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Norwegian University of
Science and Technology

Identification of turbine dynamics using PMUs

Sigurd Hofsmo Jakobsen[1], Xavier Bombois[2], Kjetil Uhlen[1]

[1]Norwegian university of technology and science Department of electrical engineering

[2]Ecole Centrale de Lyon Laboratoire Ampère

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Outline

Background

Previous work

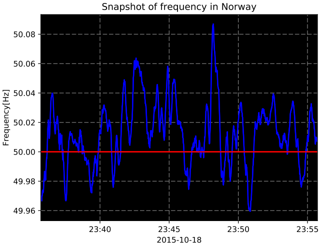
Validation of the approach

Results

Conclusions and further work

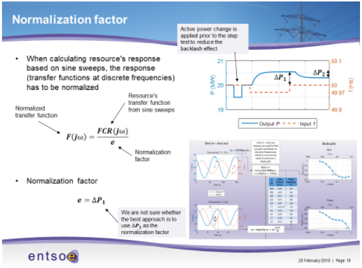
Frequency quality in the Nordics

- From 2008 the time the frequency has been outside its allowed band has increased
- The performance of hydro turbine governors play an important role



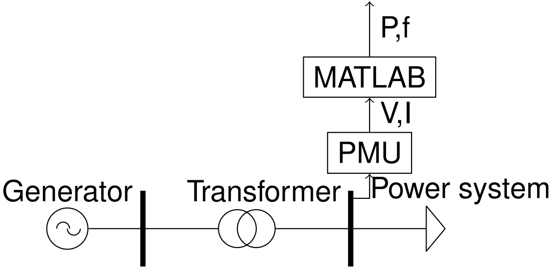
New requirements on FCR due to frequency quality

- Nordic TSOs are developing new requirements on FCR
- This includes offline testing and verification of performance



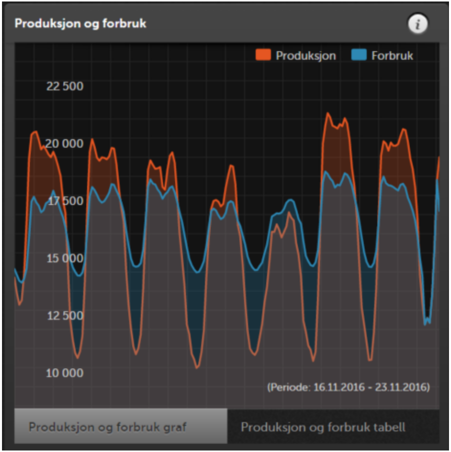
Idea on monitoring the FCR online

- Less intrusive



Idea on monitoring the FCR online

- Less intrusive
- The system is dynamic



Challenges in operation

- Towards 100% renewable electricity generation
    - Larger variability
    - More uncertainty
    - Increasing complexity

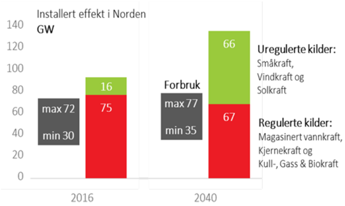


Figure: Present and future energy mix[Statnett]

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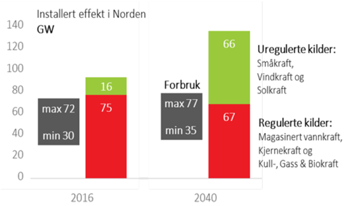

Figure: Present and future energy mix[Statnett]

Challenges in operation

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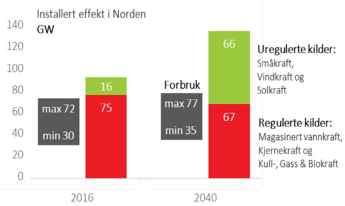
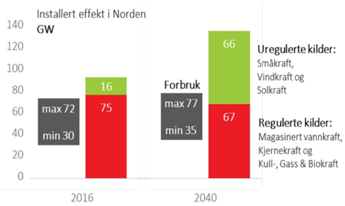


Figure: Present and future energy mix[Statnett]

Challenges in operation

- Towards 100% renewable electricity generation
  - Larger variability
  - More uncertainty
  - Increasing complexity
- More dynamics
- Less time for actions
- **Hydropower** is the main resource for balancing



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Research question

1. Do the transmission system operator (TSO) know whether or not the hydropower plants deliver the FCR they are supposed to?

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2. Can the TSO measure it online?

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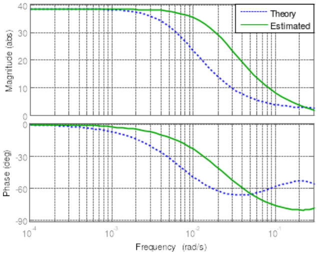
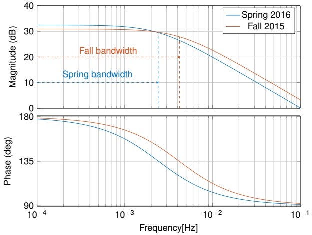
Previous articles

- Governor dynamics were identified using the ARX model structure



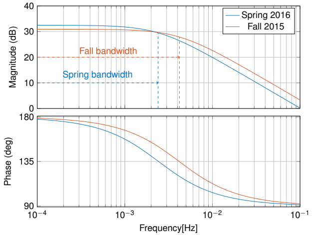
Previous articles

- Governor dynamics were identified using the ARX model structure
- Governor dynamics were identified using time domain vector fitting



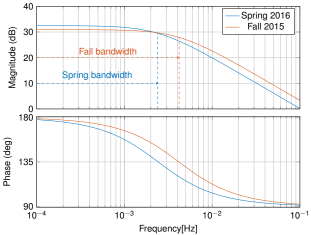
Previous articles

- Governor dynamics were identified using the ARX model structure
- Governor dynamics were identified using time domain vector fitting
- There are also other papers in the literature using other methods for online identification, however, mostly relying on data from disturbance recordings.



Question leading to this work

- Why do we get different results?



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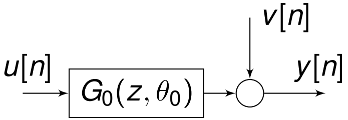
- Why do we get different results?
- The signals we use are corrupted by noise.



Question leading to this work

- Why do we get different results?
- The signals we use are corrupted by noise.
- From system identification we have that the error will be asymptotic normally distributed

$$\sqrt{N}(\hat{\theta}_n - \theta^*) \in AsN(0, P_\theta)$$

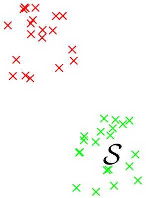
Question leading to this work

- Why do we get different results?
- The signals we use are corrupted by noise.
- From system identification we have that the error will be asymptotic normally distributed
- However, first we need to prove the identifiability of the system

True system: $\mathcal{S}$

x: unbiased

x: biased



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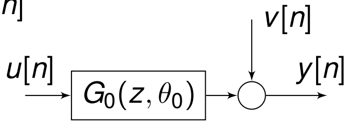
System identification basic

- Assume that a data set $Z^N = \{u[n], y[n] | n = 1 \ldots N\}$ has been collected.
- The dataset Z^N is assumed generated by

$$\mathcal{S} : y[n] = G_0(z, \theta_0)u[n] + H_0(z, \theta_0)e[n] \quad (1)$$

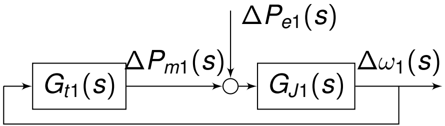


- Using the data set Z^N we want to find the parameter vector θ^N minimizing

$$\hat{\theta}_N = \arg\min_{\theta} \frac{1}{N} \sum_{n=1}^{N} \epsilon^2(n, \theta) \quad (2)$$

Modeling used for the validation

- The system we are identifying



Modeling used for the validation

- The system we are identifying
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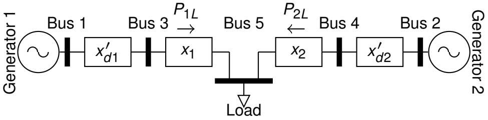
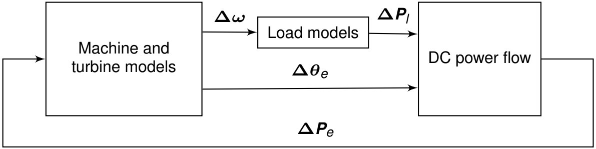


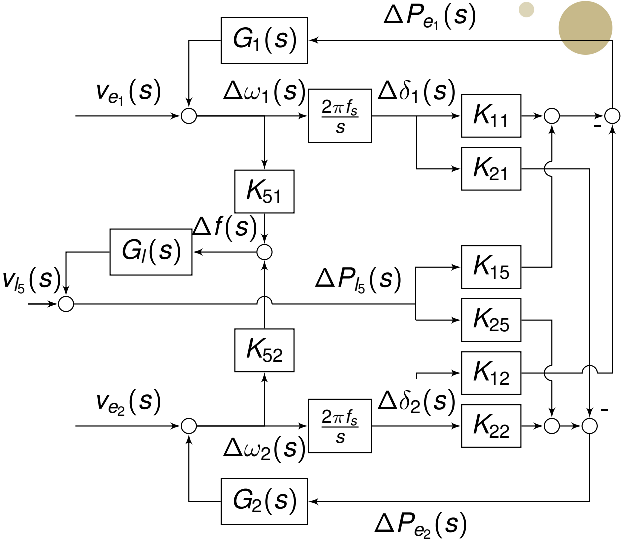
Modeling used for the validation

- The system we are identifying
- We use a small power system
- We use a dc power flow



Modeling used for the validation

- The system we are identifying
- We use a small power system
- We use a dc power flow
- This results in the following block diagram



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- A consistent estimate of the closed loop transfer function of the turbine and electromechanical dynamics can be obtained by using:

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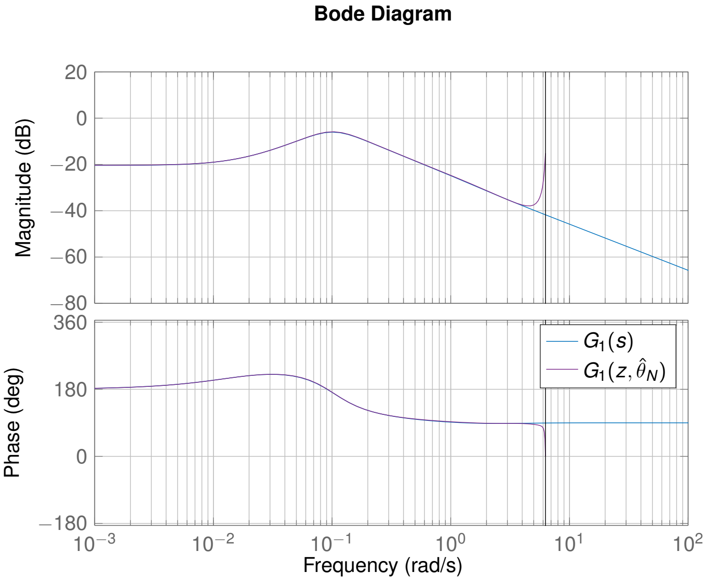
  - Measured PMU power as the input $y[n]$

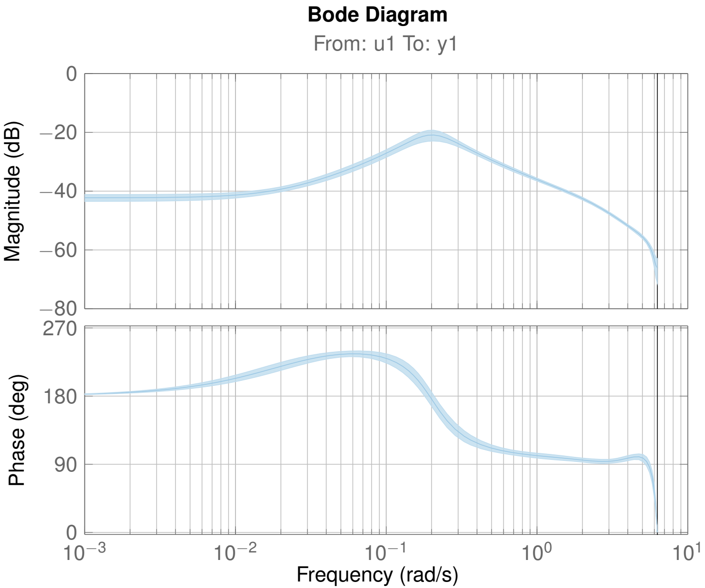
Results from the theoretical validation

- A consistent estimate of the closed loop transfer function of the turbine and electromechanical dynamics can be obtained by using:
  - Measured PMU frequency as the output $u[n]$
  - Measured PMU power as the input $y[n]$
- The proof was done with the following assumptions.
  - The system is excited by a load acting as a filtered white noise process
  - The measurement error of the electrical power is negligible.
  - The measured frequency is a good estimate of the generator speed.

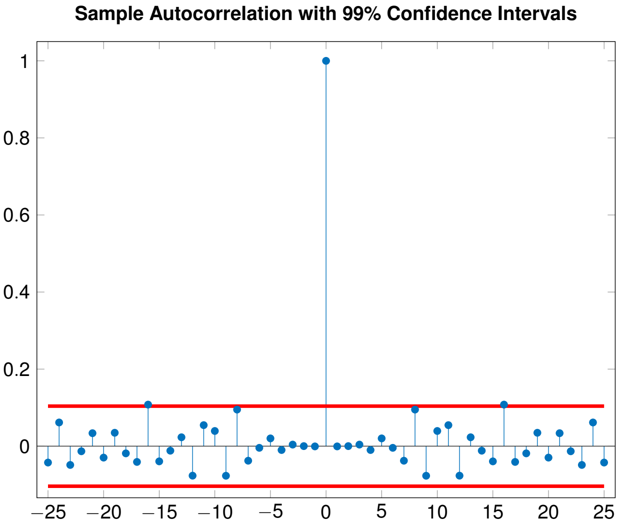
Comparison of bode plots from simulation



Model obtained using PMU data



Whiteness test on model identified using PMU data



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Conclusions and further work

- It is indeed possible to identify the turbine dynamics(closed loop with electromechanical dynamics) using PMU measurements.
- The assumptions should be further investigated

Thanks for your attention.