Technische Universität Braunschweig
AG Regenerative Energien

Using Short-Time Storage Potentials of Run-of-River Hydroelectric Plants for Frequency Control

Bastian Hase, 6th International Conference on Smart Energy Systems

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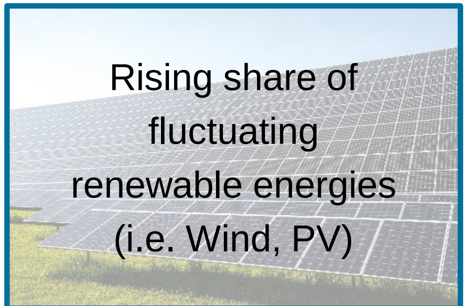
Why using ROR-hydropower for producing control energy?



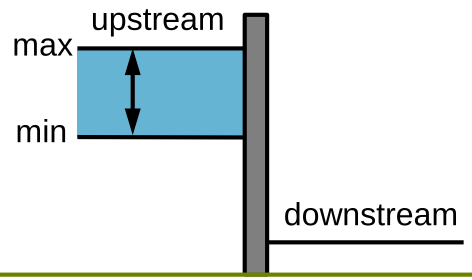
increased need for control energy

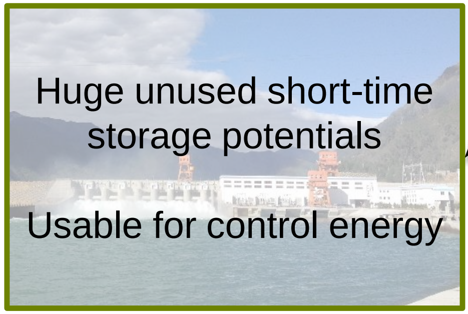
renewable technologies must fill the gap!

→ run-off-river (ROR) hydropower

reduced control energy capacities

flexible upstream water levels





- investigations on model of a 500 kW research power plant with low head (1.76 m)
- maximum allowed amplitude of reservoir level: 0.27 m

How to make use of the short term storage potentials?

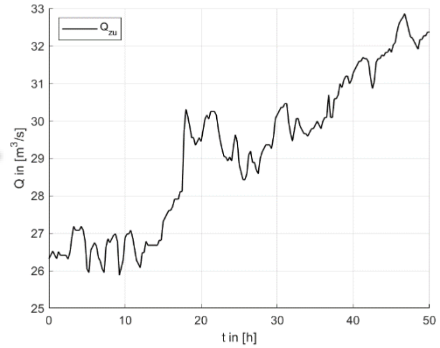
conventional operation
(quasi steady state)

constant reservoir level

flow rate machine
= flow rate river

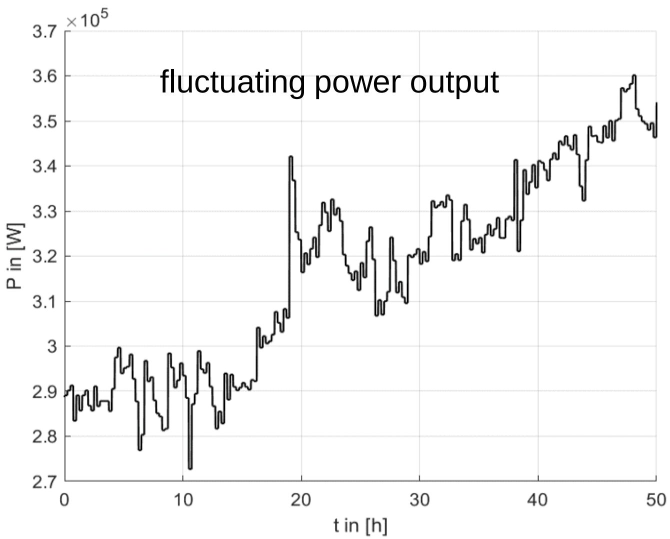
1 product
(energy only)

variable flow rate into reservoir

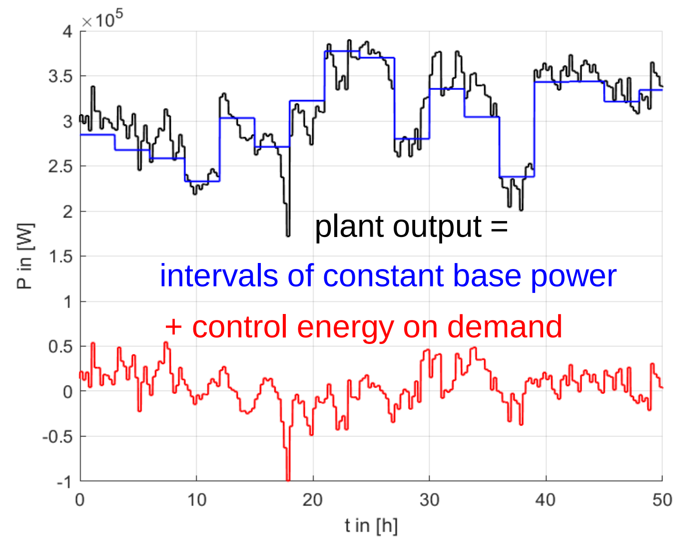


optimized operation
(using short term storage)

– variable reservoir level
– flow rate machine
≠ flow rate river
– 2 products (base power + control energy)



→ production follows flow rate



→ production scheduled in advance, behavoir similiar to conventional plants!

Design of the plant model

Static modelling approach

→ plant dynamics and hydrodynamics neglectect

Upstream reservoir level $h_U(t)$ given by ODE:

$$\dot{h}_U(t) = \frac{Q(t)}{A_{res}} - \frac{P_{B,i} + \alpha_j \cdot P_{C,Germany}(t)}{(h_U(t) - h_D(t))} \cdot \frac{1}{A_{res} \cdot \rho \cdot g \cdot \eta}$$

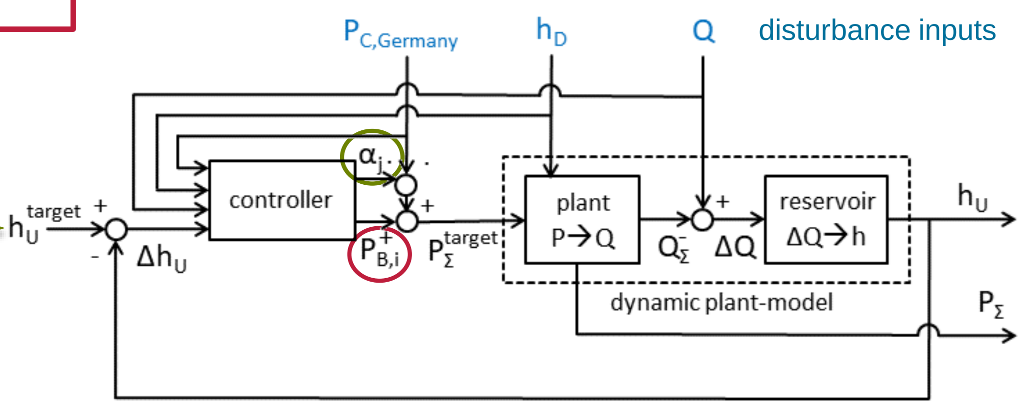
$Q(t)$	river flow rate
A_{res}	area of reservoir surface
$P_{B,i}$	base power during interval i
$h_D(t)$	downstream water level
ρ	density of water
g	earth acceleration
η	efficiency (assumed const.)
$P_{C,Germany}$	total control power activated in Germany

when driving with constant base power $P_{B,i}$

upstream water level behaves unstable!

controller

- regularly adapts base power $P_{B,i}$
- determines maximum control power capacity for each tender interval α_j



Challenges for the controller

Controller needs to estimate
disturbance inputs over a long time

short term storage potentials
$\approx 48\, min \cdot MQ$ (mean flow)

type	lead time	delivery time
FCR	129 h	168 h
aFRR	9 h	24 h
mFRR	14 h	24 h
intraday	5 min	>15 min
day ahead	12 h	> 1h

$P_{C,Germany}$: positive and negative control power approximately compensate

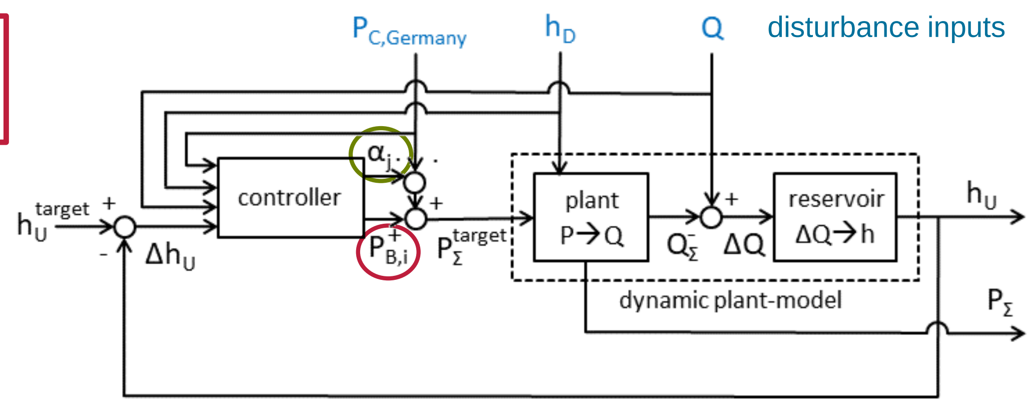
h_D: Can be calculated via rating curves (from Q_Σ)

Q: Precise forcast difficult

High influence on upstream level!

controller must guess future values

→ long intervals reduce reliabilty



Control energy potentials

investigation period: 2015-2017

mean ROR-coverage of national demand[1]:

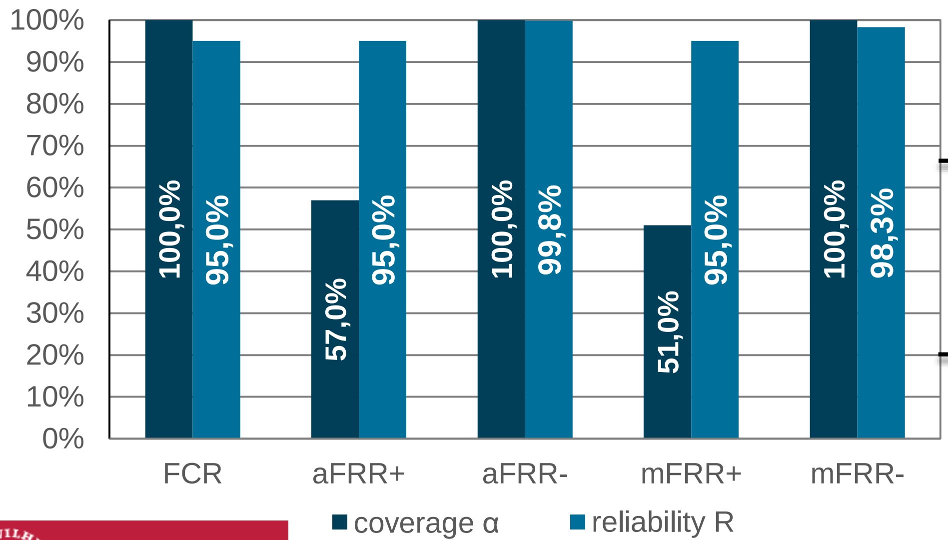
$$\alpha^{+/-} = \frac{W_C^{+/-}}{W_{C,Germany}^{+/-}} \cdot \frac{P_{Germany}}{P_{max}}$$

reliability:

$$R^{+/-} = \frac{W_C^{+/-}}{W_{C,target}^{+/-}}$$

high coverages α lead to reduced reliability R

W_C	plant‘s control energy production (2015-2017)
$W_{C,Germany}$	national control energy demand (2015-2017)
P_{max}	plant‘s rated power
$P_{Germany}$	non swelling ROR-capacitiy in Germany
$W_{C,target}$	total control energy demanded from plant



high potentials for all three types of control energy!

positive control power: backups requiered!

[1]: When extrapolated to the whole German non swelling ROR-capacities

Key findings

ROR important servant to the future energy system!
→ 3 % energy production vs. >50% of FRR potential

already low reservoir amplitudes
< 30 cm feasible for storage

base power marketing feasible with:
- lead time $t_L = 1h$
- time of constant delivery $t_D = 3h$
- reliabilities $R_B > 99.8\%$

potentials for negative FRR >> positive FRR
→ due to limited storage and power reserves

decreasing tender intervals for aFRR (07/2018)
significantly increases reliability of control energy

aFRR at $(\boldsymbol{\alpha^+}, \boldsymbol{\alpha^-}) = (\mathbf{50\%}, \mathbf{100\%})$

tender	weekly	daily	increase
reliability (+)	89.78%	97.17%	7.14%
reliability (-)	98.41%	99.83%	1.42%

current flow-model: even daily tenders
beyond forecast period of controller

in case of positive prices:
negative aFRR generates additional revenues

Outlook and further areas of research