RENOV Hydro : how to select the best hydro power plant renovation?

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IEA Annex XVI - Hidden Hydro Opportunities -
Workshop July 1st 2021 - 11h-14h – on-line event

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EPFL FMV groupe e

Schweizerische Eidgenossenschaft
Confédération suisse
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Innosuisse – Agence suisse pour l'encouragement de l'innovation

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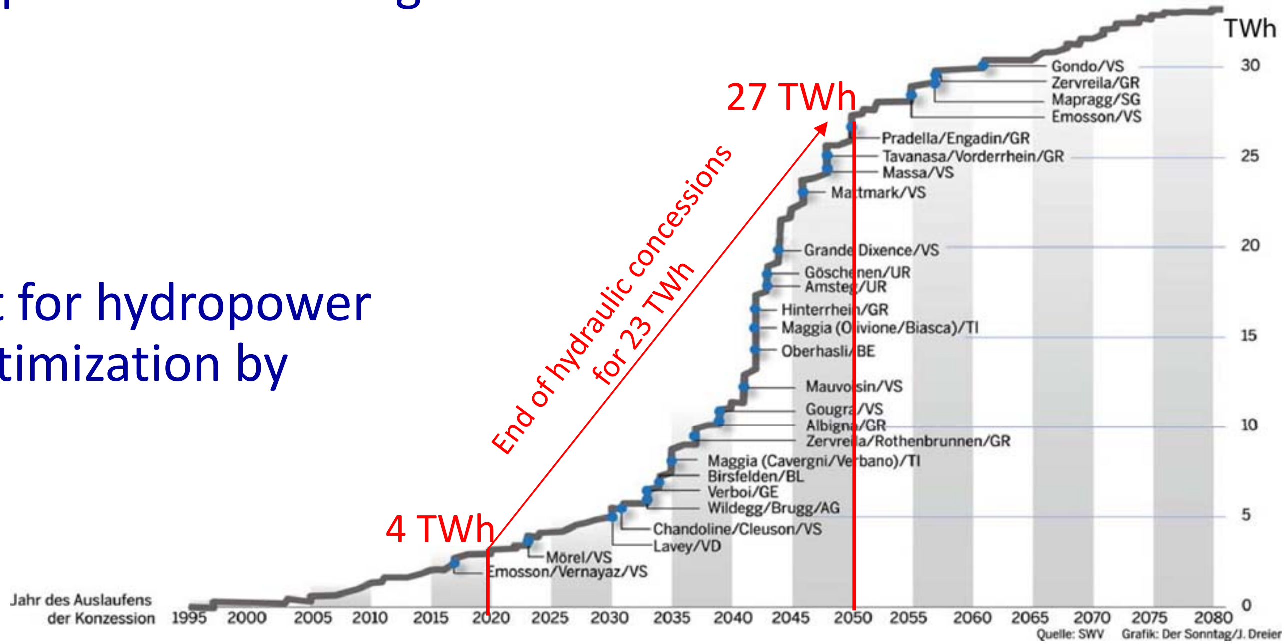
July 1st, 2021

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)



End of hydraulic concessions until 2080
(cumulative curve of annual productions)

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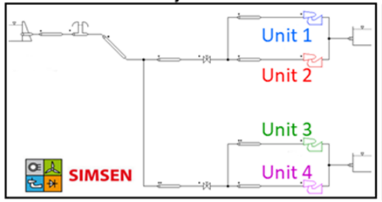
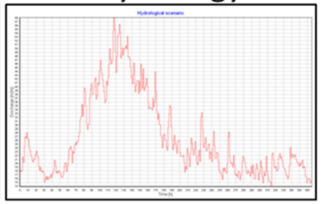
Input data for RENOV Hydro

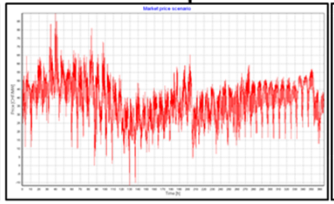
Layout



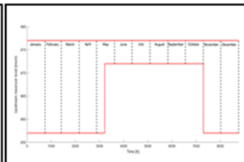
Hydrology



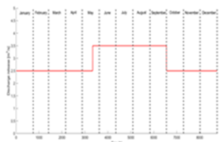
Market price



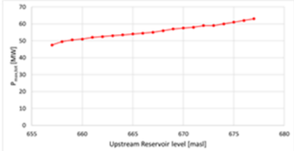
Constraints and outage for each unit



Water level limitation



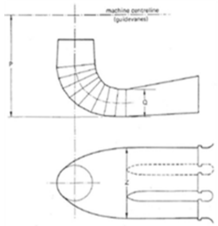
Discharge released



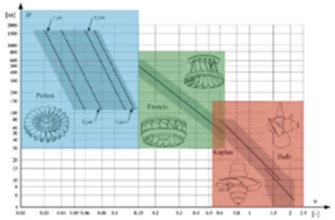
Maximum power vs water level

Selection of options (EM + GC)

Option N°1: New runner
Option N°2: Var speed (DFIM or FSFC)
Option N°3: Increase dam elevation
Option N°4: Pipe roughness
Option N°5: Pipe diameter
... ...
Option N°n: Etc.



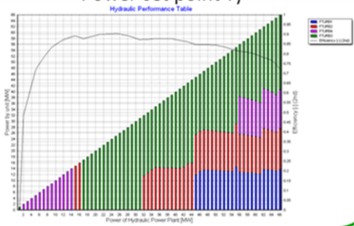
Pre-dimensioning + cost



New hill chart (Database)

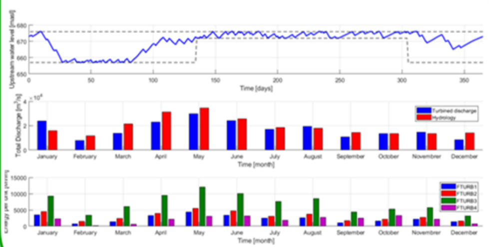
Hydraulic performance table

(What is the best efficiency of the HPP for each Power set point ?)

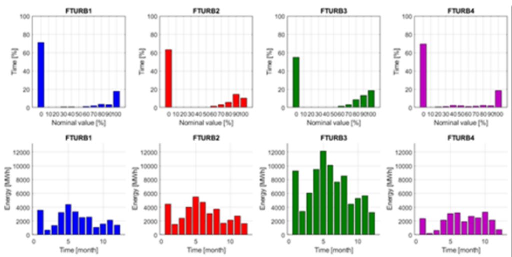


Simulation of a typical year

(Maximum potential computed with MILP algorithm)



(Energy for each unit by month)

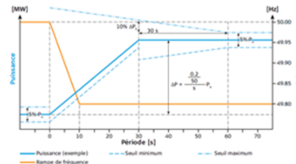


(Annual performance)

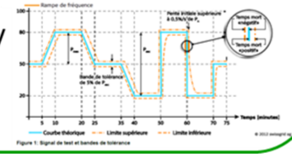
Annual energy [GWh] :	195.9
Annual profit [MCHF] :	7.19
Profitability [CHF/MWh] :	36.67
Energy coefficient [Wh/m³] :	263.6
Turbined Volume [Mm³] :	743.2

Ancillary services

Primary control



Secondary control



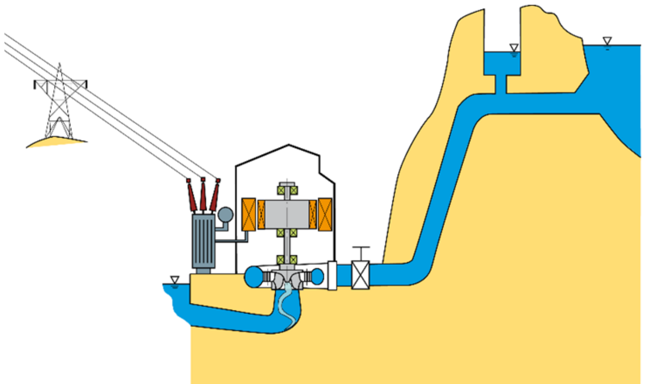
Landry *et al.*
Hydro2018
Gdansk

SIMSEN

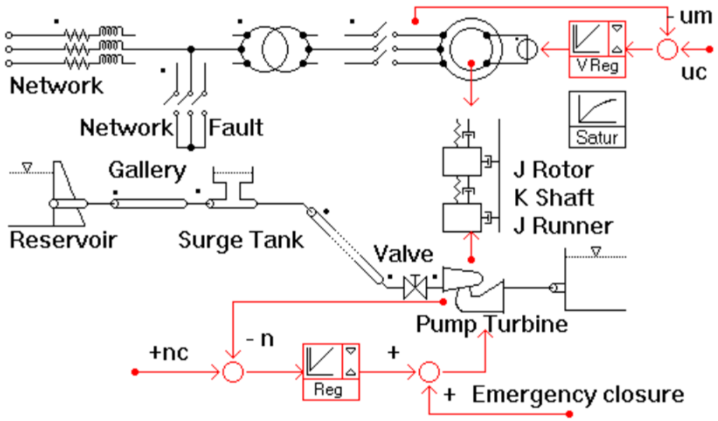
- SIMSEN Software:
  - ✓ Hydraulic circuit
  - ✓ Rotating inertia
  - ✓ Electrical installations
  - ✓ Control systems

EPFL

SIMSEN



Modeling From water to wire



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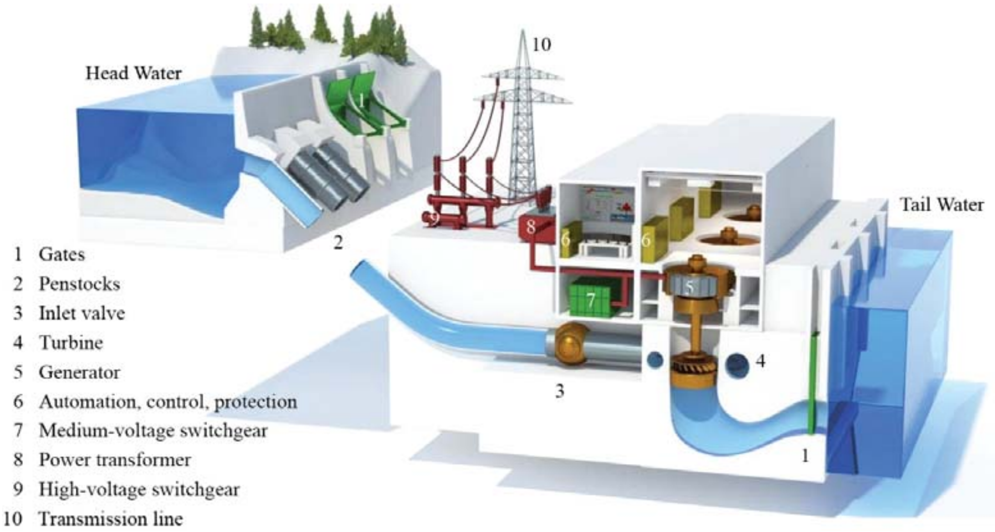
1a) Selection of the options

- 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

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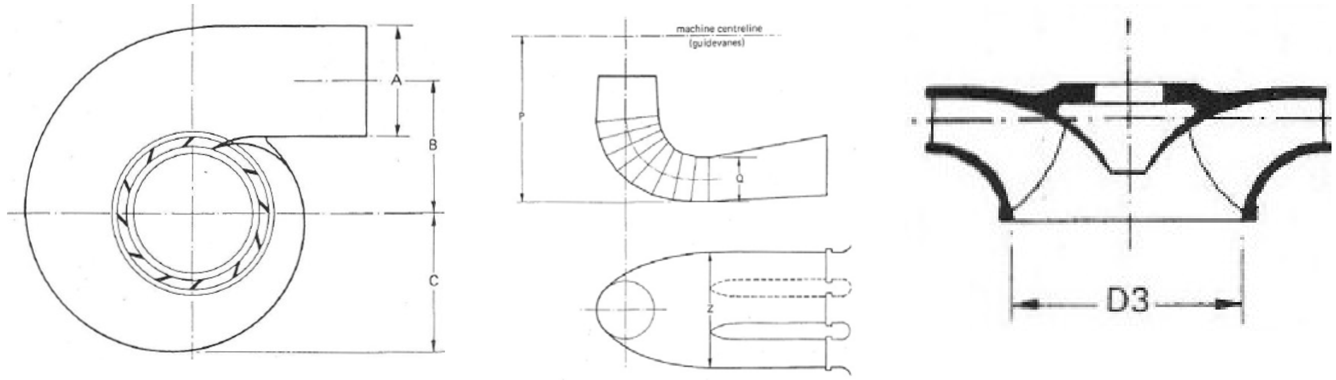
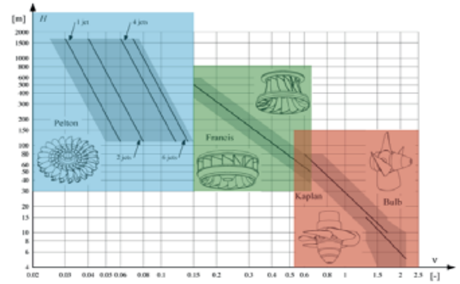
1b) Turbine layout + Cost

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

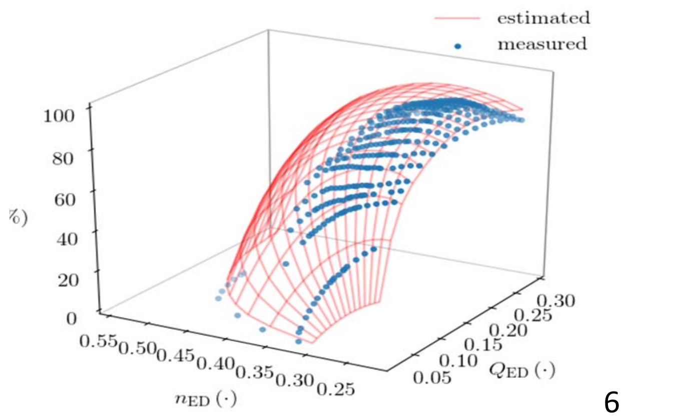


- For hydraulic machines:
  - ✓ Dimension of spiral casing, runner, draft tube, etc
  - ✓ Peak efficiency
  - ✓ Realistic performance hill chart

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



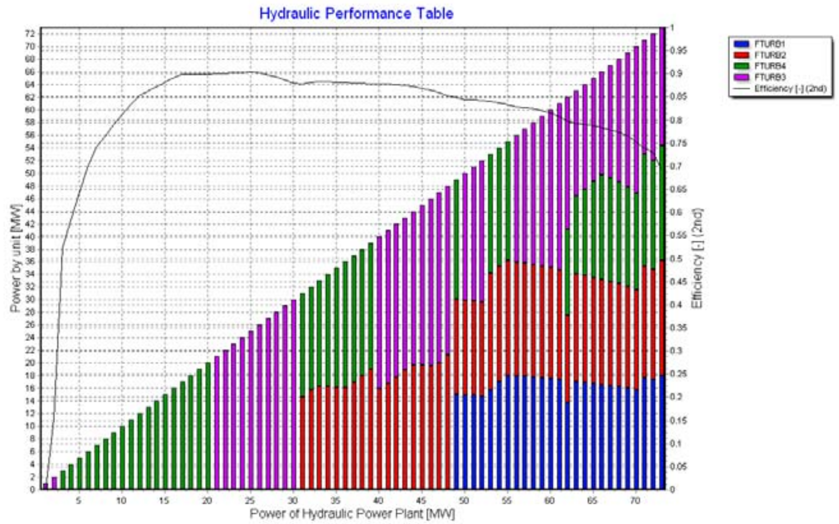
Hillchart prediction model



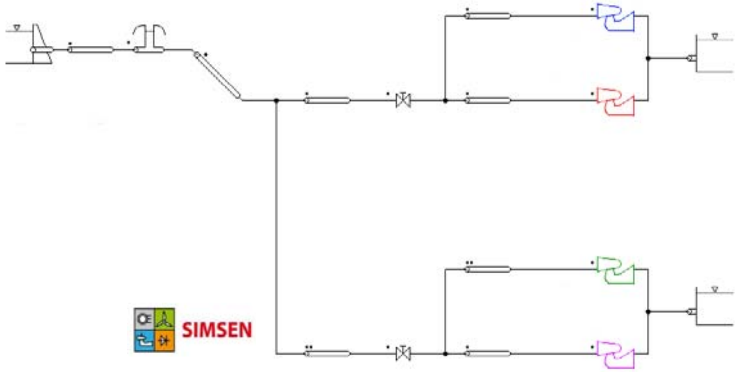
2) Hydraulic performance table

- 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



$$\eta_{global} = \frac{\sum_{i=1}^{\#Units} P_{m,i}}{\sum_{i=1}^{\#Units} \rho g Q_i H_i}$$



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

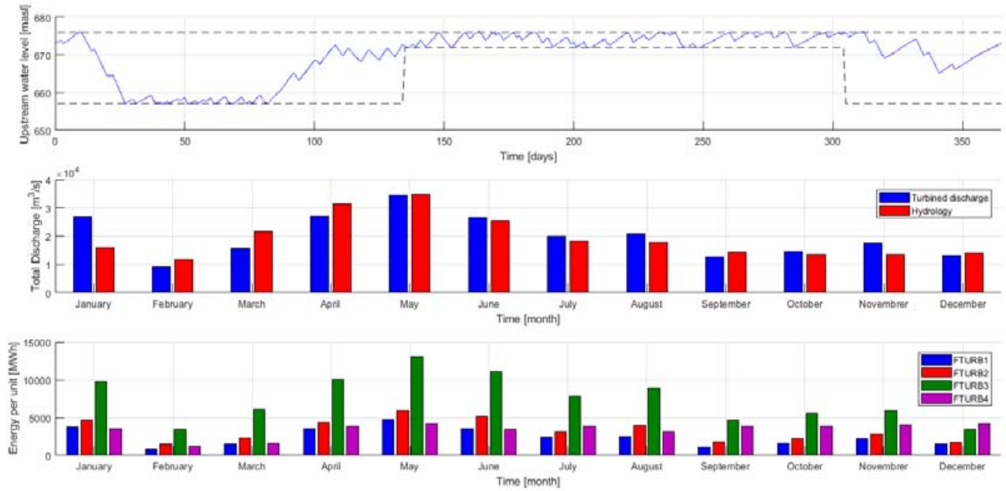
For 4 Francis turbine units, 2000 different operating conditions were simulated

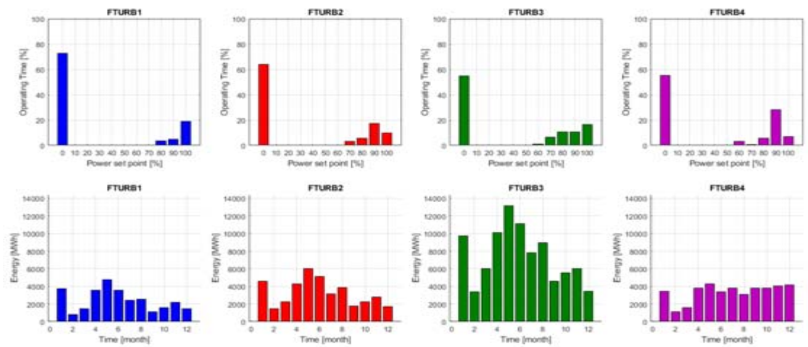
3) Simulation of an operating year

- 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)

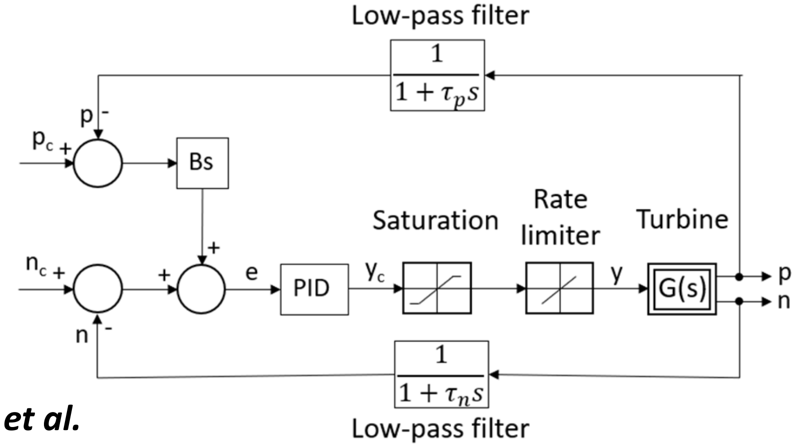
- Computation of energy and economic Key Performance Indicators:
  - ✓ Annual energy generation
  - ✓ Annual amount of turbined/pumped water
  - ✓ Energy coefficient
  - ✓ Annual revenues





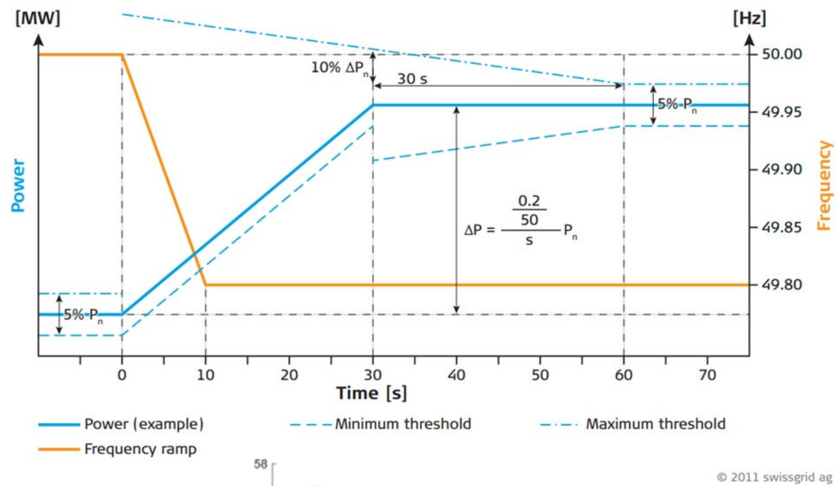
4) Ancillary services

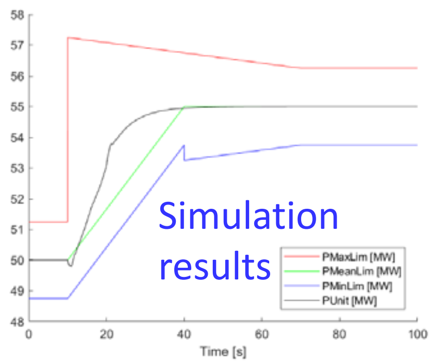
- Test for primary control capability defined by Swissgrid:
  - ✓ Frequency variation: +0.2 Hz in 10 seconds
  - ✓ Power variation must be delivered within 30 s



Landry *et al.*
Hydro2019
Porto

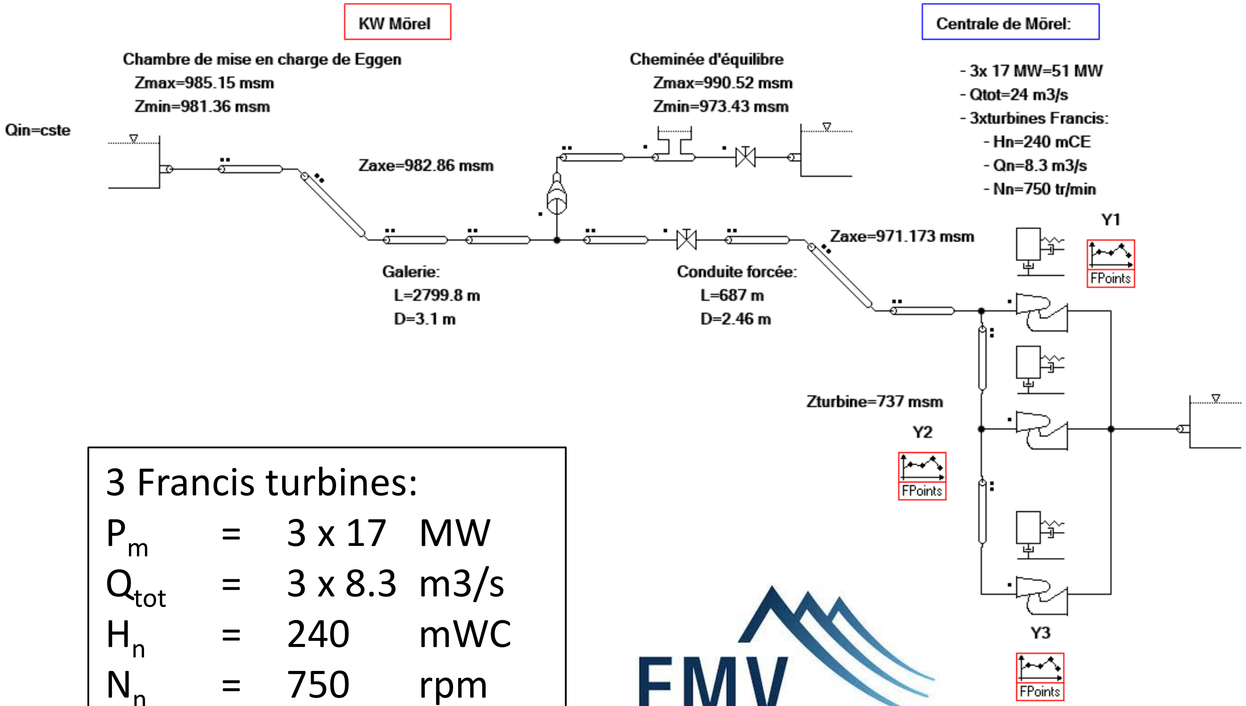
Permanent droop
$$Bs = \frac{\Delta f / f_n}{\Delta P / P_n} = K \cdot \frac{P_n}{f_n} = 4\%$$





Hydraulic power plant Mörel (CH)

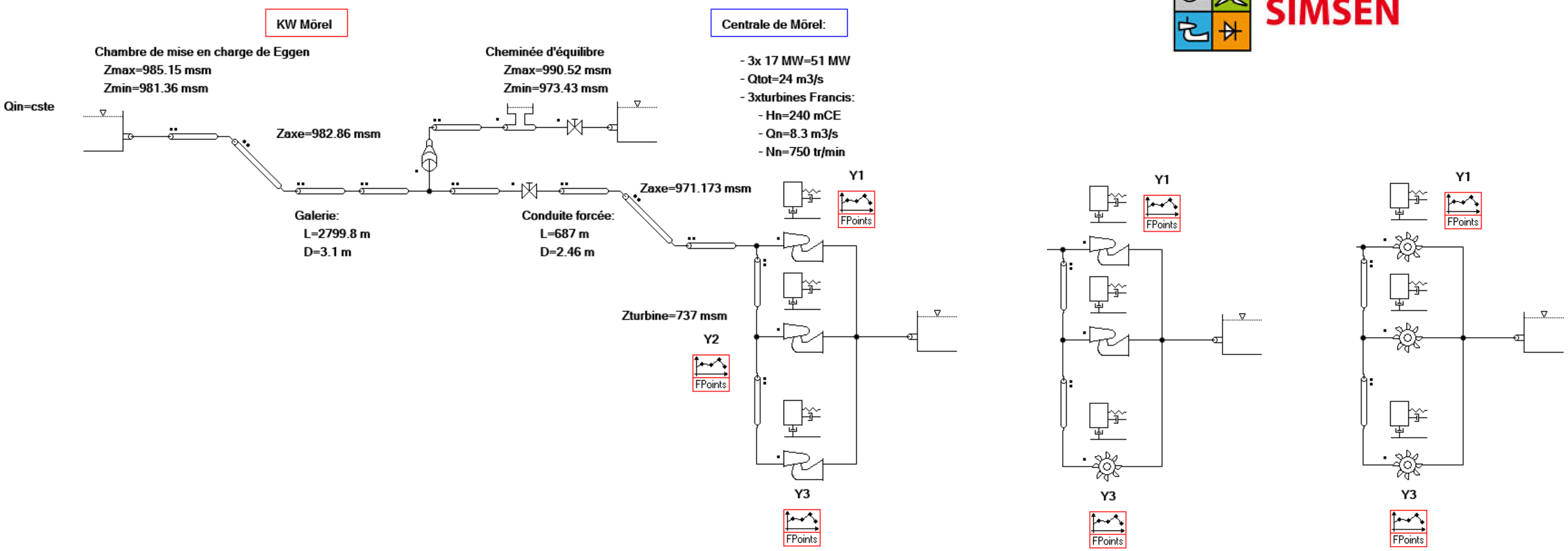
- SIMSEN model:



3 Francis turbines:			
P_m	=	3 x 17	MW
Q_{tot}	=	3 x 8.3	m3/s
H_n	=	240	mWC
N_n	=	750	rpm

Hydraulic power plant Mörel (CH)

- Renovation option:



Renovation option: **3 Francis turbines ?** **2 Francis + 1 Pelton turbines ?** **3 Pelton turbines ?**

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Hydraulic power plant Mörel (CH)

- Performance indicators:

	3 Francis	2 Francis + 1 Pelton	3 Pelton
Annual energy [GWh]	**+2.23 %**	**-4.80 %**	**-5.00 %**
Annual revenue [MCHF]	**+2.26 %**	**-5.35 %**	**-5.44 %**
Average unit revenue [CHF/MWh]	**+0.02 %**	**-0.57 %**	**-0.53 %**
Investment cost [-]	**Ref**	**+ 14 %**	**+ 43 %**

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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 control)
- Applied to 5 different HPP test cases in upper Rhône Valley (CH)
- RENOVHydro outcomes implemented as new libraries in SIMSEN:
  - ✓ Turbine libraries, FMU co-simulations, RENOVHydro Decision-making Assistant

Thank you for your attention!

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RENOVHydro project granted by SFOE, Swiss Federal Office of Energy (Grant funding SI/501436-01)
SHAMA project granted by the SFOE, Swiss Federal Office of Energy (Grant funding SI/501435-01).

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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.**

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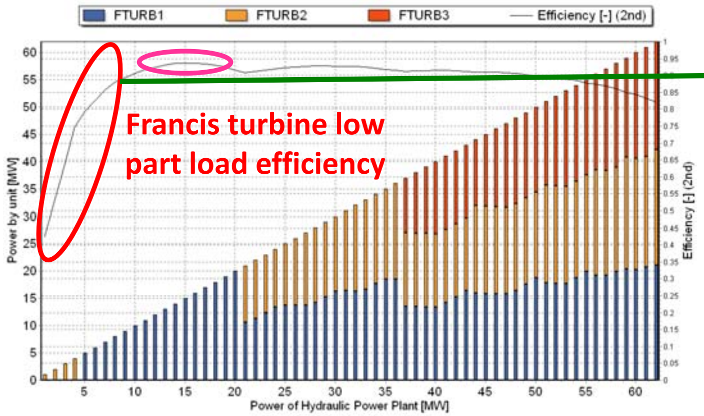
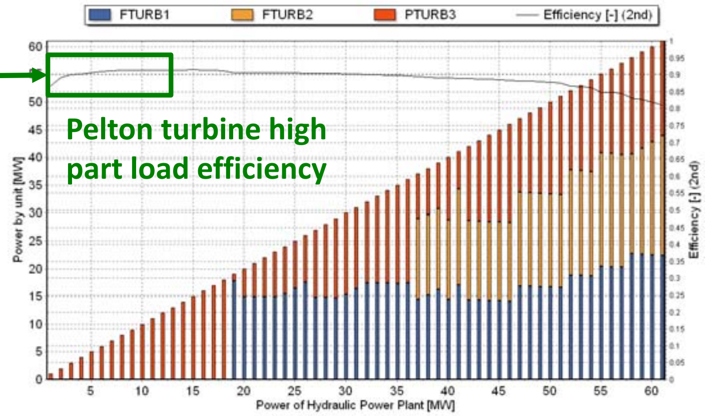
Hydraulic power plant in Mörel

- ## Hydraulic performance table:

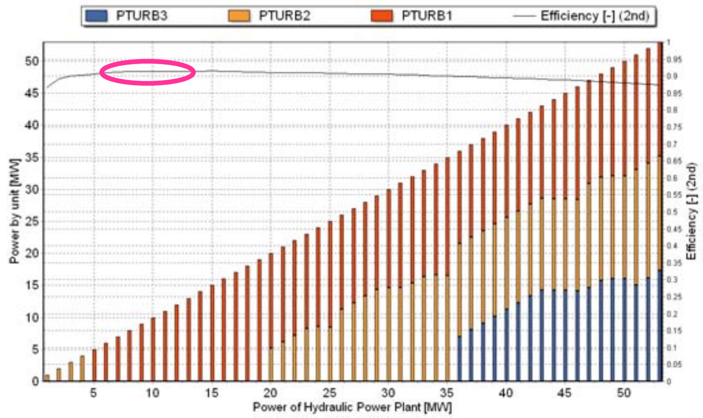
3 Francis turbines



2 Francis + 1 Pelton turbines



3 Pelton turbines



- **Strategy:**
  - ✓ Improve part load global efficiency by using Pelton turbine
- **Facts:**
  - ✓ Peak efficiency of Pelton turbine (η_{global}^=0.915) lower than Francis turbine (η_{global}^=0.936)
  - ✓ One unit to allow redundancy
  - ✓ Units mostly operated at full load