University of South-Eastern Norway

Project:

Title:

Autonomous reactive power control for increased utilization of the hydropower generator

Proposed title for the Norwegian application:

System optimization in the interface between power producer and grid owner for more efficient system services

Thomas Øyvang

NO-US Collaboration Webinar, June 17, 2020

Porsgrunn, Telemark, Norway

Background

- there are **reactive power reserves** and **large thermal time constants** available in the hydroelectric generator that can be used for increased voltage support for shorter periods (15-30 min).

- Increased production of reactive power will result in a larger field current (and stator current). To protect the machine, the currents will be ramped down by conservative time constraints when certain criteria are met. (Safety=relay)

- New advanced control can make optimal decisions based on the actual state of the machine and through a digital twin.

LAGER SMARTE, DIGITALE GENERATORER

Digitale generatorer skal analysere kraftnettet som en sjakkspiller

– Mange frykter at robotene tar over verden. Men i kraftbransjen kan det bli katastrofe hvis robotene *ikke* tar over strømproduksjonen, sier stipendiat Thomas Øyvang .

ELLEN SYNNØVE VISETH ENERGI 13. NOV. 2018 - 10:50

forskning.no

Helse Miljø Samfunn Teknologi Naturvitenskap Blogg **Meninger**

– Ved hjelp av avanserte regulatorer og algoritmer, opptrer den seg som en sjakkspiller, som spår fremtidige trekk, skriver forskern (Foto: Jan Erik Olsen / Skagerak Energi)

Fremtidens strømproduksjon:

Denne generatoren lager sine egne spilleregler

FORSKEREN FORTELLER: **Fortidens strømproduksjon ble fullstendig styrt av mennesker. Dagens generatorer blir automatisk driftet igjennom forhåndsinnstilte begrensninger. Fremtidens smarte generatorer kan derimot lage sine egne spilleregler.**

Background- Reactive power exchange!

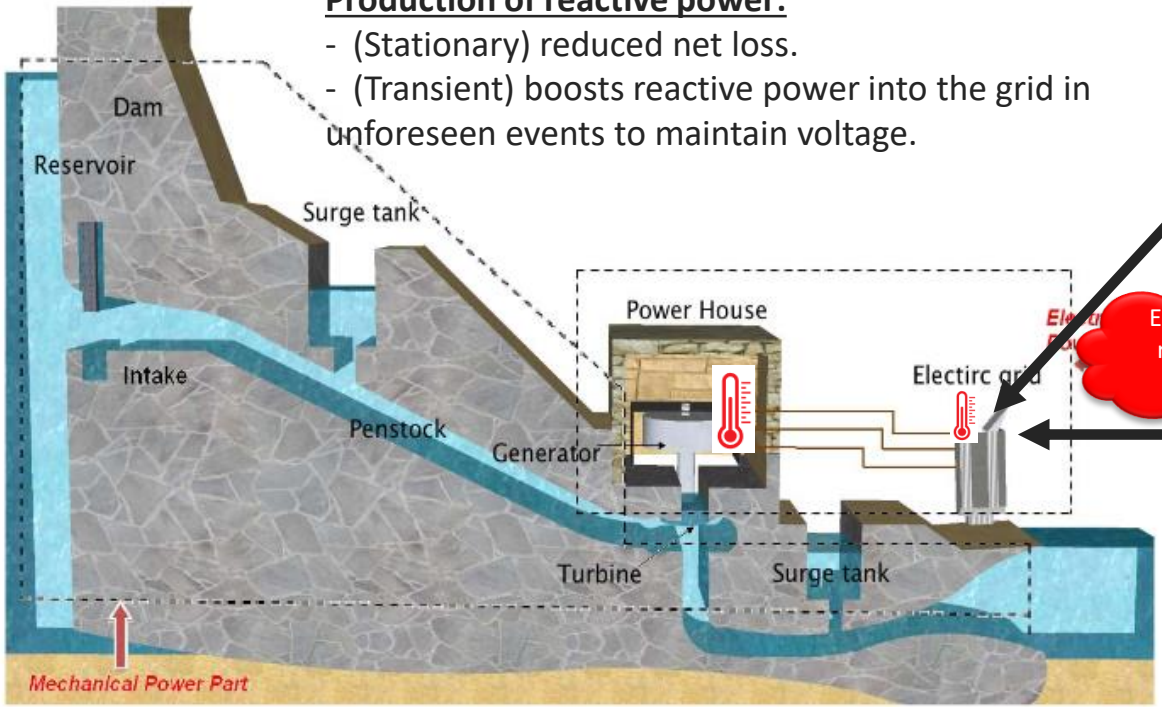
The wind is blowing and the sun is shining…. Flexible hydropower generator?

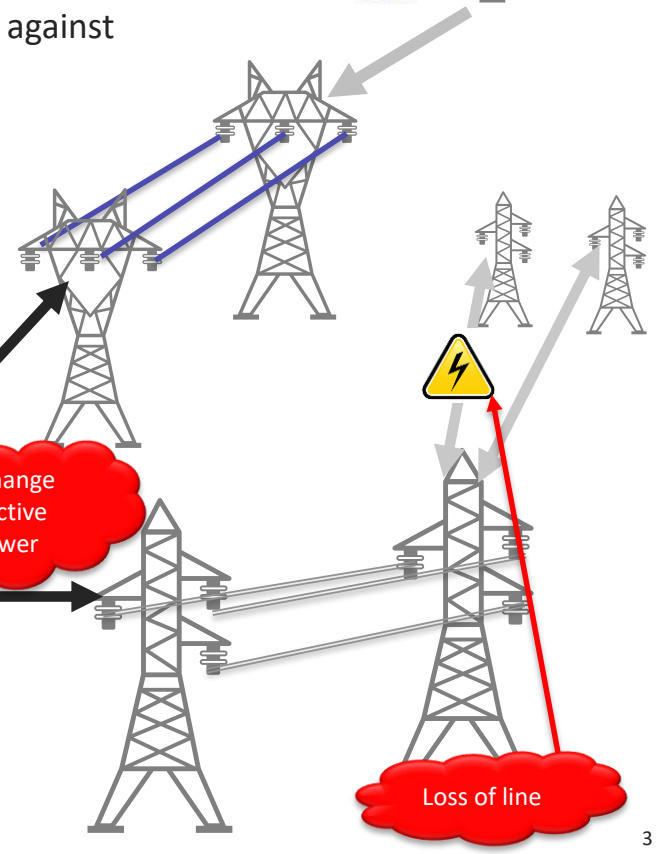
Absorption of reactive power:

- maintain the voltage profile and protect transformers against overvoltage.

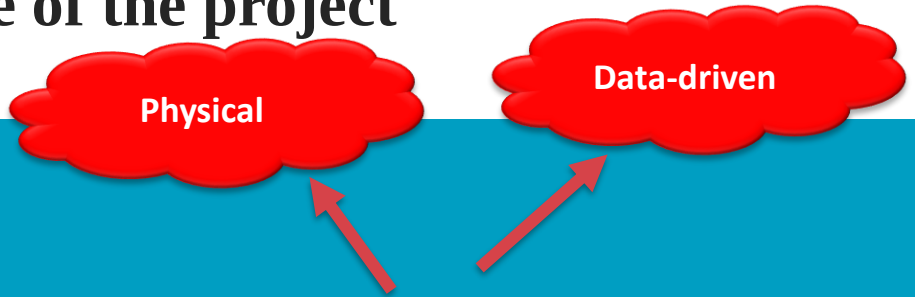
Production of reactive power:

- (Stationary) reduced net loss.
- (Transient) boosts reactive power into the grid in unforeseen events to maintain voltage.





Main objective of the project



The main objective is to develop hybrid models and algorithms (virtual twins) for real-time control of the generator based on the actual state of relevant components during flexible operation.

A new control system!

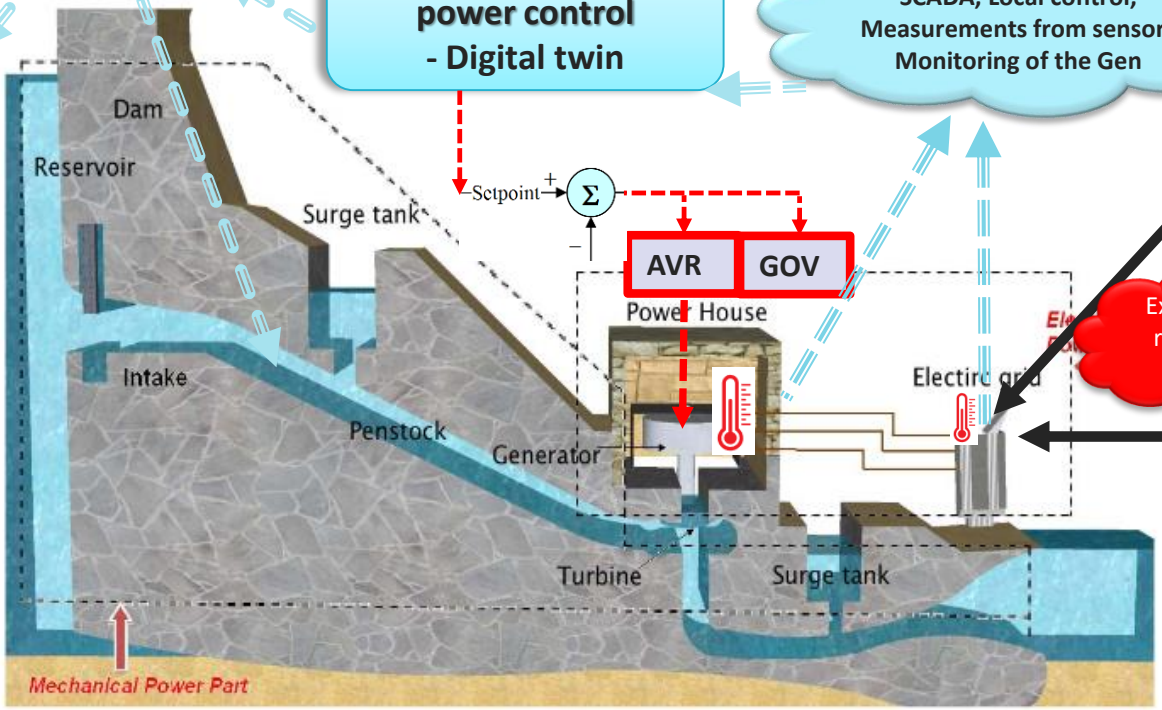
Accessing data and give control signals
Monitoring and protect the machine

Digital twins (soft-sensors):
Physical models, Data-driven models
(machine, ancillary systems, waterway, grid)
Lifetime models, etc

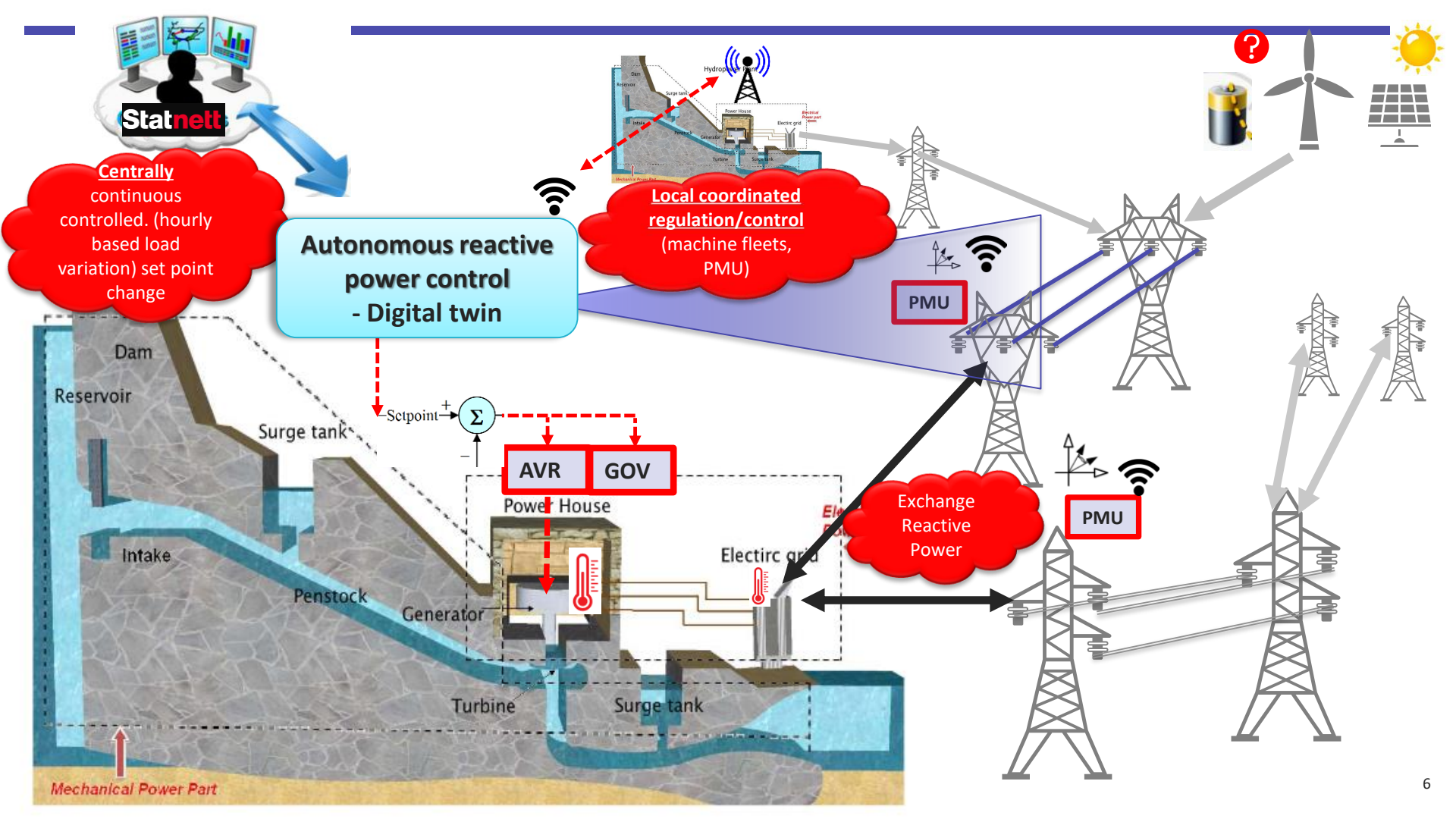
Waterway control system. Floodgate control

Autonomous reactive power control - Digital twin

Cloud/Datalake/Azure
SCADA, Local control,
Measurements from sensors
Monitoring of the Gen



Exchange reactive power


Statnett
Centrally
continuous
controlled. (hourly
based load
variation) set point
change
Autonomous reactive
power control
- Digital twin
Local coordinated
regulation/control
(machine fleets,
PMU)
PMU
Dam
Reservoir
Surge tank
Setpoint
AVR
GOV
Power House
Intake
Penstock
Generator
Electirc grid
Turbine
Surge tank
Mechanical Power Part
Exchange
Reactive
Power
PMU

Functionality!

- System service
- Optimal operation

Enhanced system services in a future reactive power market:
Preview BID from the Controller (Parametre):
Θ1: Q=8 MVAr, Duration: 1 hour, Cost: NOK/Mvarh
Θ2: Q=30 MVAr, Duration : 20 min, Cost: NOK/Mvarh
Θ3: Q=3 MVAr, Duration : 2 hours, Cost: NOK/Mvarh
Two revenue models (income): 1: Measure MVAr
2: Paid for MVA rated value according to active voltage regulation

What can the machine offer?

Can autonomously perform grid support!

Autonomous reactive power control - Digital twin

Can suggest optimal operation!

The controller can look ahead in time to propose (offer) optimal paths for the delivery of reactive power based on the actual condition and capacity.

Power Plant Owner: Optimal operation
Operating temp, cooling, e.g.,
WAE - weighted average efficiency estimation
Communication with other production planning tools e.g., SHOP, water value

The project will contain the following main elements (1/2):

Models

- Develop simple models (physical and data-driven) with sufficient predictive quality for real-time feedback (digital twin). The models must identify dynamic (thermal, mechanical, etc.) phenomena in the machine and associated equipment (cables, transformers, etc.) and be able to identify any sources of error.

Control system

- Develop a new, autonomous control system that can utilize the hydroelectric generator optimally in a planned reactive power market. The control system must be robust and handle a considerable degree of model uncertainty. The system will not change today's primary control loop (AVR, turbine regulator), but will be an additional equipment that safeguards the machine when delivering system services to the grid.

The project will contain the following main elements (2/2):

Instrumentation

- Implement extended instrumentation (also soft sensors) and measurement methods on relevant machines, and make real-time data available for the project. AI and machine learning algorithms (dynamic systems) will be used, and an interaction with the power grid will be included using PMU measurements.

Testing

- Testing should be carried out in the Hydropower Laboratory and Smartgridlab at NTNU (and at US partner) and will be done to examine the system's functionality and stability.
- If possible, the system will be tested on a research unit for full scale tests. A prototype will be developed and a possible patent considered.

Project status

- **Project leader:** Thomas Øyvang (USN)
- KPN application to the Norwegian Research Council 2nd of September.
  - 2-3 PhD students
- **R&D Institutions:** USN, NTNU
- **Possible Norwegian Partners:** Statkraft, Statnett, Skagerak Kraft and Nett, Hymatek Controls
- **Possible US partners** (in dialogue): **NREL** and/or **EPRI**
  - NREL: National Renewable Energy Laboratory
  - EPRI: Electric Power Research Institute

Thank You!

Relevant publications

- Paper 1: IEEE Transactions on Industrial Electronics, Title: **Online Model-Based Thermal Prediction for Flexible Control of an Air-Cooled Hydrogenerator,** https://ieeexplore.ieee.org/document/8495032

- Paper 2: IEEE Transaction on Power Systems, Title: **Enhanced Power Capability of Generator Units for Increased Operational Security using NMPC**, https://ieeexplore.ieee.org/document/8853314

- Paper 3: PES GM: **Future Operational Regimes of Bulk Power Generation in The Era of Global Energy Transition: Grid Codes, Challenges and Open Issues**,

  Jonas Kristiansen Nøland, Matteo Leandro, Arne Nysveen and Thomas Øyvang