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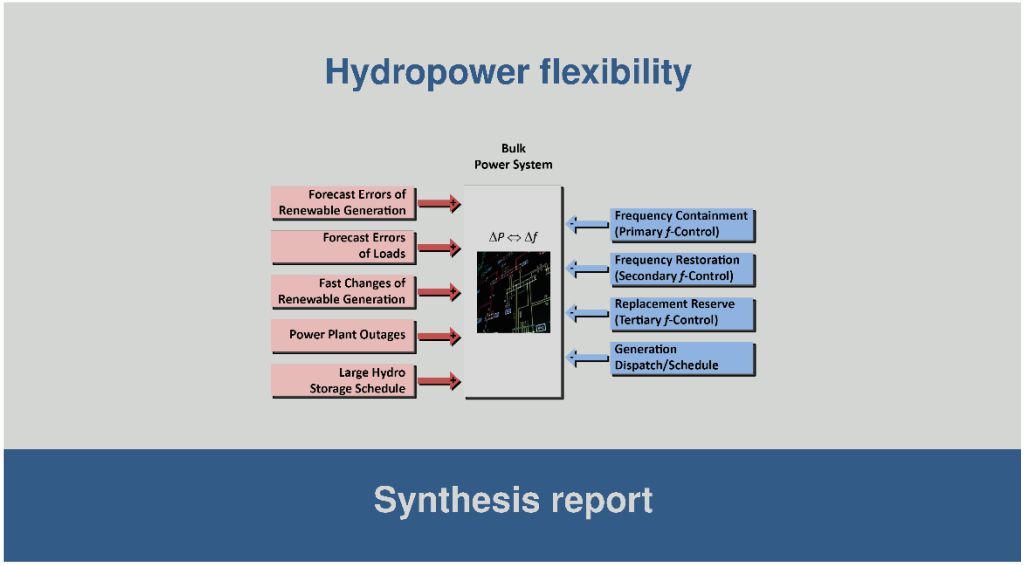
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Annual Conference White Paper



Prof. F. Avellan, EPFL

November 2, 2020

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency

Scope

- Power system needs for flexibility
- Challenges for hydroelectric power plants
- Hydroelectric flexibility technologies
- Recommendations

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- Challenges for hydroelectric power plants
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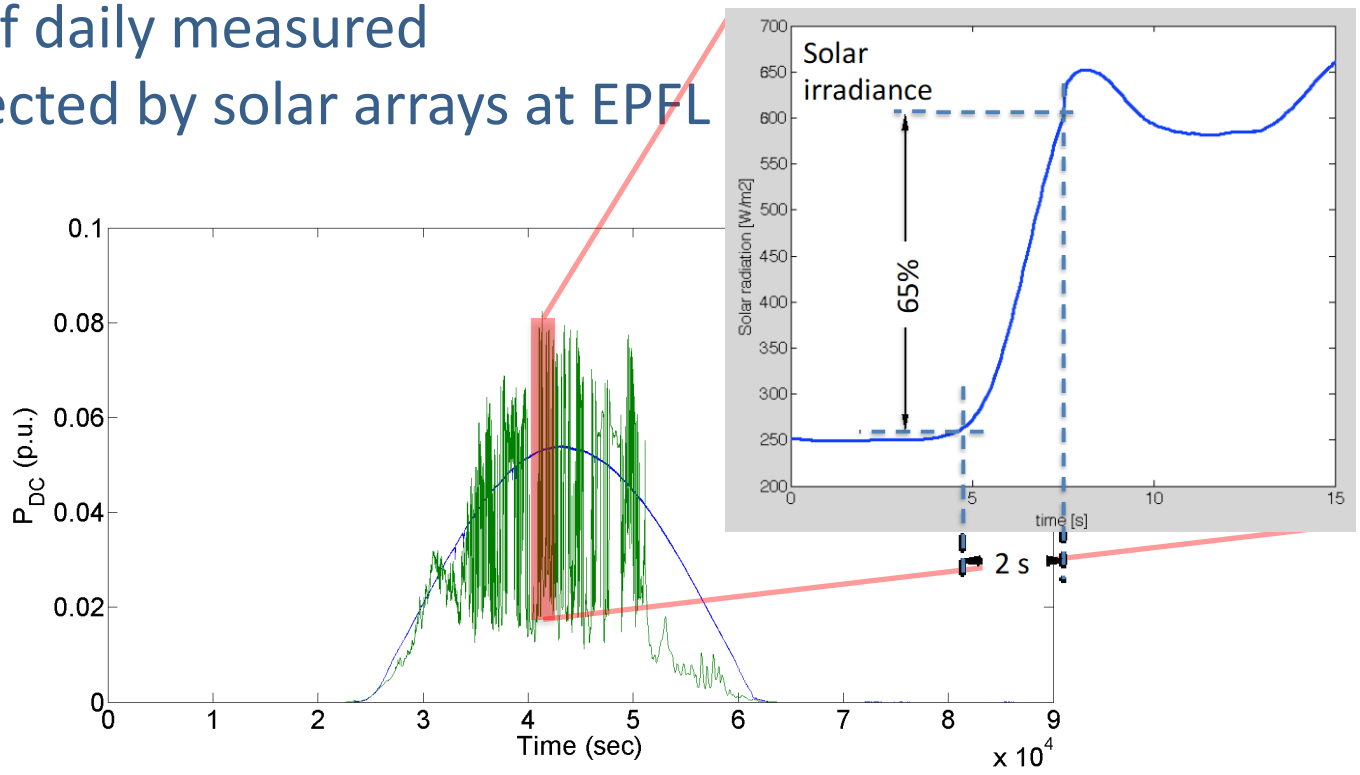
Power System Flexibility Needs

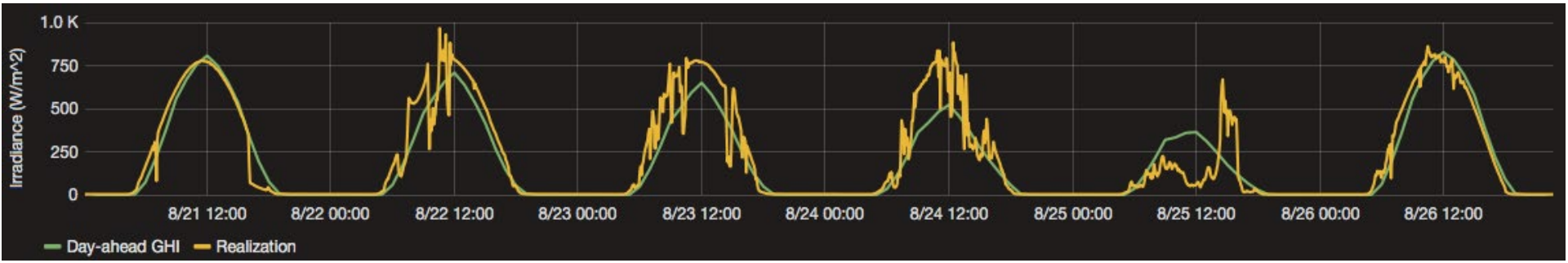
- **Securing Electricity Supply**
  - ✓ Matching the demand
  - ✓ Balancing intermittent generation
  - ✓ Mitigating hazards
- **Reserve Scheduling and Demand Forecast**
- **Time Scales**
  - ✓ Week
  - ✓ One day ahead
  - ✓ Seconds

Time-scales of PV volatility

- **Short-term PV Solar power volatility : seconds**
  - ✓ Example of daily measured power injected by solar arrays at EPFL

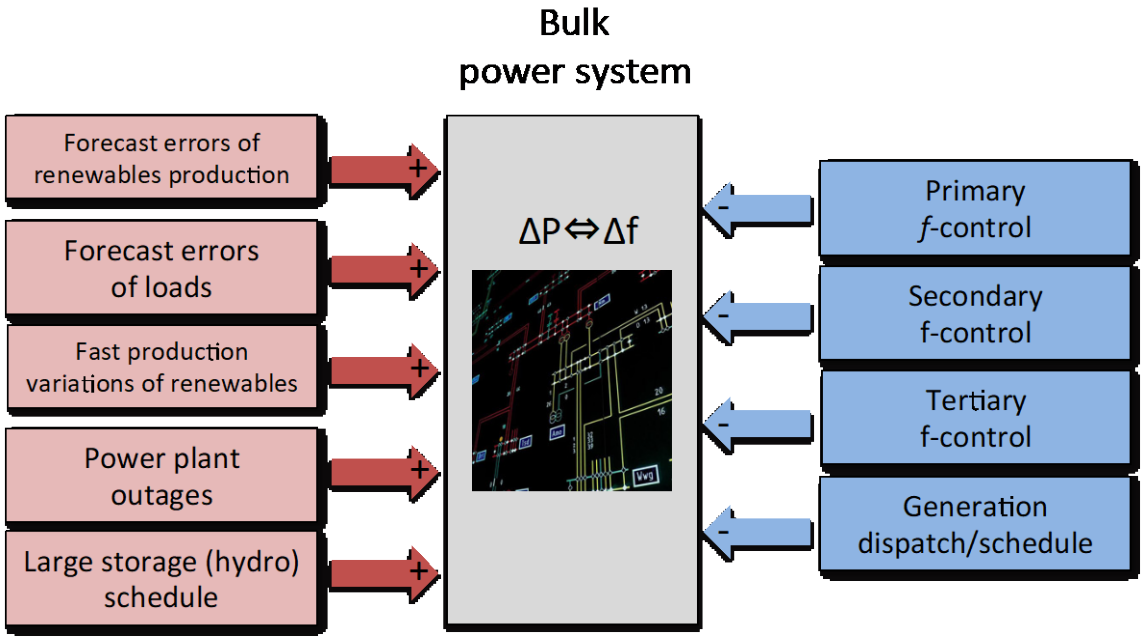


Forecast performance



- **Example of deviation from predicted (24h-ahead) and actual Global Horizontal Irradiance (GHI) @ EPFL, August 21-26, 2018**

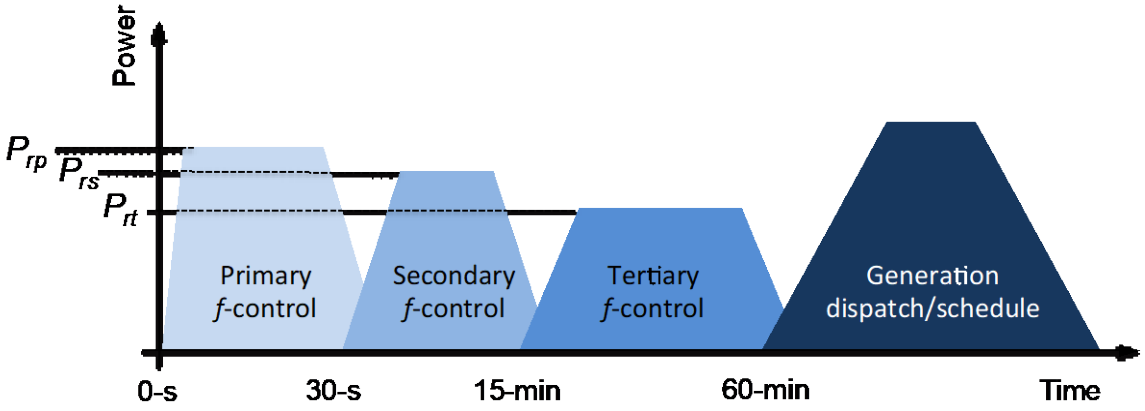
Reserve scheduling



Frequency Containment

Frequency Restoration

Replacement Reserve



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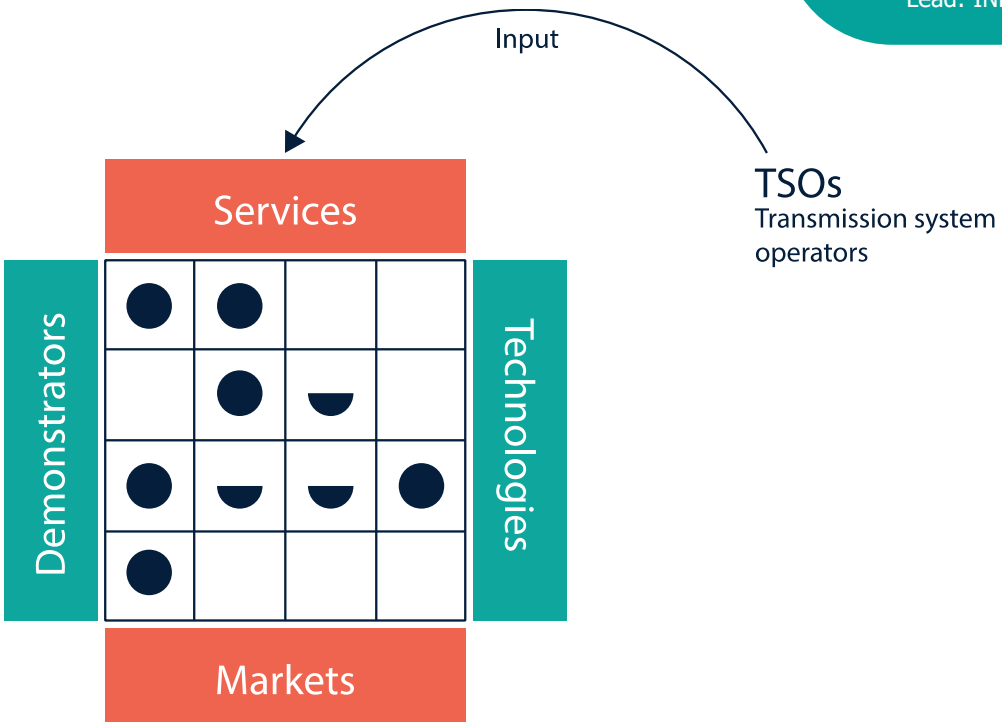
XFLEX HYDRO

WP 2
Flexibility services and specification
Lead: INESC TEC

ANCILLARY SERVICES MATRIX

The ancillary services matrix will play a key role in providing a mapping of hydro technology supporting flexibility services and how they enable hydropower to take part in new power markets. It will combine information about the latest flexibility products, flexibility markets and innovative hydroelectric technology solutions that enhance the ability of HPPs to respond to EPS flexibility needs.



INESCTEC

XFLEX HYDRO

Demonstrators

4 **Demonstrator (Z'Mutt)**
Lead: ALPIQ

5 **Demonstrator (Frades 2)**
Lead: EDP P (Voith)

6 **Demonstrator (Grand Maison)**
Lead: EDF (GE)

7 **Demonstrator (Alqueva)**
Lead: EDP CNET (GE)

8 **Demonstrator (Alto Lindoso & Caniçada)**
Lead: EDP CNET (GE)

9 **Demonstrator (Vogelgrün)**
Lead: EDF (Andritz)

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

XFLEX HYDRO

ANCILLARY SERVICES MATRIX

ANCILLARY SERVICES

Sites/Timescale	SYNCHRONOUS INERTIA 0 s	SYNTHETIC INERTIA < 500 ms	FAST FREQUENCY RESPONSE (FFR) 0.5-2 s	FREQUENCY CONTAINMENT RESERVE (FCR) < 30 s	AUTOMATIC FREQUENCY RESTORATION RESERVE (aFRR) 30 s - 15 min	MANUAL FREQUENCY RESTORATION RESERVE (mFRR) < 15 min	REPLACEMENT RESERVE (RR) > 15 min	VOLTAGE/VAR CONTROL < 1 s	BLACK START N/A	
Z' MUTT	T P	T P	T P	T P	T P	T P	T P	T P	●	FS
										VS (FSFC)
										VS & SPPS
FRADES 2										FS
	T P	T P	T P	T P	T P	T P	T P	T P	●	VS (DFIM)
										VS & SPPS & HSC
GRAND MAISON	T P	T P	T P	T P	T P	T P	T P	T P	●	FS
										FS, SPPS & HSC
ALQUEVA	T P	T P	T P	T P	T P	T P	T P	T P	●	FS
										FS & SPPS
										FS & HSC
										FS, SPPS & HSC
										VS (FSFC) & SPPS
ALTO LINDOSO & CANIÇADA	●	●	●	●	●	●	●	●	●	FS
										FS & SPPS
										VS (FSFC/DFIM) & SPPS
VOGELGRUN	●	●	●	●	●	●	●	●	●	FS Kaplan
										FS, SPPS & HBH
										VS (FSFC) Propeller
										VS, SPPS & HBH
Original terminology	Inertia		Primary frequency control (FC)		Secondary (FC)	Tertiary (FC)		Voltage control	System re-start	
Emerging frameworks	BILATERAL CONTRACTS (GB)	-	GB/IR/NORD	FCR coop.	PICASSO/IGCC	MARI	TERRE	BILATERAL CONTRACTS	BILATERAL CONTRACTS	

DEMONSTRATIONS

TECHNOLOGICAL SOLUTIONS

MARKET FRAMEWORK

LEGEND

TYPES OF HYDROP

- Pur
- P
- Reservoir sto
- Run-of-river hydropower

TYPES OF HYDRO EQUIPMENT

- Reversible Francis unit(s)
- Francis unit(s)
- Pelton unit(s)
- Kaplan/propeller unit(s)
- Electro-chemical battery

FLEXIBILITY TECHNOLOGY

SPPS	Smart Power Plant Supervisor (XFLEX product)
FS	Fixed speed
VS	Variable speed
VS (FSFC)	VS with full size frequency converter
VS (DFIM)	VS with doubly fed induction machine
HSC	Hydraulic short circuit (PSP)
HBH	Hydro-battery-hybrid

MARKET FRAMEWORKS

CE	Continental European market
GB	UK market
IR	Rep. & Northern Ireland market
NORD	Nordic market
EBGL	EU Electricity Balancing Guideline (2017/2195)
IGCC	International Grid Control Cooperation
PICASSO	Platform for International Coordination of Automated Frequency Restoration and Stable System Operation (aFRR)
MARI	Manually Activated Reserves Initiative (mFRR)
TERRE	Trans European Replacement Reserves Exchange (RR)

CAPABILITY OF ANCILLARY SERVICE

- Not currently capable of providing the service
- Capable, but could be enhanced
- Currently capable of providing the service

Challenges

- **Hydroelectric Unit**
  - ✓ Limited Operating Range (Stability, Cavitation)
  - ✓ Maintenance costs (Erosion, Wear & Tears)
  - ✓ Impact on the residual life-time (Fatigue)
- **Power plant**
  - ✓ Unit Dispatch Control
  - ✓ Hydraulic Structure Safety (Transient)
- **Environment**
  - ✓ Hydrological forecasting
  - ✓ Hydropeaking impact
  - ✓ Renaturation
- **Ancillary Service Market**

Recommendations: Flexibility Technologies

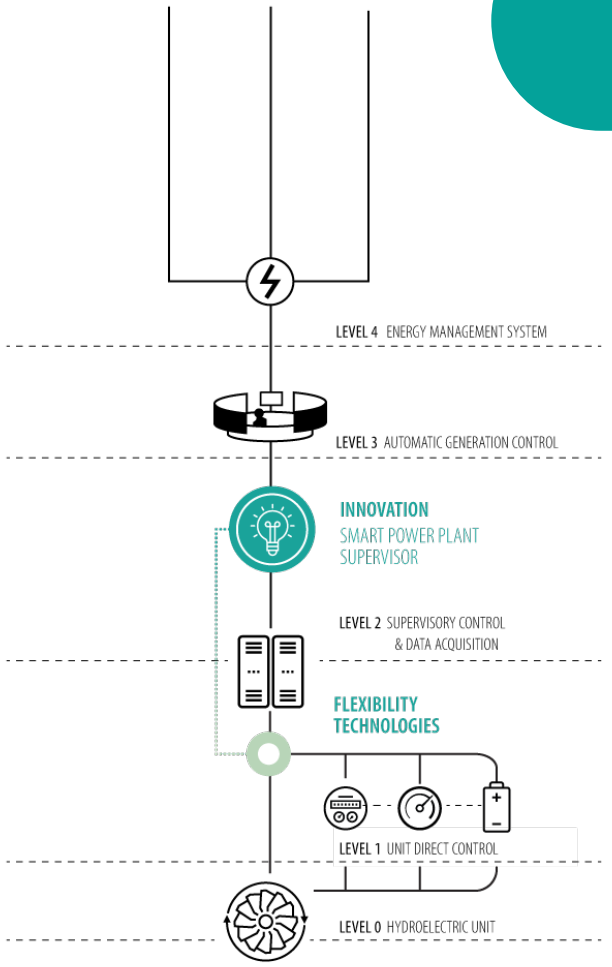
- **Hydroelectric Unit Digitalization**
  - ✓ Enhanced forecast tools
  - ✓ Advance operation tool integrating the unit operation knowledge *i.e.* engineering data, model tests and simulation data, commissioning data and operation data
  - ✓ Predictive Maintenance
- **Variable Speed Power Electronic**
  - ✓ Doubly Feed Induction Machine (Linth-Limmern – AXPO, Nant de Drance – ALPIQ/SBB)
  - ✓ Full Sized Frequency Controllers (Grimsel 2)
- **Hydraulic Short Circuit (Pumped Storage Power Scheme)**
  - ✓ Design stage (Veytaux 2)
  - ✓ Operation Extension (Nant de Drance)

XFLEX HYDRO

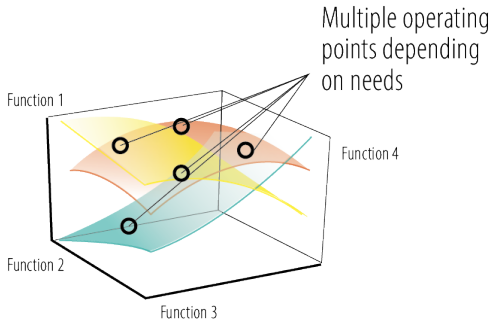
WP 3
Smart Power Plant Supervisor
Lead: EPFL

SMART POWER PLANT SUPERVISOR (SPPS)

Brings the turbine dynamics and conditions knowledge into advanced control unit operation and predictive maintenance



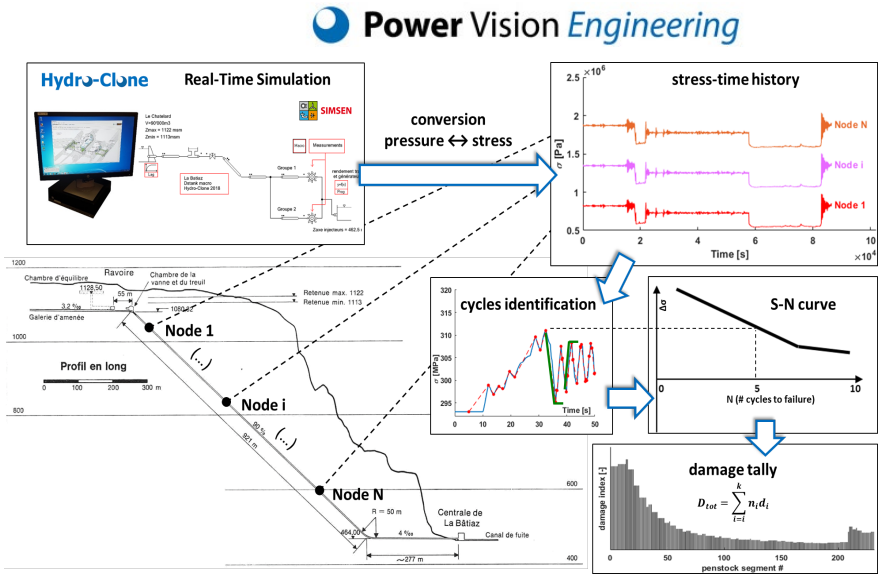
AFTER
Flexible range of operation based on a multidimensional analysis including energy grid needs

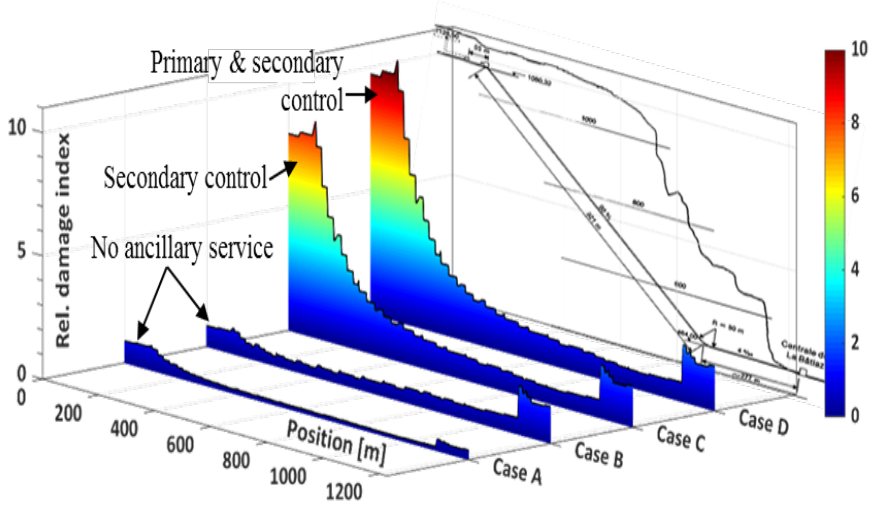


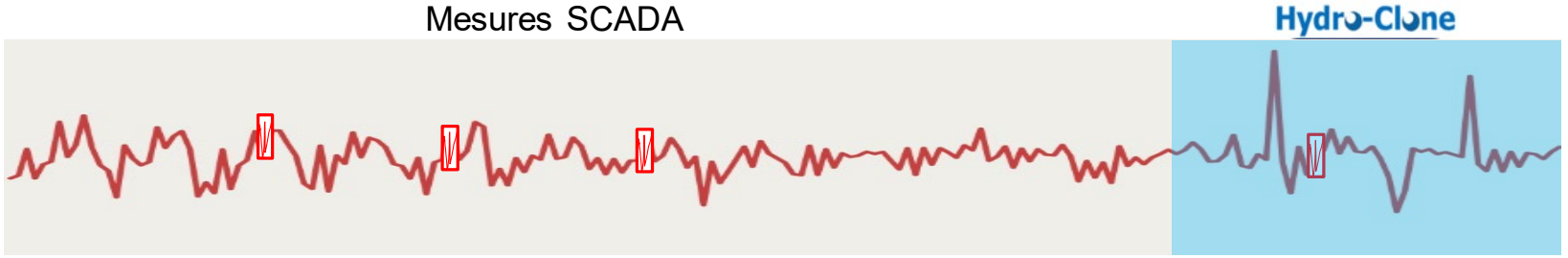
EPFL

Vagnoni, E. et al. *"Analysis of the operation time history of a Kaplan turbine in the Vogelgrun run-of-river power plant to extend the operating conditions and provide flexibility to the power system"*, Hydro2020 IEA Session on Session 16 – IEA Overcoming the barriers to development of hidden hydro opportunities.

Penstock Fatigue Monitoring







Dreyer, M. et al. *"Digital clone for penstock fatigue monitoring"*, IAHR Workshop on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, October 9-11, 2019, Stuttgart, Germany, published by IOP Conf. Series: Earth Environ. Sci. Vol. 405.

Recommendations: Flexibility Technologies

- **Unit Hybridization**
  - ✓ About 10% the rated power to handle the fast change instead of the governing system (XFLEX Hydro Vogelgrün Demonstrator, France)
  - ✓ Buffering power change to mitigate hydropeaking effect by decreasing the rate of discharge ramp up or slow down
- **Environment**
  - ✓ Seamless forecasting of stream/river discharge at the time scale from a few minutes to weeks)
  - ✓ Compensation Basin

XFLEX HYDRO

WP **9**

Demonstrator (Vogelgrün)
Lead: EDF (Andritz)

DEMONSTRATOR

VOGELGRÜN
FRANCE

x4

39MW

RUN-OF-RIVER

1959

BATTERY/ TURBINE HYBRID TECHNOLOGY

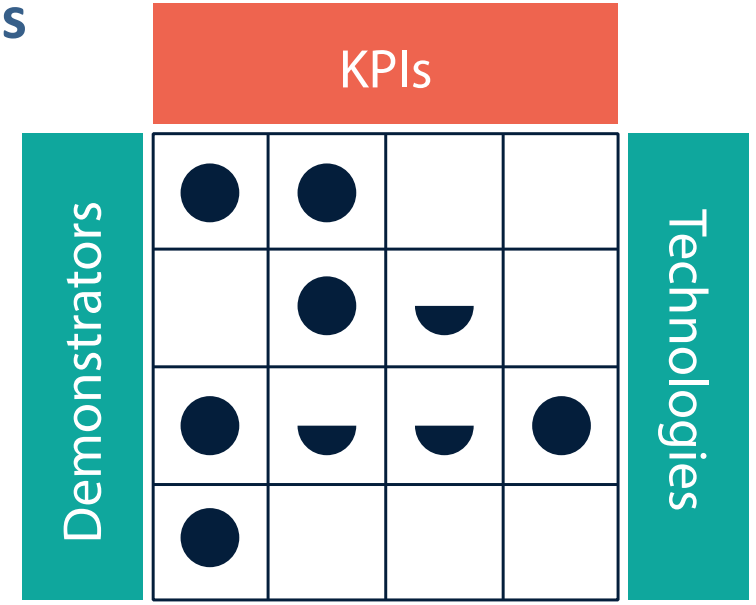
Vogelgrun is a run-of-river hydropower plant located in France near the border with Germany. The plant has four low head turbines, and in XFLEX HYDRO one unit will be equipped with a battery hybrid. The battery system will add energy storage to share response capability with the hydraulic unit, and use a master control to optimise flexibility services and wear and tear.

Key Objectives:

- Hybridise the turbine unit with a battery of suitable energy capacity and power converter rating, to improve fast and dynamic frequency response of the combined system.
- Significantly reduce turbine wear and tear, and quantify it.
- Evaluate the possibility of upgrading the 39 MW fixed-speed, double-regulated Kaplan turbine unit – with an enhanced variable speed, single-regulated propeller unit.

Recommendations: KPI Matrix

- Extended operation range
- Fast Start and Stop
- Fast Ramp-up/Ramp-down
- Fast turbine-pump / pump-turbine transition
- Optimized maintenance intervals
- Extended availability
- Increased annual efficiency
- Performance maximization
- Digitalization



Conclusions

- **Flexibility needs make hydroelectricity an enabler for massive deployment of Solar PV and Wind Resources**
- **Strongly driven by ancillary service market design (swissgrid)**
- **Flexibility Deployment Methodology**

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Thank you All !

Prof. F. Avellan, EPFL

November 2, 2020

In cooperation with the CTI

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Swiss Competence Centers for Energy Research

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Commission for Technology and Innovation CTI