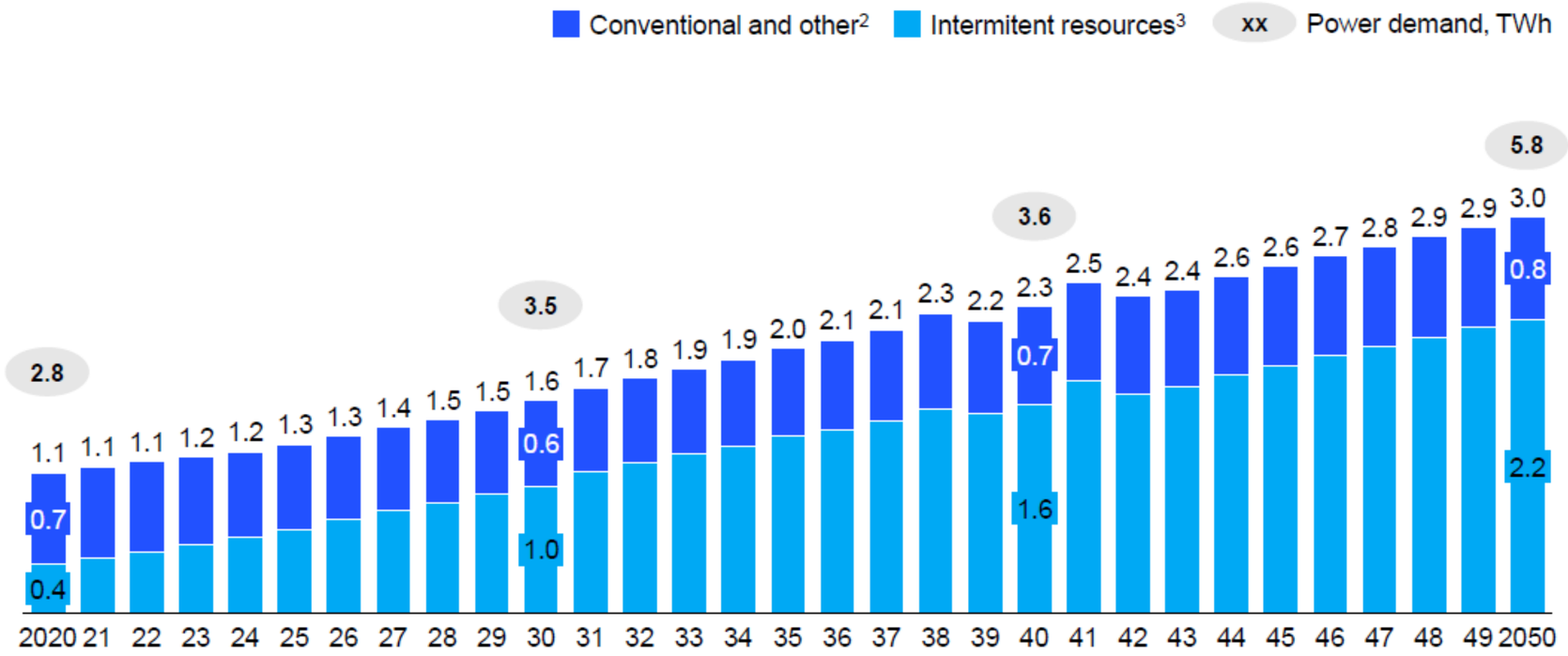
Dr. Elena Vagnoni, EPFL

The Hydropower Extending Power System Flexibility (XFLEX HYDRO) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857832.

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

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

THE PROJECT

With increasing levels of variable renewables in the energy system, XFLEX HYDRO brings together a consortium of partners collaborating to enhance hydropower's flexibility services and potential impact in modern power markets.

2019 | INNOVATION | DEMONSTRATION | DEPLOYMENT | 2024

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

6 demonstrators
1 follow-up

Pumped storage
Variable speed
Hydraulic short circuit

Reservoir storage
Extended modes
Run of river
Battery hybrid

White paper and roadmap

Market uptake

Dissemination cross-cut

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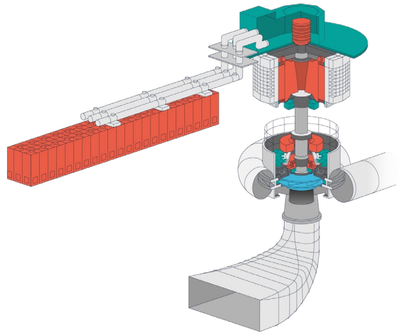
THE CONSORTIUM

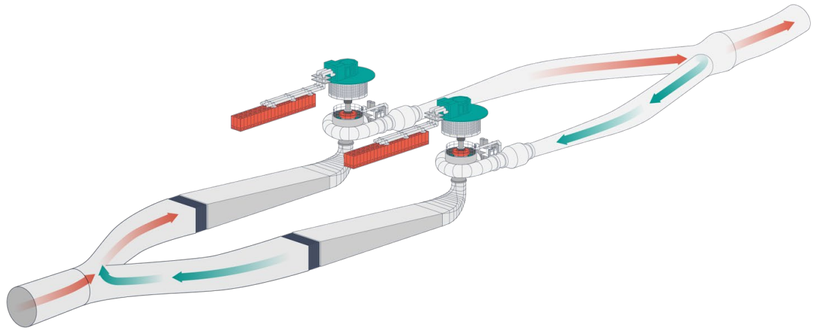
- 19 project partners including universities, industries and research centers
- 5 Countries: France, Germany, Portugal, Spain, Switzerland
- Duration : 54 months
- Project effort : 1’474.50 Man-Months
- Project total budget : 18.163 M€
- EU contribution : 15.104 M€

THE TECHNOLOGIES

Variable Speed

Capability of hydroelectric units to produce power at grid frequency regardless of the turbine’s rotational speed.



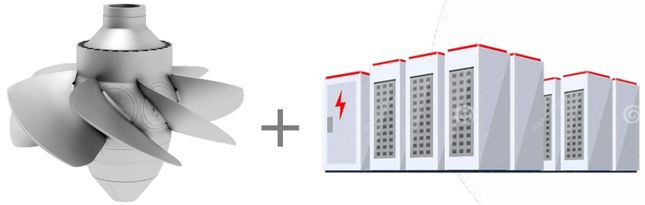


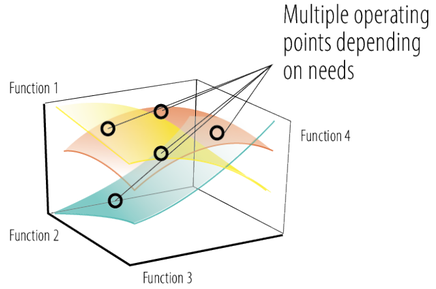
Hydraulic Short Circuit (HSC)

Simultaneous pumping and generating on different units of the same pumped-storage power plant

Hybridization with Battery Energy Storage System (BESS)

Addition of a grid-connected battery energy storage system in parallel to the hydroelectric unit.

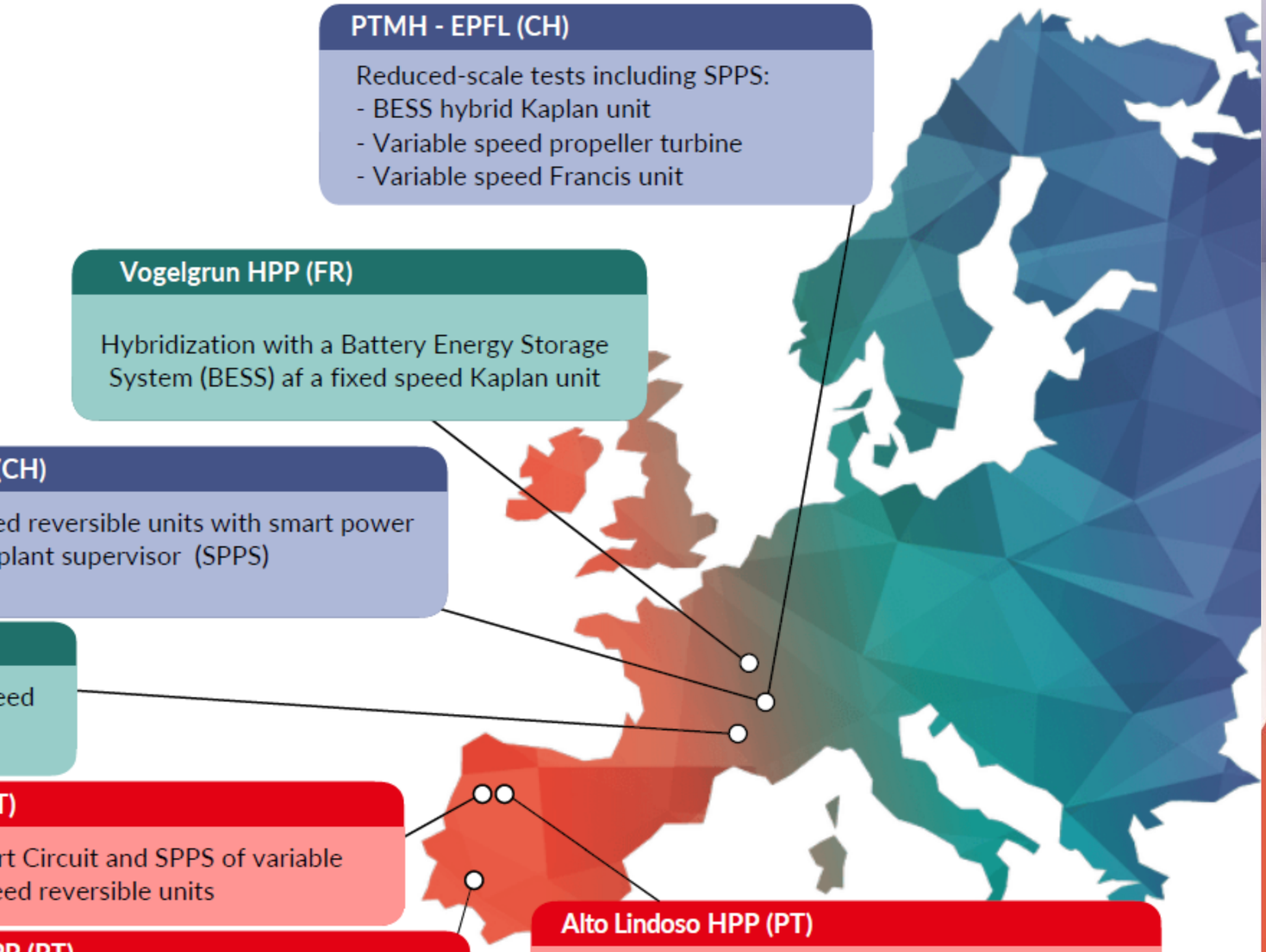




Digitalization→ Smart Power Plant Supervisor (SPPS)

Digital solution leveraging model-based optimization framework

THE DEMONSTRATORS



PTMH - EPFL (CH)

Reduced-scale tests including SPPS:
- BESS hybrid Kaplan unit
- Variable speed propeller turbine
- Variable speed Francis unit

Vogelgrun HPP (FR)

Hybridization with a Battery Energy Storage System (BESS) af a fixed speed Kaplan unit

Z'Mutt HPP (CH)

Variable speed reversible units with smart power plant supervisor (SPPS)

Grand'Maison HPP (FR)

Hydraulic Sfort Circuit and SPPS of fixed-speed quaternary groups

Frades 2 HPP (PT)

Hydraulic Short Circuit and SPPS of variable speed reversible units

Alqueva HPP (PT)

Hydraulic Short Circuit and SPPS of fixed speed reversible units

Alto Lindoso HPP (PT)

SPPS of fixed speed Francis units

PROJECT RESULTS

INNOVATION

2019 | INNOVATION | DEMONSTRATION | DEPLOYMENT | 2024

Flexibility Matrix

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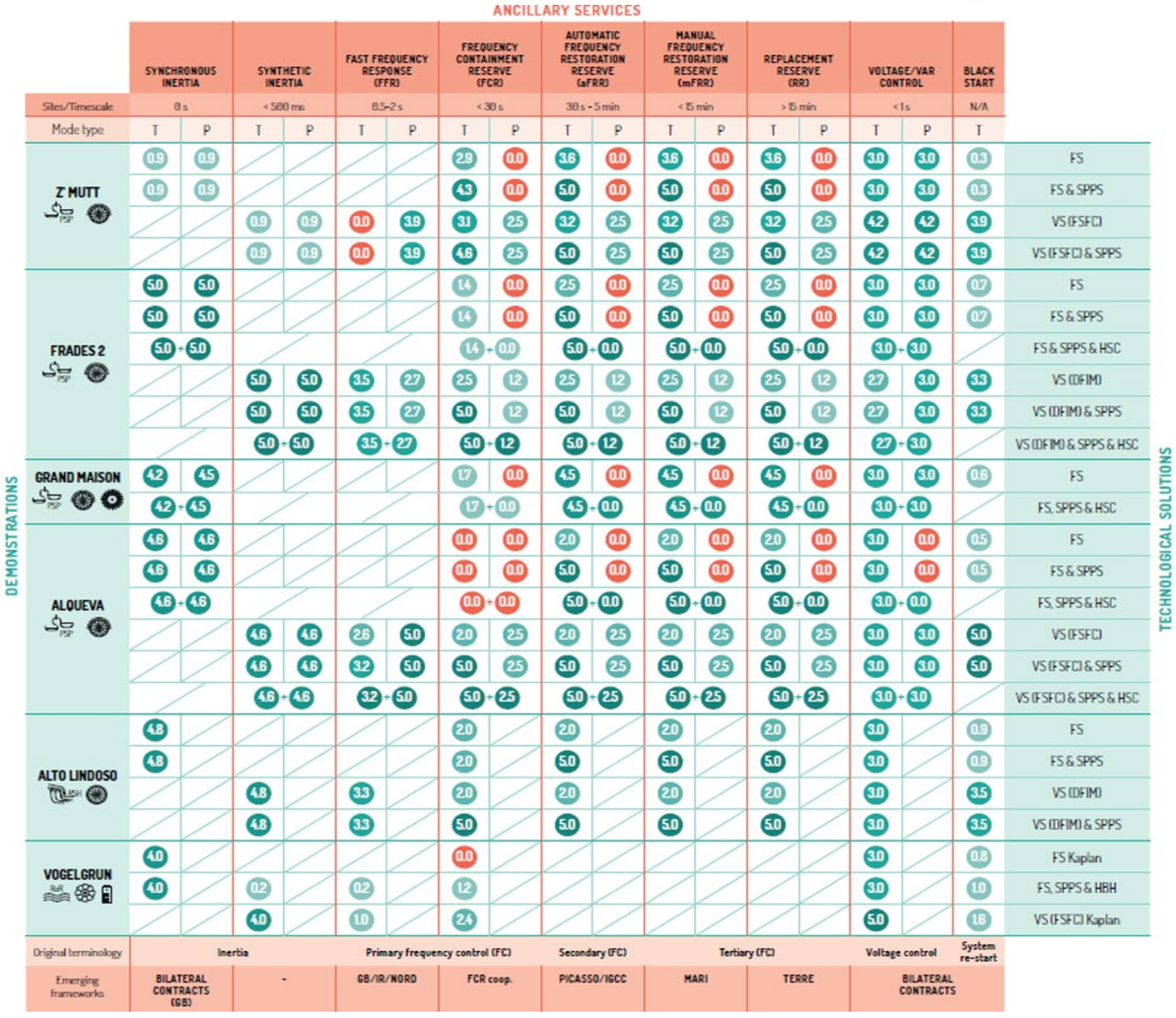
Dissemination cross-cut

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



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PROJECT RESULTS
INNOVATION

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

6 demonstrators 1 follow-up

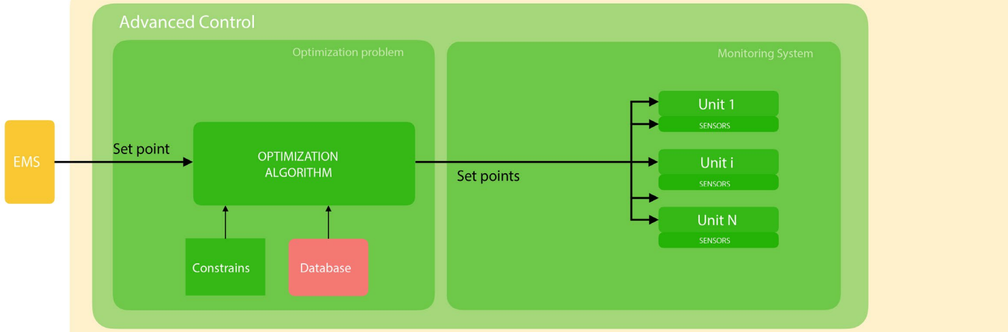
White paper and roadmap

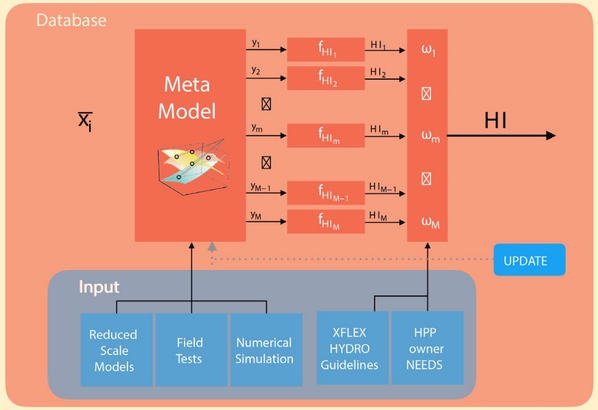
Market uptake

Dissemination cross-cut

Smart Power Plant Supervisor – SPPS

- ✓ Dedicated research activities to build knowledge on the hydroelectric units operation
- ✓ Modelling techniques for multi-dimensional hillchart
- ✓ Complex optimization problems for steering the operation





Set point:
$z_i \mid i \in [1, \ldots, N]$
where N = n° of units

State variable:
$\bar{x}_i = (H_i, Q_i, N_i, \alpha_i)$

Database variables:
$y_m \mid m \in [1, \ldots, M]$
where M = SPPS variables
such as $\eta, \sigma, c_p \ldots$

PROJECT RESULTS

DEMONSTRATION

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

6 demonstrators 1 follow-up

White paper and roadmap

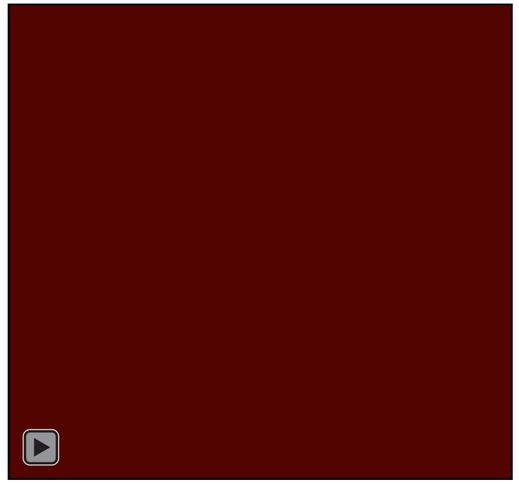
Market uptake

Dissemination cross-cut

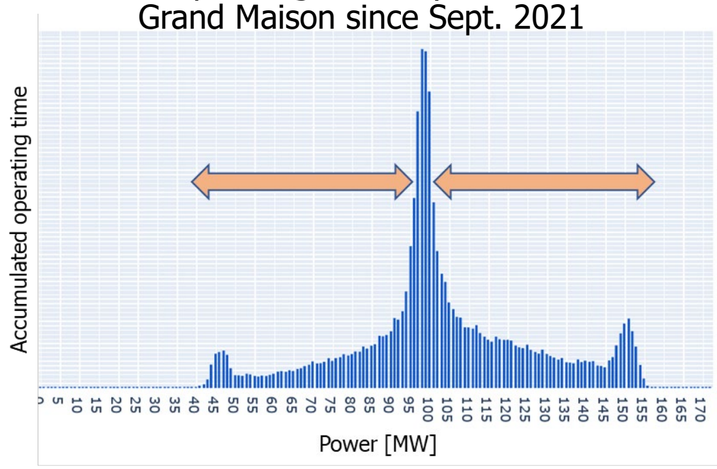
Demonstration of the feasibility and advantages of the innovative hydroelectric technology system integration solutions in pumped storage power plants with either reversible pump-turbines or parallel units in tandem operation with Hydraulic Short Circuit (HSC).

- ✓ Demonstration in Grand Maison
- ✓ Demonstration in Frades
- ✓ Demonstration in Alqueva

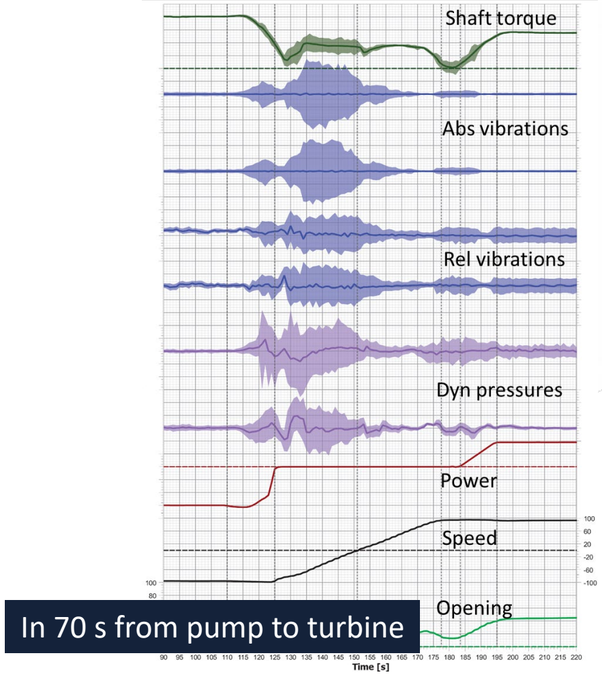
3D transient numerical simulations for Alqueva



Enhanced operating flexibility thanks to HSC in Grand Maison since Sept. 2021



Fast mode change implemented in Frades



In 70 s from pump to turbine

PROJECT RESULTS
DEMONSTRATION

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

6 demonstrators
1 follow-up

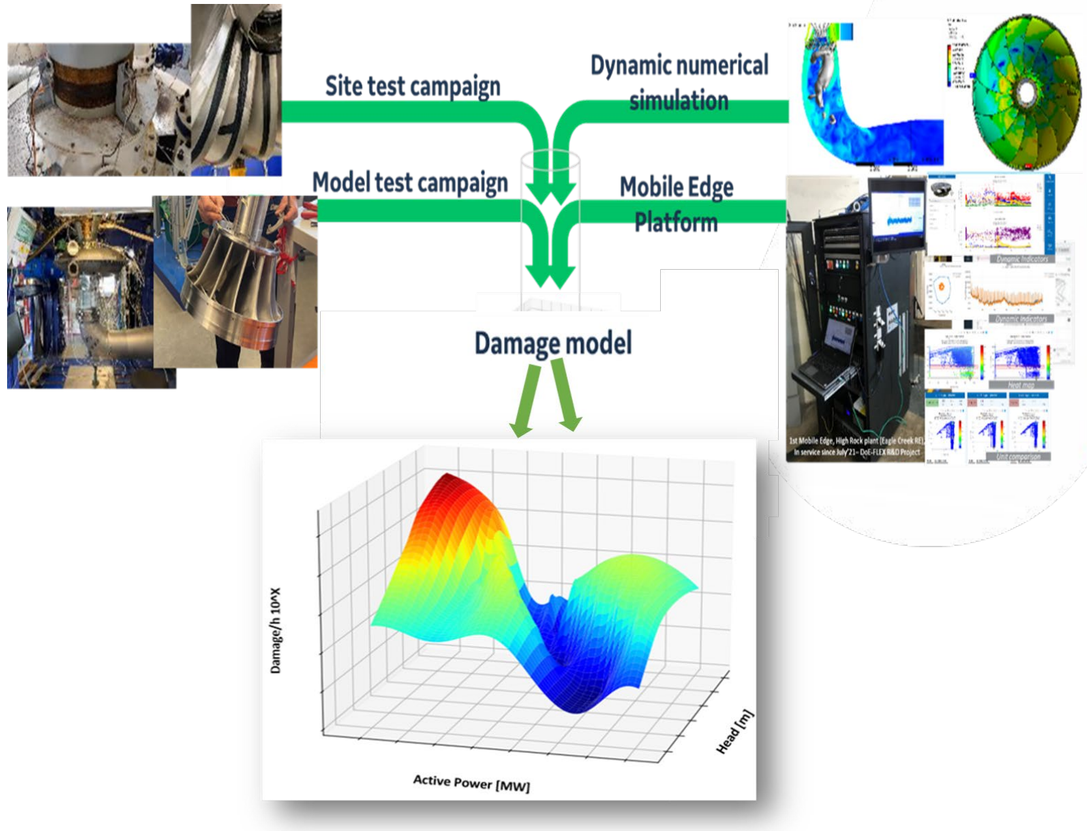
White paper and roadmap

Market uptake

Dissemination cross-cut

Demonstration of the feasibility and advantages of the innovative hydroelectric technology system integration solutions in storage hydropower plants

- ✓ Operating range extension and fatigue minimization demonstrated in Alto Lindoso
- ✓ Advanced Joint control successfully in operation



PROJECT RESULTS
DEMONSTRATION

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

6 demonstrators 1 follow-up

White paper and roadmap

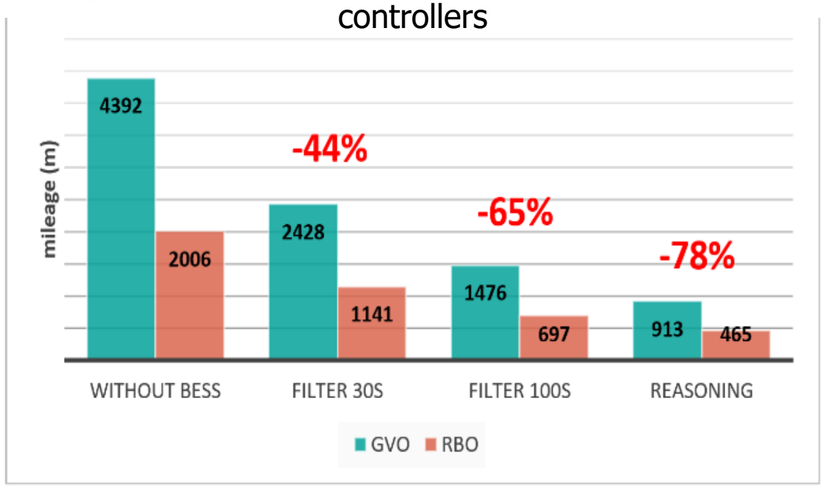
Market uptake

Dissemination cross-cut

Demonstration of the feasibility and advantages of the innovative hydroelectric technology system integration solutions in run of river power plants

- ✓ Increased flexibility and wear and tear reduction: demonstration of the hybridisation with a battery energy storage system at Vogelgrun

Mileage reduction with and without battery for different controllers



Battery at Vogelgrun

PROJECT RESULTS

DEPLOYMENT

Flexibility Matrix

Smart Power Plant Supervisor (SPPS)

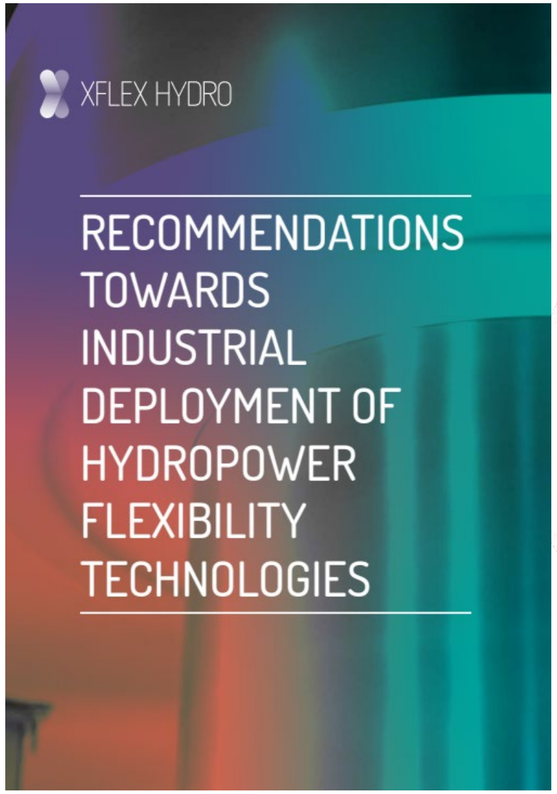
6 demonstrators 1 follow-up

White paper and roadmap

Market uptake

Dissemination cross-cut

Technical white paper and the roadmap for the scalability and deployment of XFLEX HYDRO solutions



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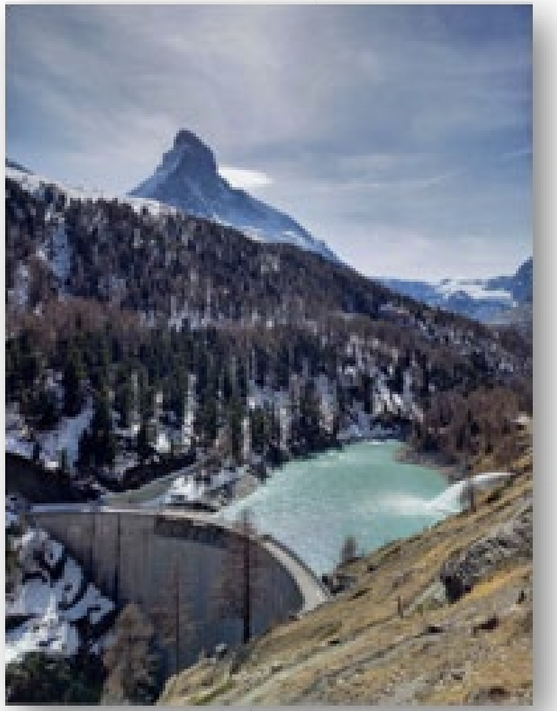
Guidelines for pumped-storage power plants

Z'Mutt dam



Hydropower plant features:

- Reversible groups: Francis-type reversible pump-turbines
- Quaternary groups: Pelton turbines + centrifugal pumps or reversible pump-turbines
- Head range 50 – 900 m

Main limitations to be overcome for flexibility:

- Operating range extension of the hydroelectric unit
- Ramping rate of the hydroelectric unit
- Start-up time of the hydroelectric unit
- Mode transitions from generating to pumping and vice-versa
- Fatigue-induce damage in the hydraulic machine runner during start-up sequences

XFLEX HYDRO technologies which can be implemented:

- Smart Power Plant Supervisor
- Variable Speed
- Hydraulic Short Circuit

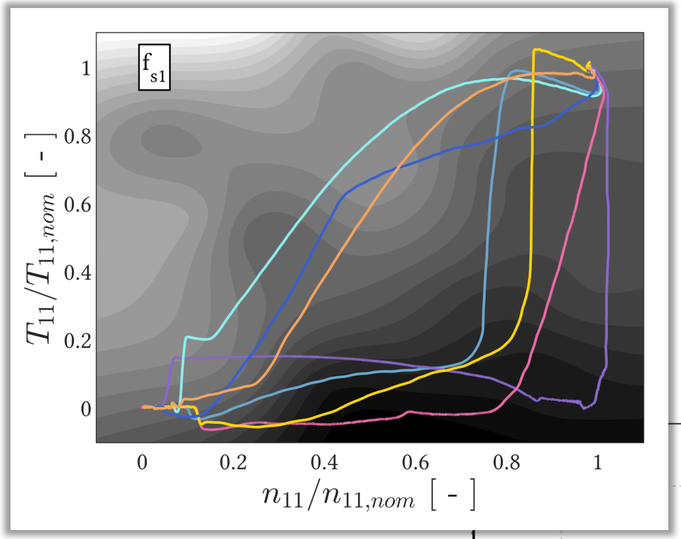
Guidelines for pumped-storage power plants

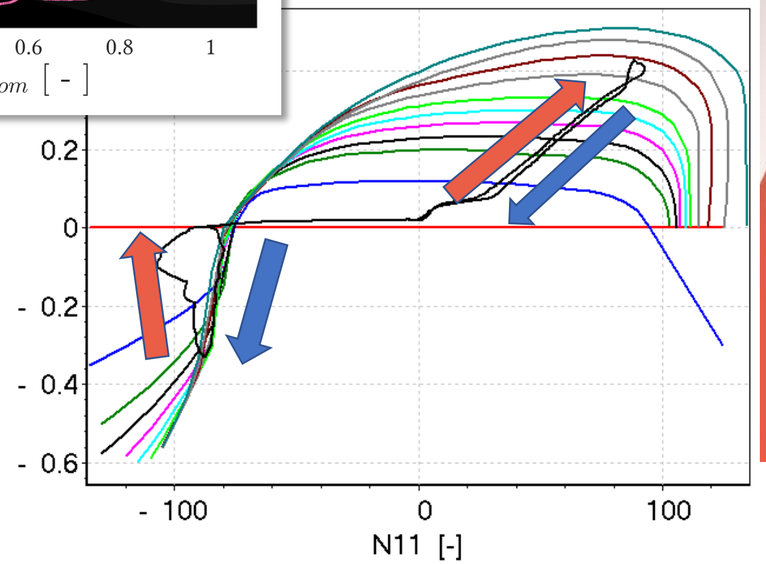
How to improve start-up time, mode transition and ramping rate by reducing the fatigue-induce damage on the runner? → Variable speed & SPPS

Reversible groups with full size-frequency converter

Main workflow:

- 1D numerical simulations for:
  - Safe operation of the hydraulics and control parameters
  - Identification of the best trajectories
- 3D numerical simulations and reduced scale model tests for:
  - Study of the flow phenomena
  - Assessment of the fatigue-induced damage
- Field tests for validation and performance





Guidelines for pumped-storage power plants

DEMONSTRATIONS

	EXTENDED OPERATION RANGE	START-UP TIME	RAMP-UP/RAMP-DOWN	TURBINE TO PUMP / PUMP TO TURBINE MODE TRANSITION	MAINTENANCE	PLANT EFFICIENCY	DIGITALISATION	
	[range %]	[s] from standstill to nominal power	[%/s] power rate to change set-point	[s]	[h of operation]	% on the operating range	(-)	
Z' MUTT PSP	T: [50%, 100 %] P: [-100 %]	T: 90 s P: 180 s	P: - T: 3.5 % / s	T to P : 1800 s P to T : 1'500 s	5000 h	T[82.1 %, 88.0 %]	L1-L1	Fixed Speed
	T: [50%, 100 %] P: [- 100%, -50%]	T: 15 s P: 35 s	P + T : 7 % /s	T to P : 50 s P to T : 50 s	> 5000 h	T[84.8 %, 86.3 %]	L1-L1	VS (FSFC)
	T: [50%, 100 %] P: [- 100%, -50%]	T: 25 s P: 35 s	P + T : 7 % /s	T to P : 60 s P to T : 60 s	> 5000 h	T[84.8 %, 86.3 %]	L2-L2	SPPS & VS (FSFC)
FRADES 2 PSP	T: [52% ,100%] P: [-100%]	T: 180 s P: 360 s	P: - T: 1.8 % /s	T to P: 660 s	4000h	T[89%, 93%] P[92%, 93%]	L1-L1	Fixed Speed
	T: [47% ,100%] P: [-100%, -77%]	T: 60 s P: 240s	P + T: 4.4%/s up to 8.2 %/s	T to P: 660s P to T: 180 s	4000h	T[88%, 94%] P[93%, 94%]	L1-L1	VS (DFIM)
	T: [0%, 25%] - [47%,100%] P: [-100%, -77%] - [-51%, 0%]	T: 45 s P: 240s	P + T: 4.4%/s up to 8.2 %/s	T to P: 660s P to T: 60 s	> 4000h	T[88%, 94%] P[93%, 94%] HSC [81%, 88%]	L2-L2	SPPS & VS & HSC
GRAND MAISON PSP	T:[15%, 100%] P:[-100%]	T: 90s P:180s	P: - T: 2.5 %/s	T to P: 1800s P to T: 1500s	1000h	T[81%, 88%] P[84%, 87%]	L1-L1	Fixed Speed
	T:[10%, 100%] P:[-100%, -50%]	T: 90s P:180s	P + T: 2.5 %/s	T to P: 1800s P to T: 1500s P to HSC: 30 s	4000h	T[81%, 88%] P[84%, 87%] HSC [66%, 81%]	L3-L2	SPPS & HSC
ALQUEVA PSP	T: [25 %, 100 %] P: [-100 %]	T: 180 s P: 540 s	P: - T: 1.95 %/s	T to P: 1800 s P to T: 1500 s	14000h	T[80%, 86%] P[84%, 87%]	L1-L1	Fixed Speed
	T: [0, 100 %] P: [-100 %]	T: 180 s P: 540 s	P: - T: 1.95 %/s	T to P: 1800 s P to T: 1500 s	>14000h	T[84%, 88%] P[84%, 87%]	L3-L2	SPPS
	T: [0, 100 %] P: [-2%, -100 %]	T: 180 s P: 540 s	P + T: 1.95 %/s	T to P: 1800 s P to T: 1500 s	>14000h	T[84%, 88%] P[84%, 87%]	L3-L2	SPPS & HSC
	T: [0, 100 %] P: [-50%, -100 %]	T: 60 s P: 200 s	P + T: 5 %/s 50%/s for black	T to P: 300 s P to T: 200 s	14000h	N/A	L1-L1	VS (DFIM)

TECHNOLOGICAL SOLUTIONS

Guidelines for flexible storage hydropower plants

Alto Lindoso dam

Hydropower plant features:

- Francis turbines
- Head range 100 – 300 m

Main limitations to be overcome for flexibility:

- Operating range extension of the hydroelectric unit
- Fatigue-induce damage in the hydraulic machine runner during start-up sequences

XFLEX HYDRO technologies which can be implemented:

- Smart Power Plant Supervisor
- Variable Speed

Guidelines for flexible storage hydropower plants

How to extend the operating range?

How to limit the fatigue-induce damage in the hydraulic machine runner during start-up sequences ?

	EXTENDED OPERATION RANGE	START-UP TIME	RAMP-UP/RAMP-DOWN	TURBINE TO PUMP / PUMP TO TURBINE MODE TRANSITION	MAINTENANCE	PLANT EFFICIENCY	DIGITALISATION	
	[range %]	[s] from standstill to nominal power	[%/s] power rate to change set-point	[s]	[h of operation]	% on the operating range	(-)	
ALTO LINDOSO RSH	[47.5 %, 100 %]	90 s	1.6 %/s	-	2000h	[81% - 91%]	L1-L1	Fixed Speed
	[0, 100 %]	90 s	1.6 %/s	-	> 2000h	[83% - 91%]	L3-L2	SPPS
CANIÇADA RSH	[57%, 100%]	180 s	1 %/s	-	2000 h	N/A	L1-L1	Fixed Speed
	[37%, 100%]	180 s	1 %/s	-	> 2000 h	N/A	L1-L1	VS (FSFC)

Guidelines for run-of-river power plants

Vogelgrun power house

Hydropower plant features:

- Kaplan or propeller turbines
- Head range 5 – 30 m

Main limitations to be overcome for flexibility:

- Start-up time of the hydroelectric unit
- Ramping rate of the hydroelectric unit
- Wear and tear of the blades servo mechanism for power regulation

XFLEX HYDRO technologies which can be implemented:

- Hybridisation with Battery Energy Storage System
- Smart Power Plant Supervisor
- Variable Speed

Guidelines for run-of-river power plants

How to improve start-up time and ramping rate by reducing the wear and tear of the mechanical components?

	EXTENDED OPERATION RANGE	START-UP TIME	RAMP-UP/RAMP-DOWN	TURBINE TO PUMP / PUMP TO TURBINE MODE TRANSITION	MAINTENANCE	PLANT EFFICIENCY	DIGITALISATION	
	[range %]	[s] from standstill to nominal power	[%/s] power rate to change set-point	[s]	[h of operation]	% on the operating range	(-)	
VOGELGRUN RoR	[20 %, 100 %]	120 s	300 s	-	100'000 h	[77% - 90%]	L1-L1	Fixed Speed
	[20 %, 100 %]	120 s	30 s	-	100'000h & 94% improvement for blade gasket	[77% - 90%]	L3-L2	SPPS & BESS
	[20 %, 100 %]	45s	30s	-	100'000h & 100% improvement for blade gasket	[55% - 86%]	L3-L2	SPPS & VS (FSFC - Propeller Turbine)

KEY TAKEAWAYS

- Great potential for **XFLEX HYDRO technological solutions** for enhancing **flexibility** and the **reliable operation** of the plants as supported by the **Ancillary Services Matrix** and **Key Performance Indicators** assessment.
- **Multiple replicable solutions** depending on the **needs and ancillary services markets requirements** and opportunities.
- **XFLEX HYDRO guidelines** on **flexibility** improvements will **steer the upgrades needs** of existing hydropower plants or the **equipment needed** for new one of all types.

THANK YOU!

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