



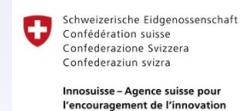
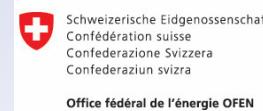
RENOVHydro: how to select the best hydro power plant renovation?

C. Nicolet, C. Landry, A. Béguin

S. Crettenand, C. Todde

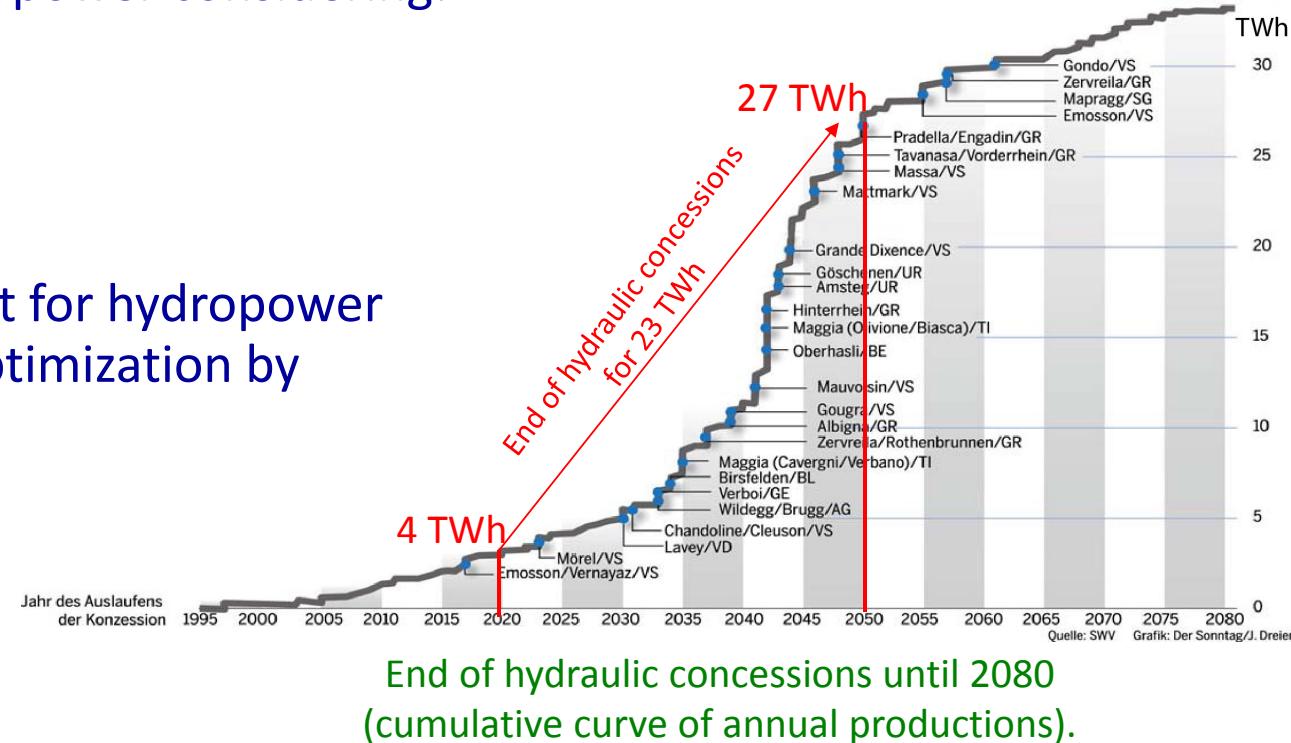
J. Gomes, M. Bozorg, S. Chamoun, P. Allenbach, P. Manso, M. Paolone, F. Avellan

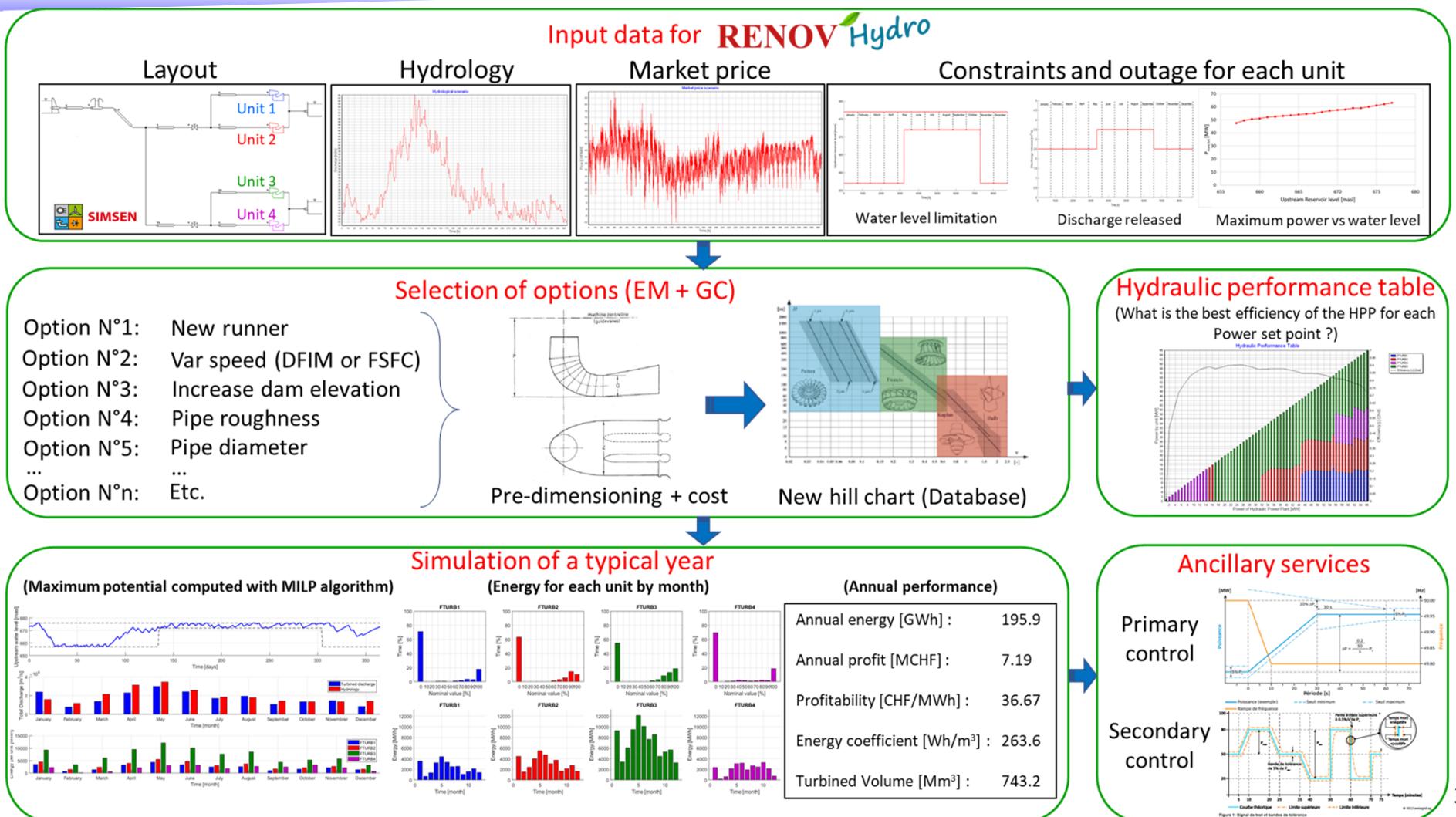
SCCER-SoE, Lausanne, EPFL, Switzerland, 3-4 September 2019



Context and Key goals

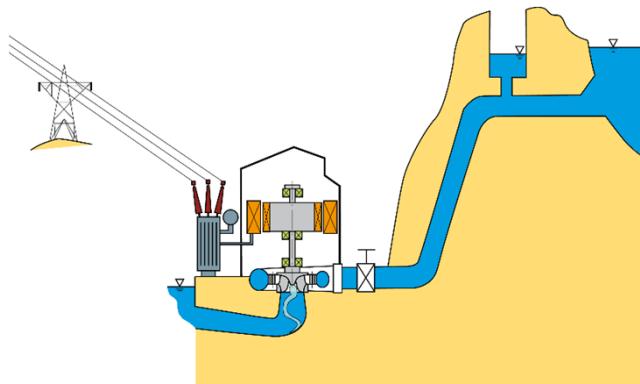
- Quantify the true potential of hydropower considering:
 - ✓ Concession ends
 - ✓ Technology limits
 - ✓ Environment conditions
 - ✓ Costs
- Develop a decision-making assistant for hydropower project potential renovation and optimization by considering:
 - ✓ Hydraulic structures
 - ✓ Hydraulic turbines
 - ✓ Electrical systems
 - ✓ Services to the grid (Ancillary services)





SIMSEN

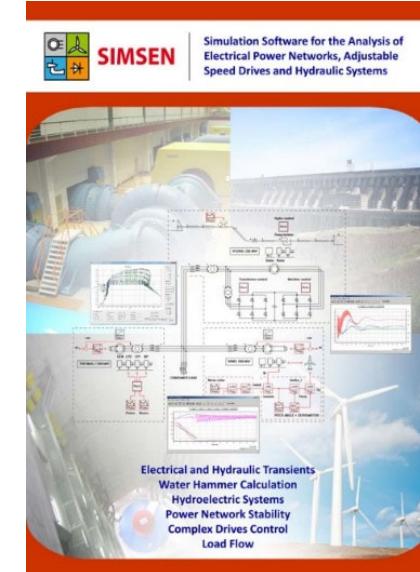
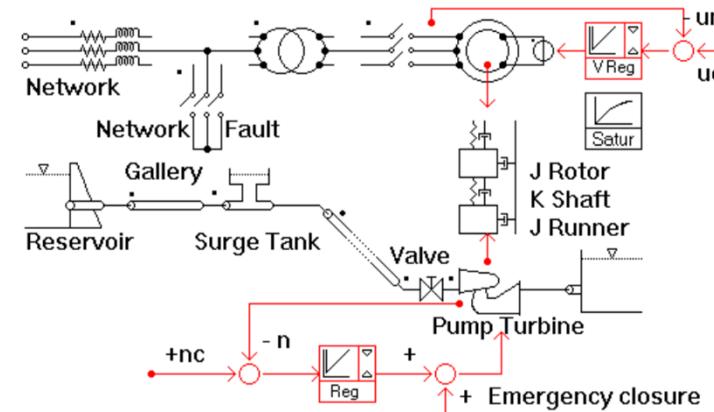
- SIMSEN Software:
 - ✓ Hydraulic circuit
 - ✓ Rotating inertia
 - ✓ Electrical installations
 - ✓ Control systems





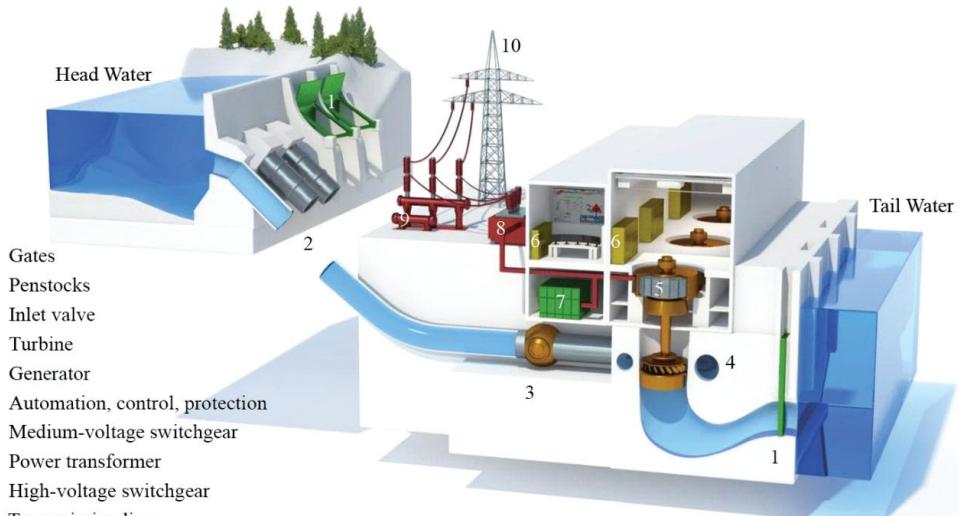


Modeling
From water
to wire



1a) Selection of the options

- For hydraulic structure:
 - ✓ Increase reservoir storage, decrease head losses
 - ✓ Add new tunnel, penstock
- For hydraulic machines:
 - ✓ Upgrade runner, turbine or unit
 - ✓ Add a unit, new pumping capacity
- For electrical equipment:
 - ✓ Variable speed (FSFC, DFIM)
 - ✓ Increase of generator capacity, available rotating inertia

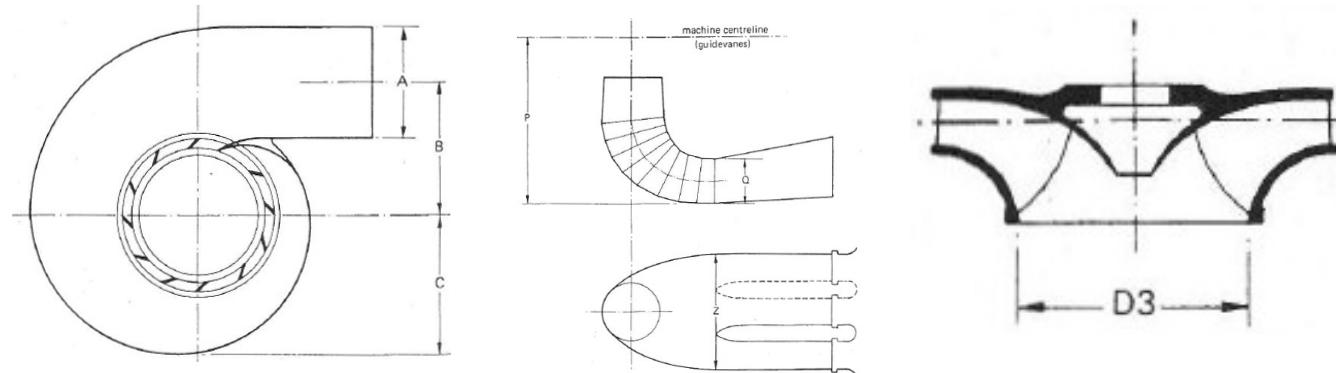


Reference: Andritz Hydro, www.andritz.com

Combinations of renovation options

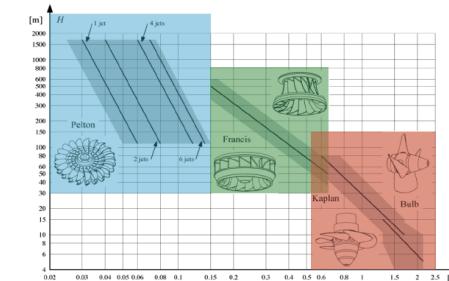
1b) Turbine layout + Cost

- Input data:
 - ✓ Mechanical power
 - ✓ Rated head
 - ✓ Year of commissioning
 - ✓ Frequency of electrical grid

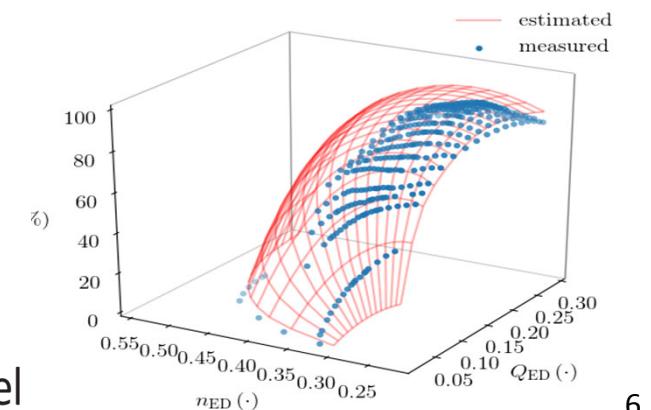


- For hydraulic machines:
 - ✓ Dimension of spiral casing, runner, draft tube, etc
 - ✓ Peak efficiency
 - ✓ Realistic performance hill chart

Polynomial bi-variate functions based on Hermite polynomials → Coefficients optimized with EPFL-LMH database (measurement on reduce scale models)

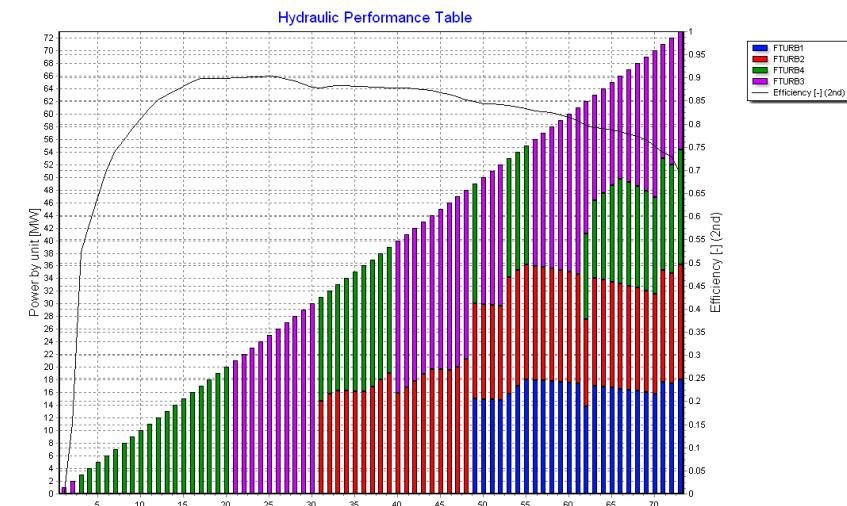
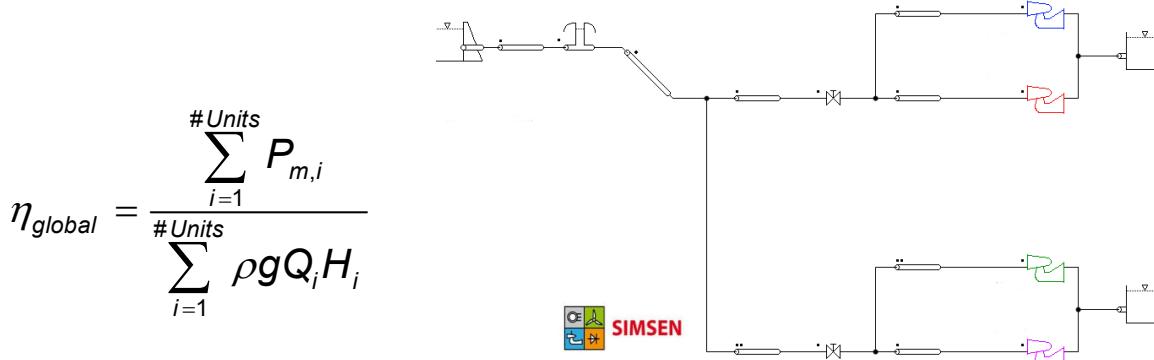


Hillchart prediction model



2) Hydraulic performance table

- Assessment HPP performances over the entire operating range:
 - ✓ Each unit combination
 - ✓ Each guide vane opening combination
 - ✓ Each upstream water levels
- Computation of the maximum performance:
 - ✓ For a given power set point
 - ✓ For a given gross head

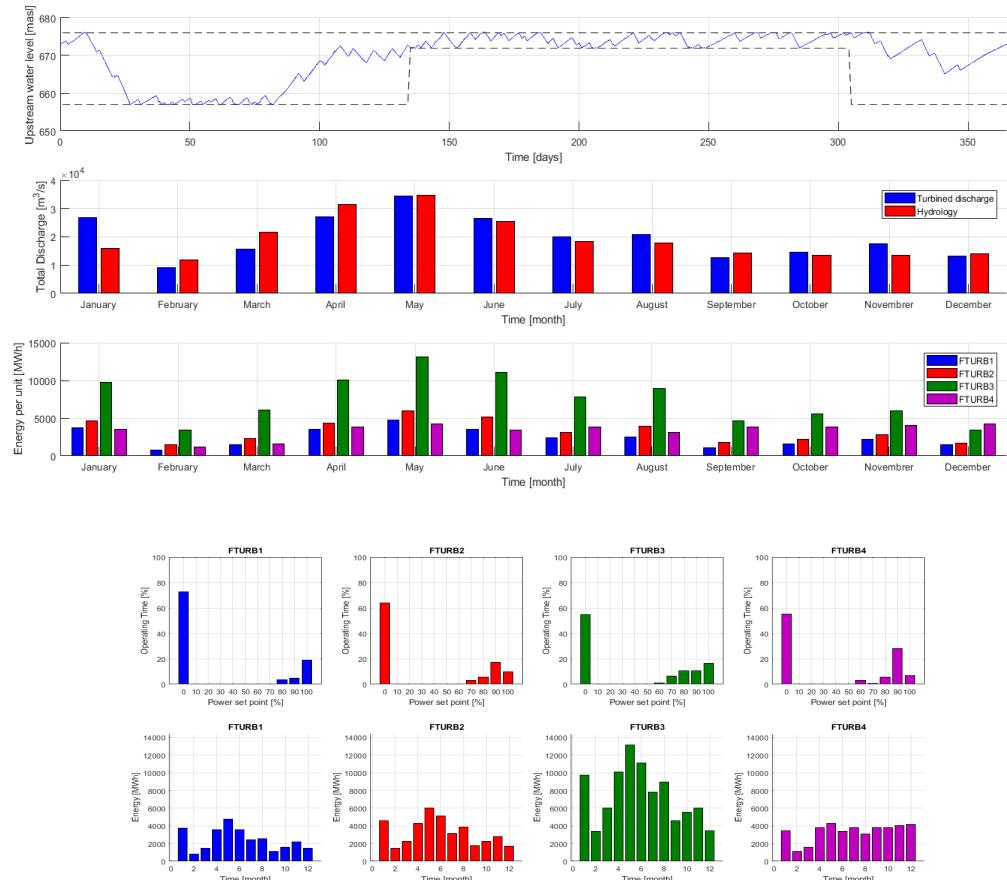


Units engagement for each power set point
($Z_{upstream} = 677\text{masl}$)

For 4 Francis turbine units, 2000 different operating conditions were simulated

3) Simulation of an operating year

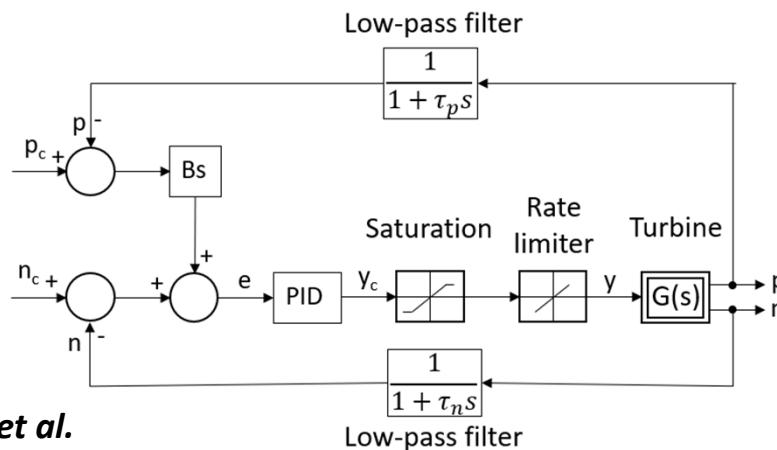
- Input data:
 - ✓ Electricity market price time history
 - ✓ Hydrology time history
 - ✓ Constraints:
 - Min and max water elevation
 - Min and max power set point for each unit
 - Max power set point as function of water level
 - Limits of released flow (environmental rules, ...)
- Maximization of annual revenue with mathematical optimization approach (MILP)
- Computation of Energy and Economic indicators:
 - ✓ Annual energy generation
 - ✓ Annual amount of turbined/pumped water
 - ✓ Energy coefficient
 - ✓ Annual revenues



4) Ancillary services

- Test for primary control capability defined by Swissgrid:

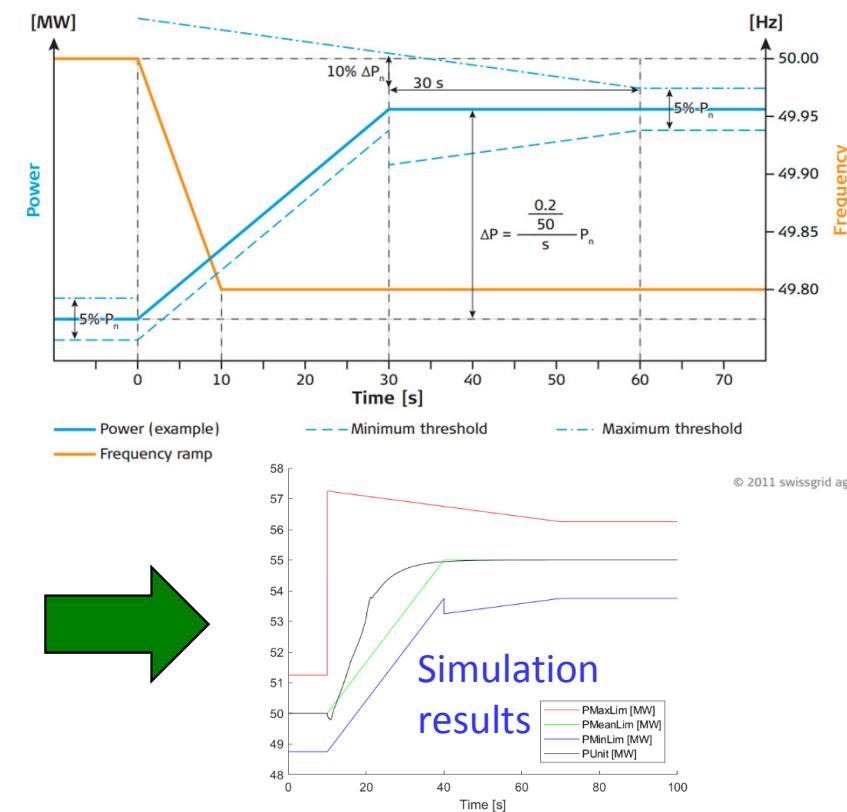
- ✓ Frequency variation: +0.2 Hz in 10 seconds
- ✓ Power variation must be delivered within 30 s



Landry et al.
Hydro2019
Porto

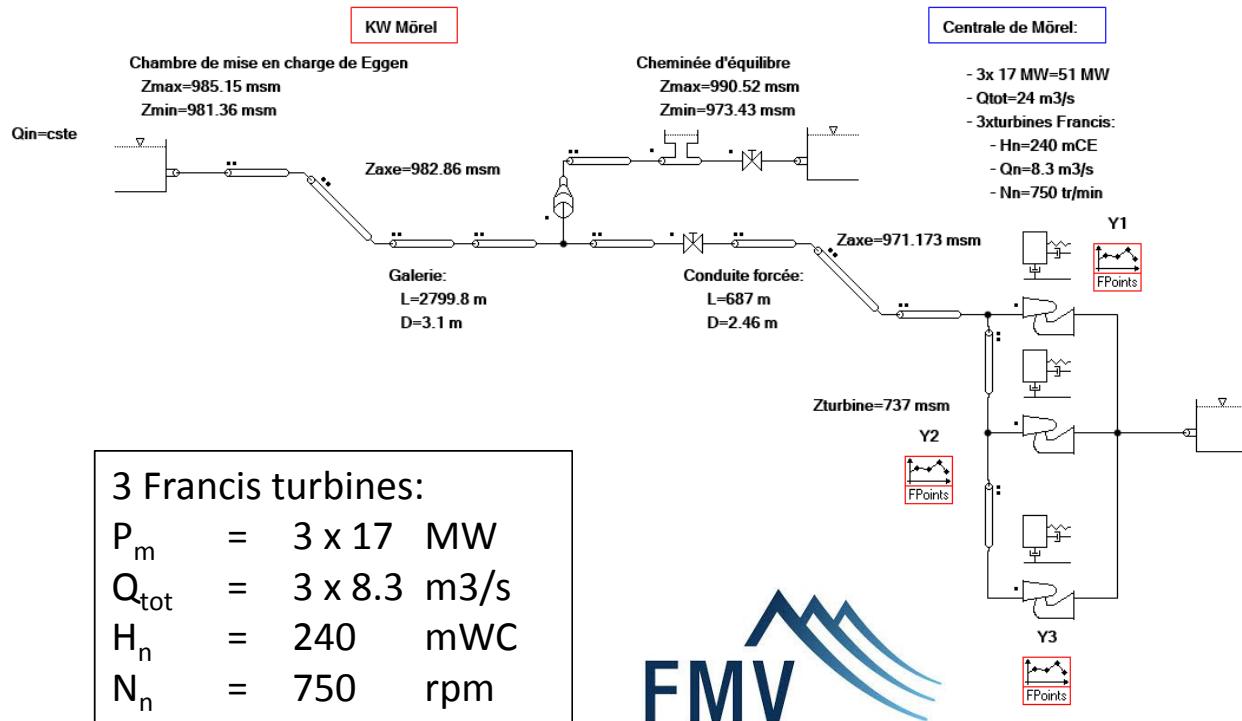
Permanent droop

$$Bs = \frac{\Delta f}{\Delta P} = K \cdot \frac{P_n}{f_n} = 4\%$$



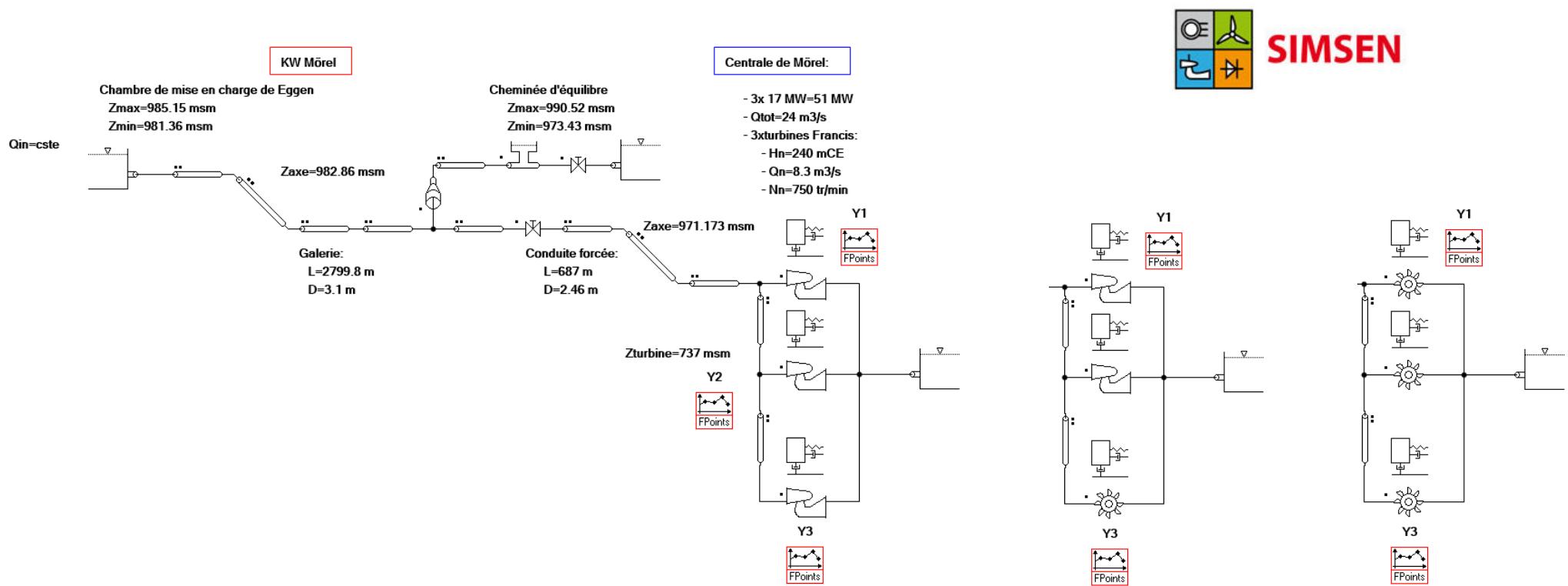
Hydraulic power plant in Mörel

- SIMSEN model:



Hydraulic power plant in Mörel

- Renovation option:



Renovation option:

3 Francis turbines ?

2 Francis + 1 Pelton turbines ?

3 Pelton turbines ?

Specification of the unit

- 3 x Francis (Original)

Pm	=	17	MW
Hn	=	240	mWC
Qn	=	8.3	m ³ /s
Nn	=	750	rpm
Dref	=	1.044	m
Nq	=	35.44	-
Eta	=	92.7	%

- 3 x Francis (New)

Pm	=	17	MW
Hn	=	240	mWC
Qn	=	7.58	m ³ /s
Nn	=	750	rpm
Dref	=	1.037	m
Nq	=	33.86	-
Eta	=	95.3	%
Prix _{unit}	=	1	- (Ref)
Prix _{tot}	=	3	-

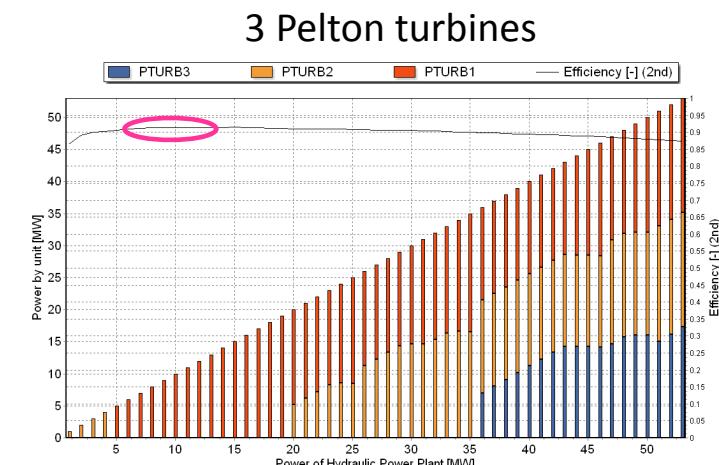
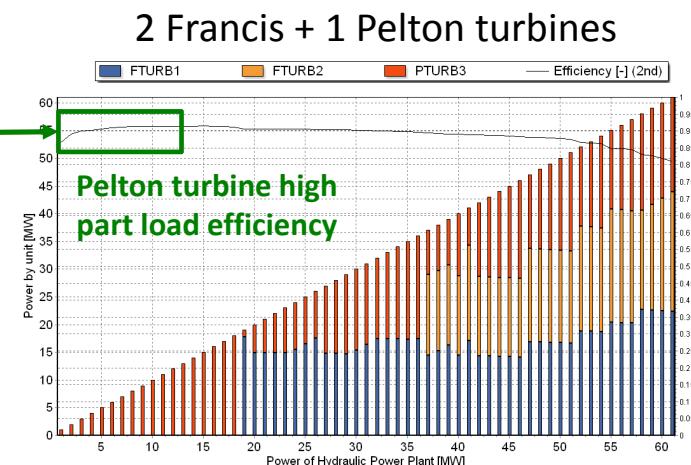
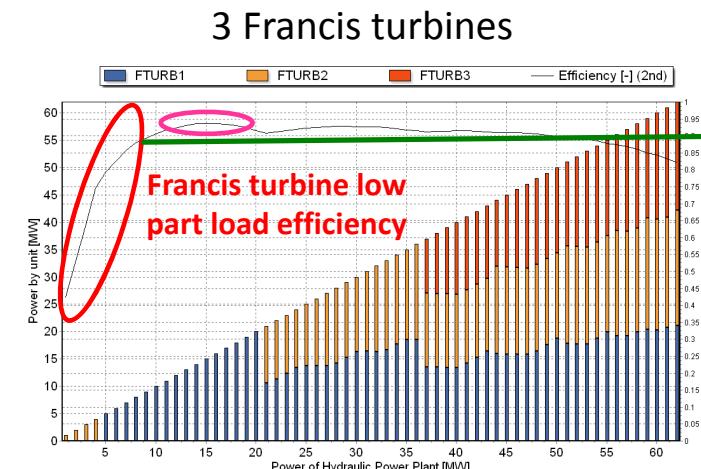
- 3 x Pelton (New)

Pm	=	17	MW
Hn	=	240	mWC
Qn	=	7.75	m ³ /s
Nn	=	375	rpm
Dref	=	1.587	m
Nq	=	17.12	-
Eta	=	93.2	%
Prix _{unit}	=	1.43	-
Prix _{tot}	=	4.30	-

The cost of the unit take into account the cost of the electromechanics (turbines, governors, generator, transformer, auxiliary systems, ...), **but not the civil modifications.**

Hydraulic power plant in Mörel

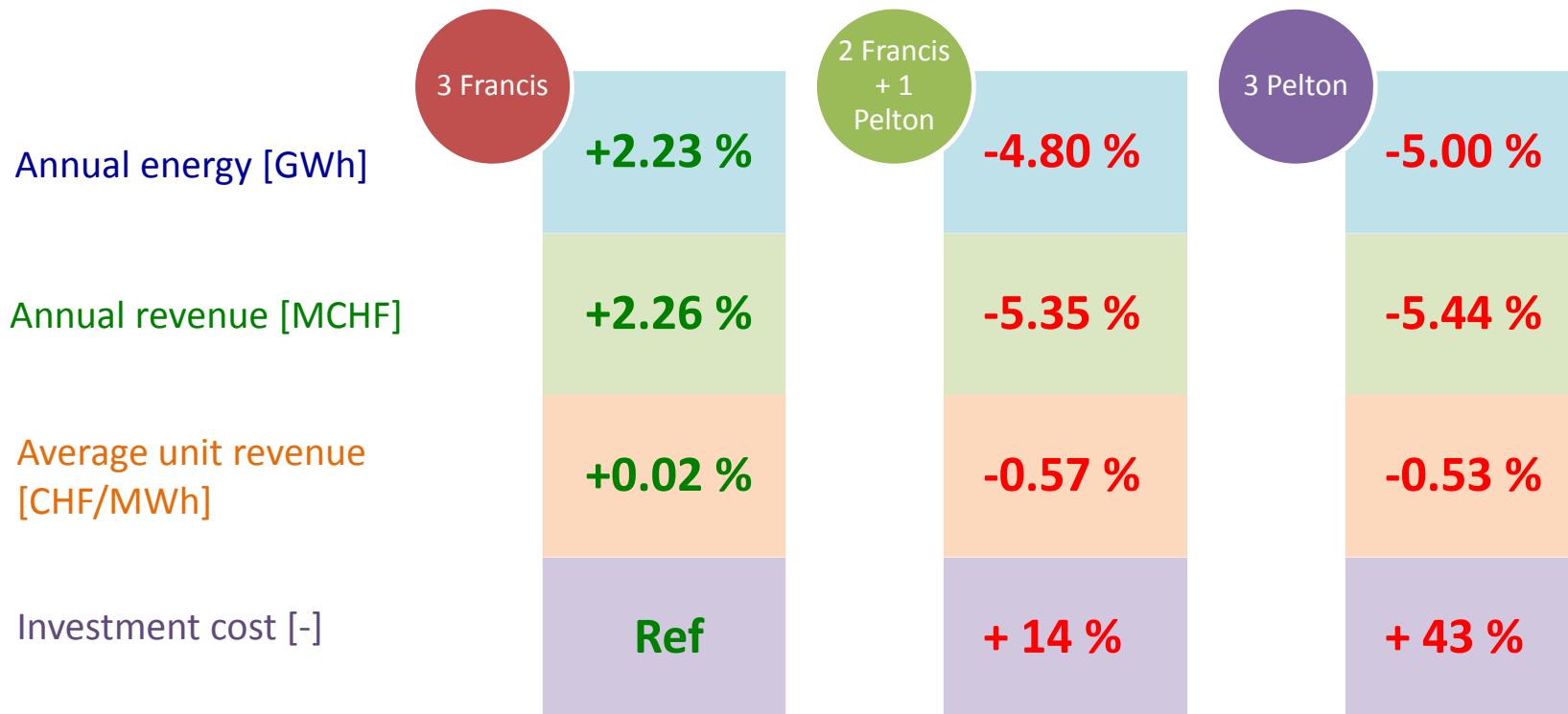
- Hydraulic performance table:



- Strategy:
 - ✓ Improve part load global efficiency by using Pelton turbine
- Facts:
 - ✓ Peak efficiency of Pelton turbine ($\eta_{\text{global}} \approx 0.915$) lower than Francis turbine ($\eta_{\text{global}} \approx 0.936$)
 - ✓ One unit to allow redundancy
 - ✓ Units mostly operated at full load

Hydraulic power plant in Mörel

- Performance indicators:



Conclusion

- 3 years project with 4 academic partners and 3 industrial partners
- Multidisciplinary project:
 - ✓ Mechanical, electrical and civil engineering
- Development of a Decision-making Assistant for Hydropower Project Potential Evaluation and Optimization:
 - ✓ Use SIMSEN software as a backbone
 - ✓ Fast and automatic scenario assessment for a given market price and inflow time history
 - ✓ Optimization of HPP revenues in electricity market including ancillary services (primary and secondary control)
- Applied to 5 different HPP test cases in upper Rhône Valley
- RENOVHydro outcomes implemented as new libraries in SIMSEN:
 - ✓ Turbine libraries, FMU co-simulations, RENOVHydro Decision-making Assistant

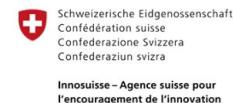
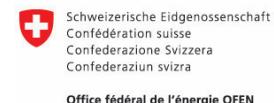
Thank you for your attention!

POSTERS:

RENOVhydro: 3.1.1
SMALL-Flex: 5.6, 5.13
Penstock Fatigue: 5.7



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