Annual Conference
White Paper

Prof. F. Avellan, EPFL
November 2, 2020
Scope

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

Bulk power system

- Forecast errors of renewables production
- Forecast errors of loads
- Fast production variations of renewables
- Power plant outages
- Large storage (hydro) schedule

ΔP ↔ Δf

- Primary f-control
- Secondary f-control
- Tertiary f-control
- Generation dispatch/schedule

Frequency Containment
Frequency Restoration
Replacement Reserve
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.
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.
## ANCILLARY SERVICES MATRIX

### ANCILLARY SERVICES

<table>
<thead>
<tr>
<th>Site/Timeframe</th>
<th>Synchronous Inertia</th>
<th>Synthetic Inertia</th>
<th>Fast Frequency Response (FtFR)</th>
<th>Frequency Containment Reserve (FCR)</th>
<th>Automatic Frequency Restoration Reserve (AFCRR)</th>
<th>Manual Frequency Restoration Reserve (MFCRR)</th>
<th>Replacement Reserve (RR)</th>
<th>Voltage/Var Control</th>
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### MARKET FRAMEWORK

- **CE**: Continental European market
- **GB**: UK market
- **IR**: Rep. & Northern Ireland market
- **NORD**: Nordic market

### TECHNOLOGICAL SOLUTIONS

- **SPS**: Smart Power Plant Surveillance OF U/LX products
- **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

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- **CE**: Continental European market
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### DEMONSTRATIONS

- **ZMUTT**: Run-of-river hydro power
- **FRADES 2**: Kaplan/propeller unit
- **GRAND MAISON**: Electro-chemical battery
- **ALDEVA**: Kaplan/propeller unit
- **ALTO LINDOSO & CANIÇADA**: Electro-chemical battery
- **VÖGELGRUN**: Kaplan/propeller unit

### EMERGING FRAMEWORKS

- **BILATERAL CONTRACTS (GB)**: Currently capable of providing the service
- **FB/IR/NORD**: Not currently capable of providing the service
- **ICKASS/IGCC**: Not currently capable of providing the service
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### ORIGINATORS

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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
  ✓ Hydropoaking 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)
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.

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

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
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
Thank you All!

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November 2, 2020