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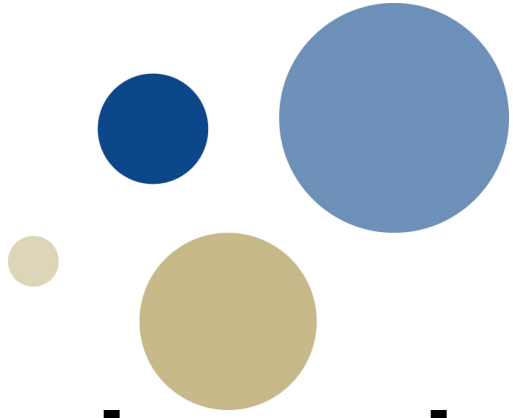

Identification of turbine dynamics using PMUs

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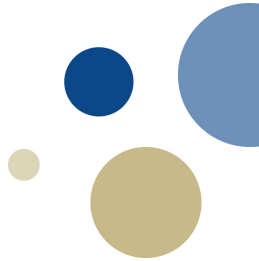
Department of electrical engineering

May 16, 2018

Outline



- Background
- Previous work
- Theoretical validation
- Results
- Conclusions and further work

Background
Power Systems

- Large interconnected system

Figure: Nordic power system[ENTSO-e]

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Power Systems

- Large interconnected system
- Balancing challenge

Figure: Nordic power system[ENTSO-e]

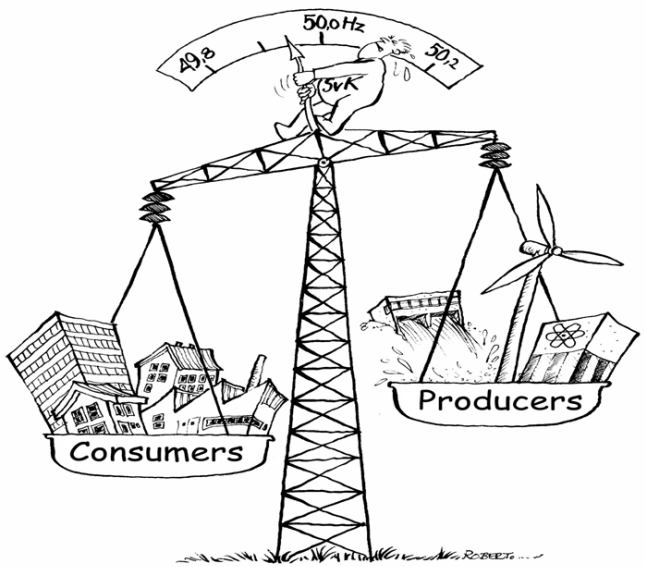

Figure: Balancing challenge[Statnett]

Background

Challenges in operation

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

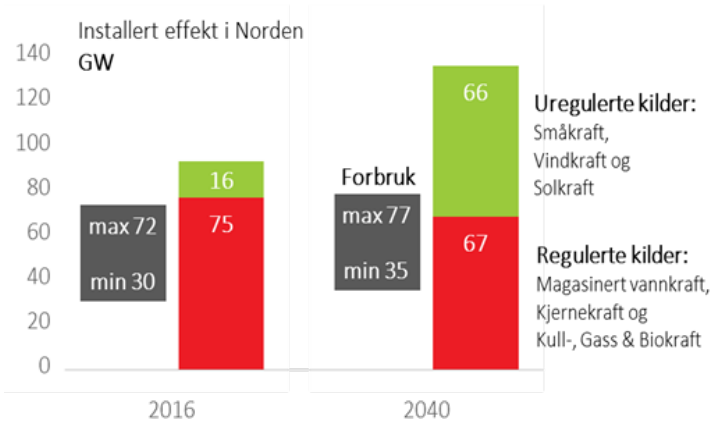

Figure: Present and future energy mix[Statnett]

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- More dynamics

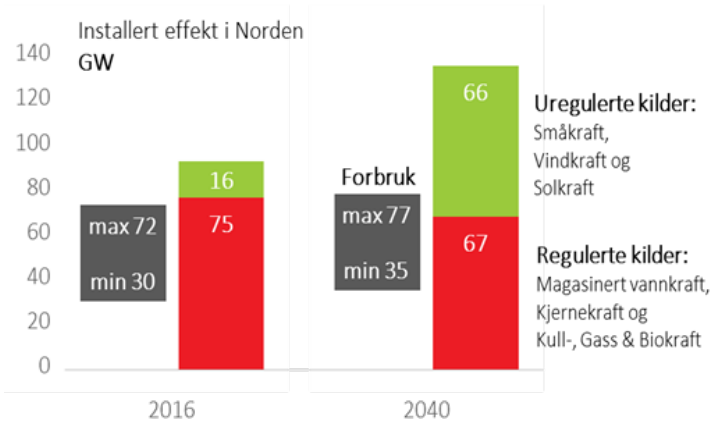

Figure: Present and future energy mix[Statnett]

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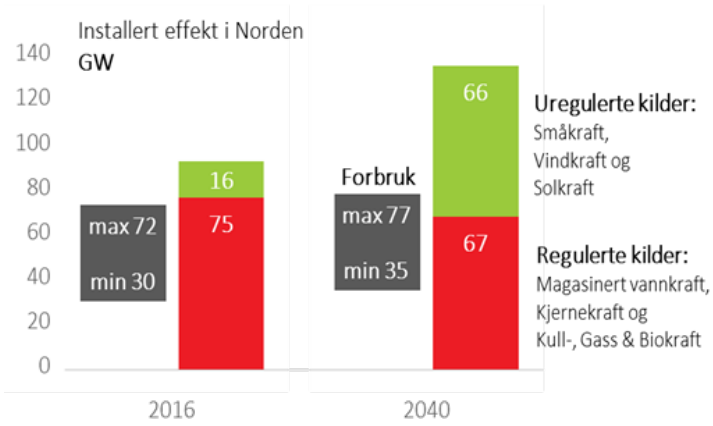

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Background
Challenges in operation

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

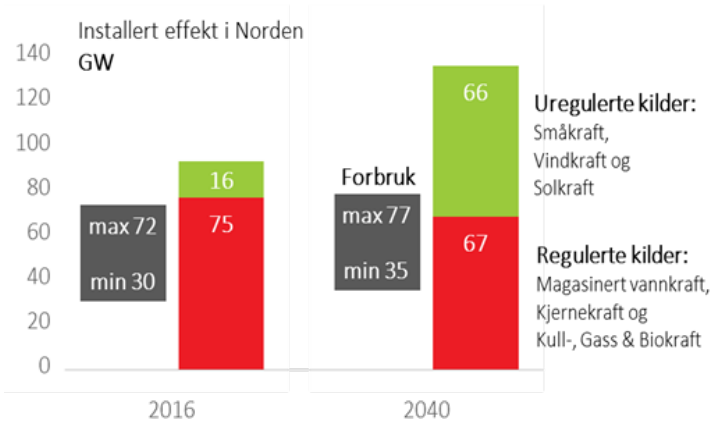
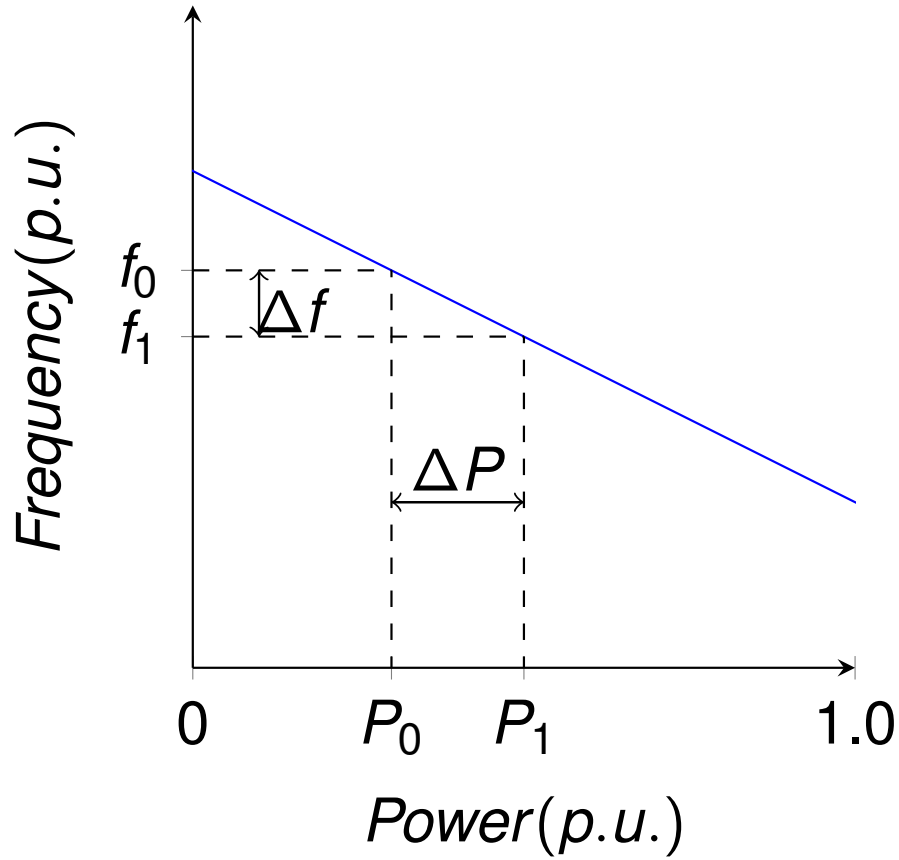


Figure: Present and future energy mix[Statnett]

Background

Frequency containment reserves (FCR)

- Power balance/frequency containment control (FCC) is mainly determined by governor response.
- Activation of primary reserves is determined by the governor droop settings.



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Frequency containment reserves (FCR)

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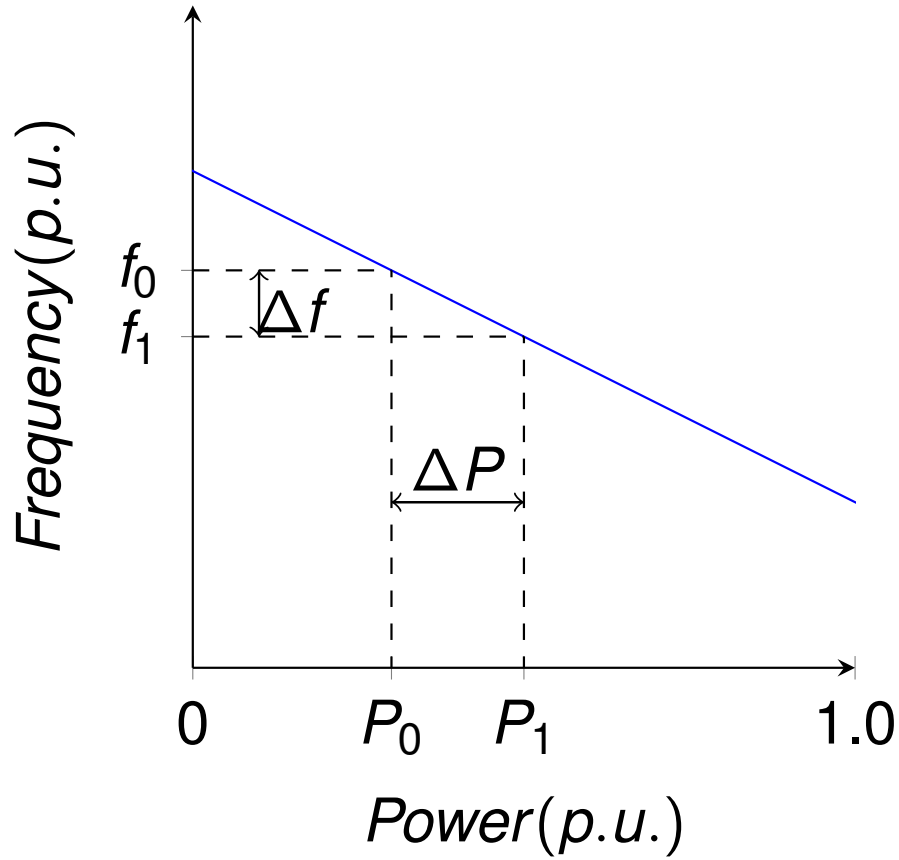
- Activation of primary reserves is determined by the governor droop settings.
- In steady state



Background

The power system is dynamic

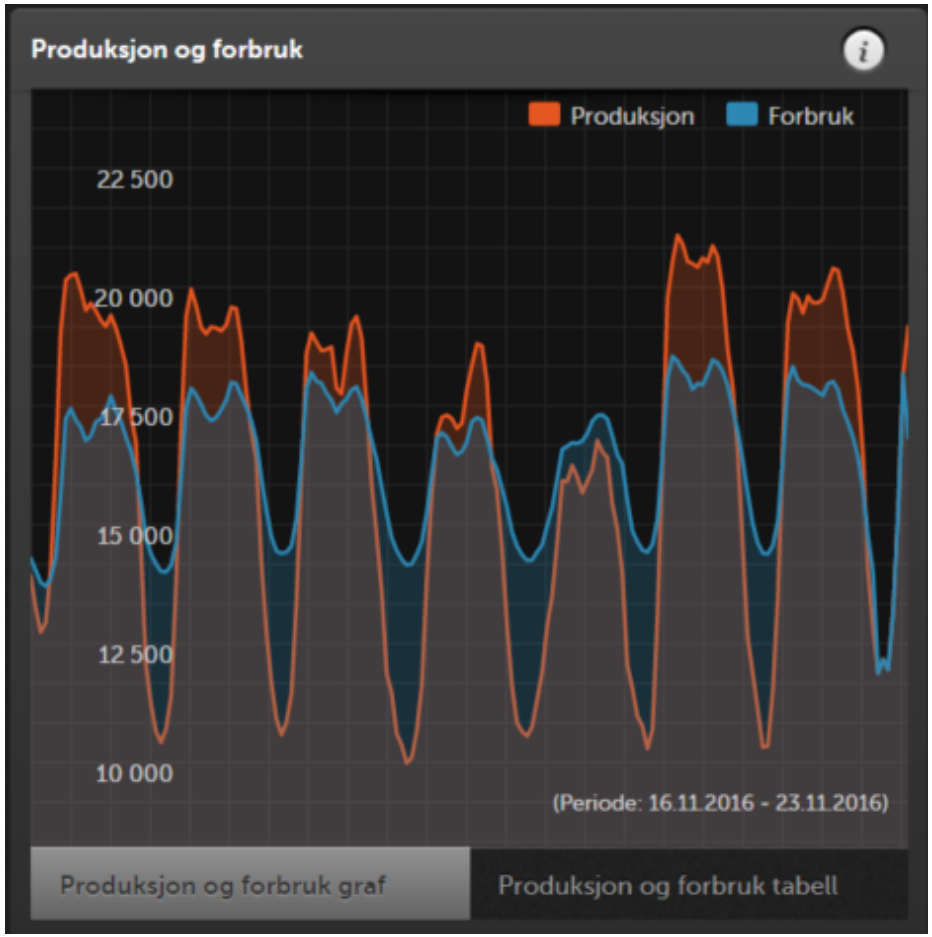
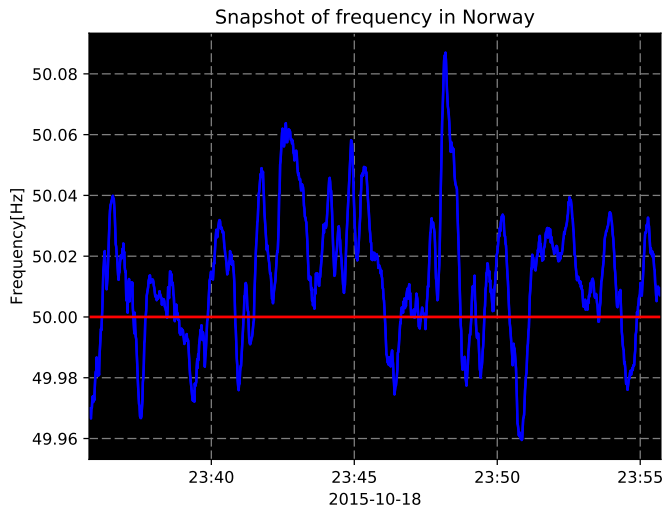


Figure: Production and consumption [statnett.no]

Background

Frequency quality in the Nordics

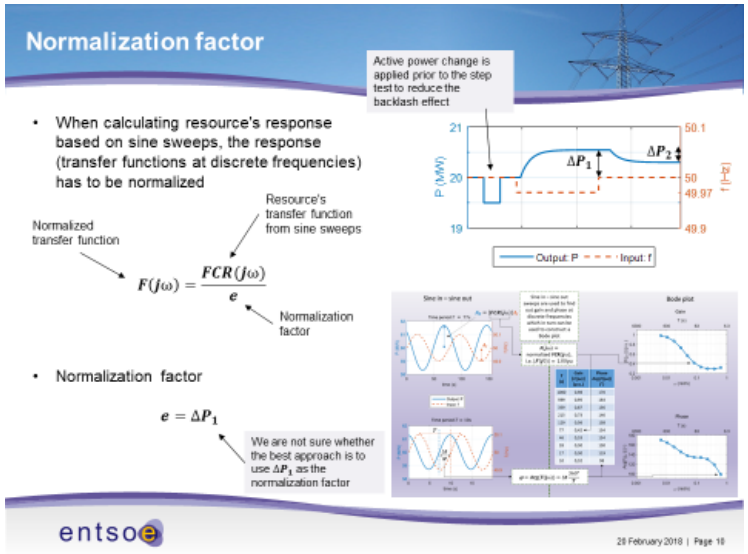
- From 2008 the time the frequency has been outside its allowed band has increased
- The performance of hydro turbine governors play an important role



Background

New requirements on FCR

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



Background
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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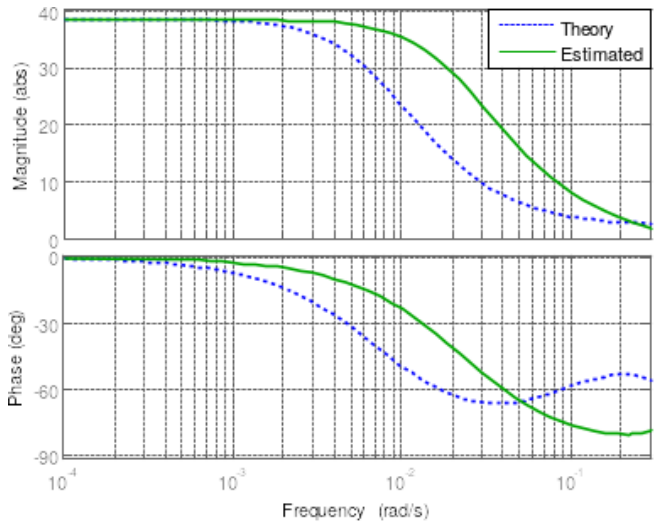
1. Do the transmission system operator (TSO) know whether or not the hydropower plants deliver the FCR they are supposed to?
2. Can the measure it online?

Previous work

- Governor dynamics were identified using the ARX model structure



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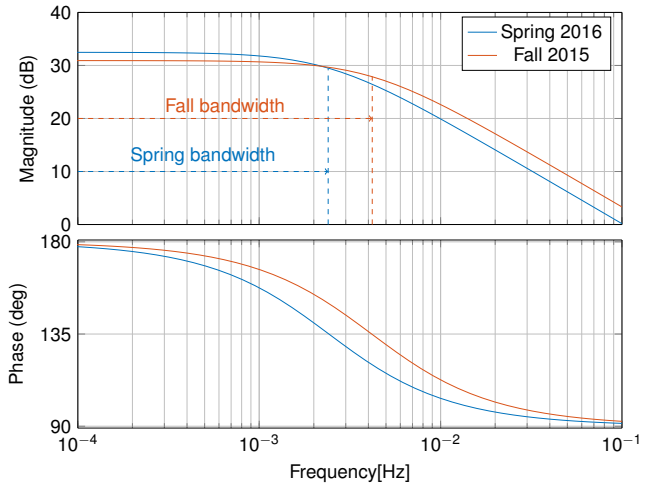
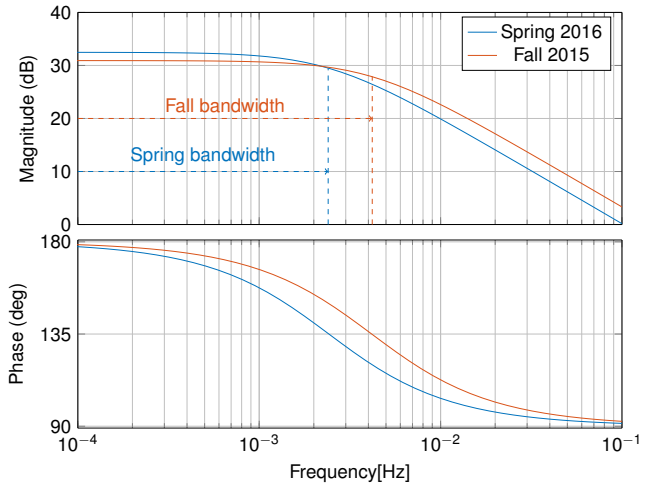


Previous work

- Governor dynamics were identified using the ARX model structure
- Governor dynamics were identified using time domain vector fitting
- However, no theoretical validation was made.



Previous work

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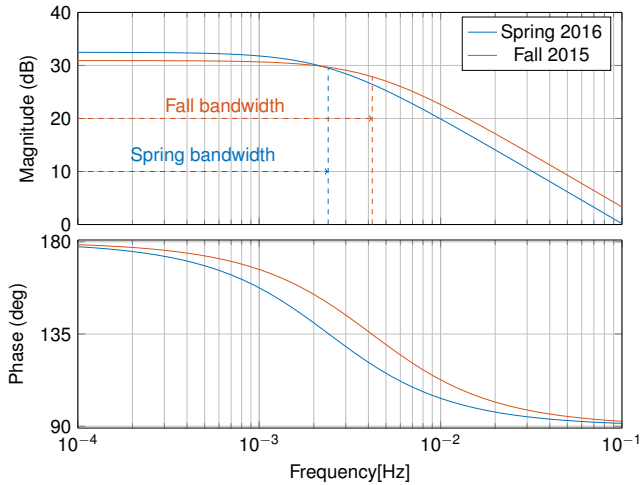
- Governor dynamics were identified using time domain vector fitting
- However, no theoretical validation was made.
- The theoretical validation was performed in this work.

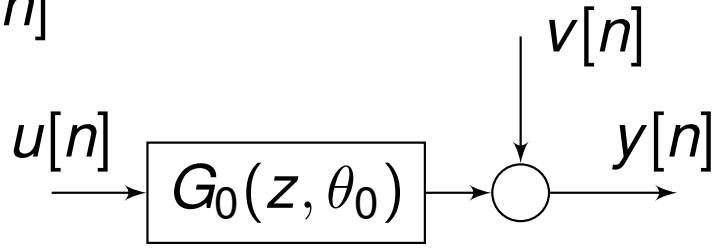


Theoretical validation

System identification basic

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

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



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

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

Theoretical validation

Consistency

- A consistent estimate means that the true parameter vector θ_0 is the unique solution to the asymptotic prediction error criterion.

$$\theta^* = \arg\min_{\theta} \bar{E}\epsilon^2(n,\theta) \tag{3}$$

with

$$\bar{E}\epsilon^2(n,\theta) = \lim_{N\to\infty} \frac{1}{N} \sum_{t=1}^{N} E\epsilon^2(n,\theta) \tag{4}$$

and

$$\epsilon(n,\theta) = H_1^{-1}(z,\theta)(y[n] - G_1(z,\theta)u[n]) \tag{5}$$

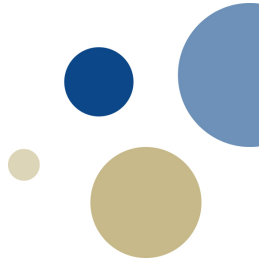
Results

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:

Results

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 $u[n]$

Results

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 $y[n]$

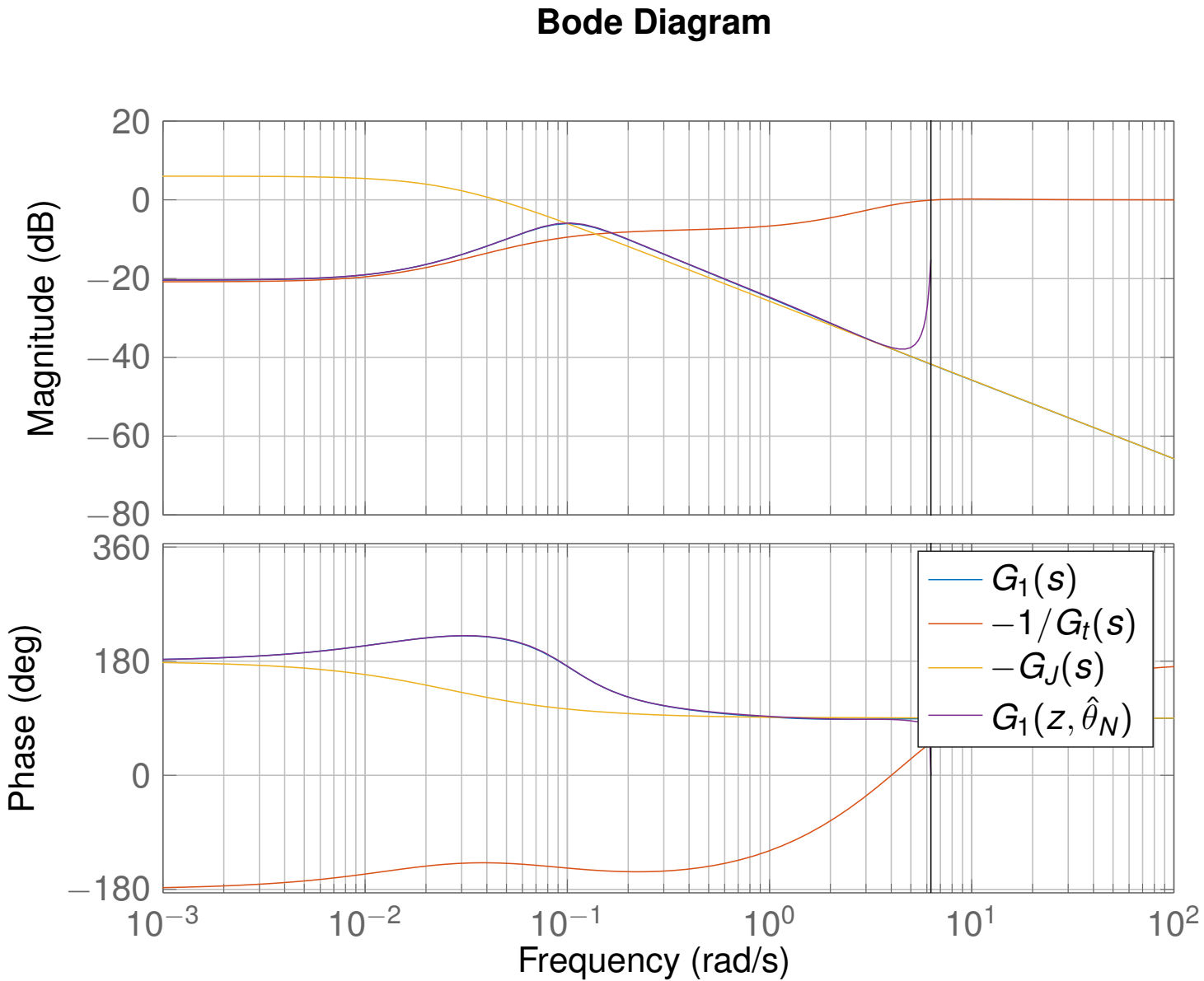
Results

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 white noise process
  - The measurement error of the electrical power is negligible.
  - The measured frequency is a good estimate of the generator speed.

Results

Results from simulations



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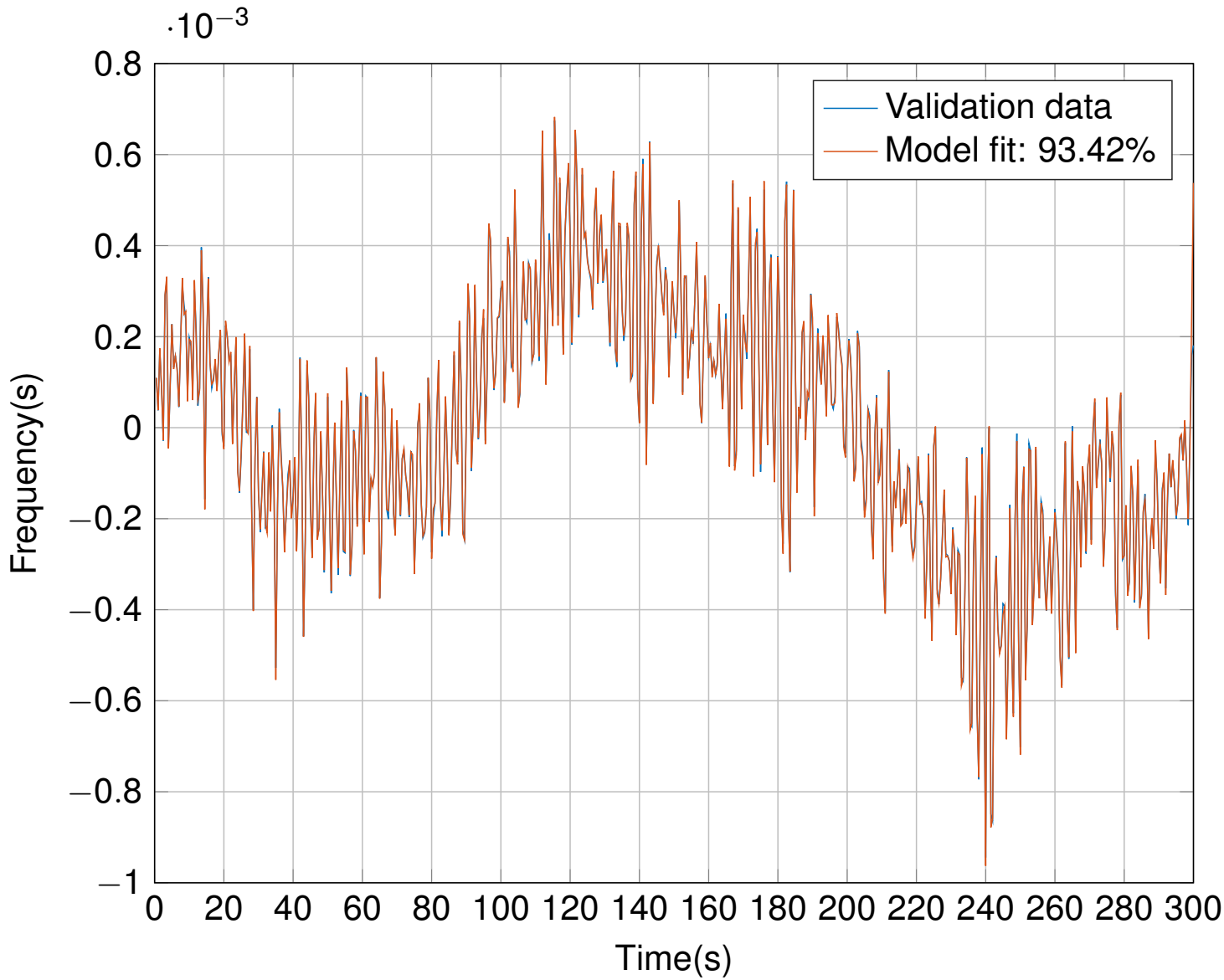

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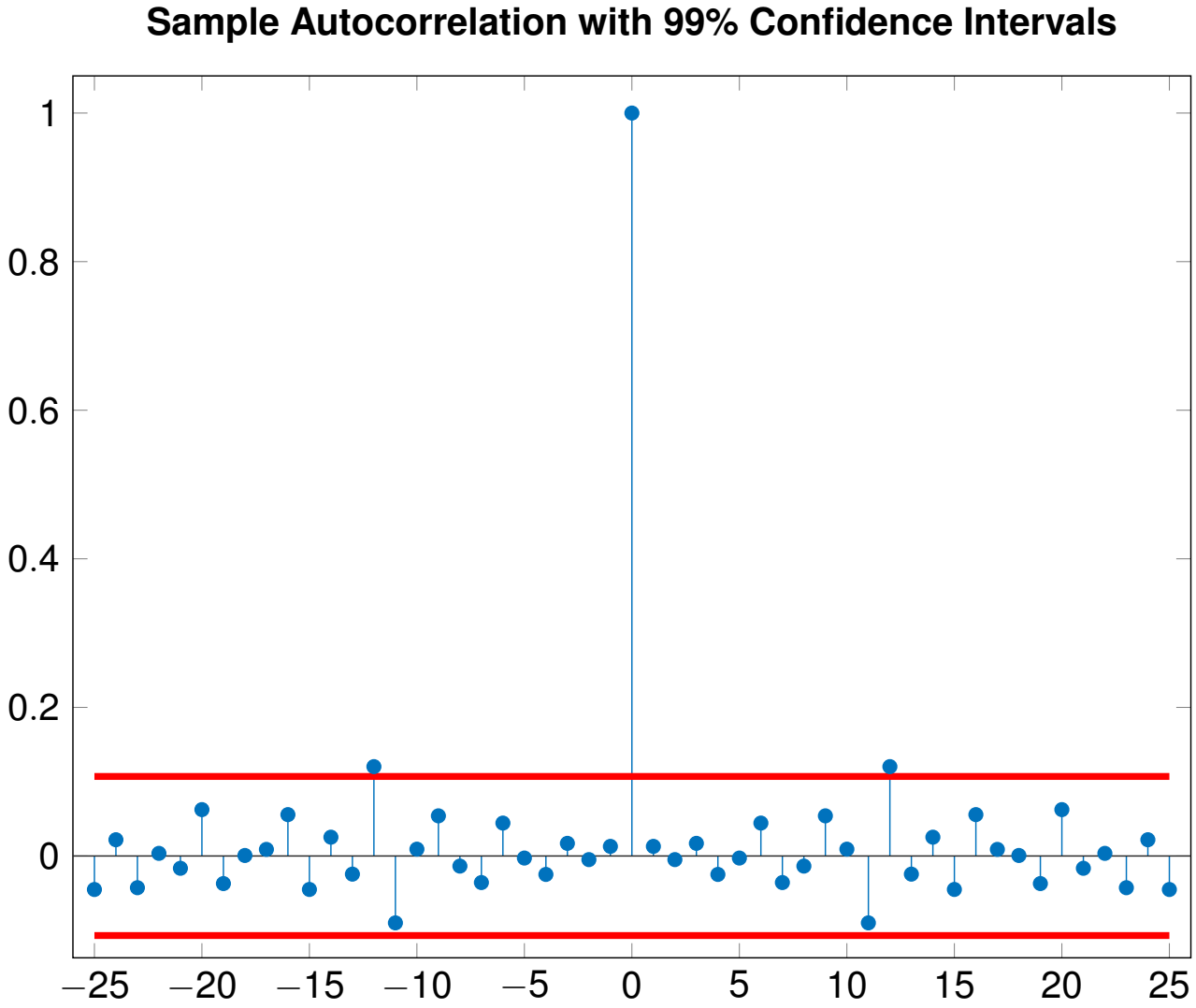
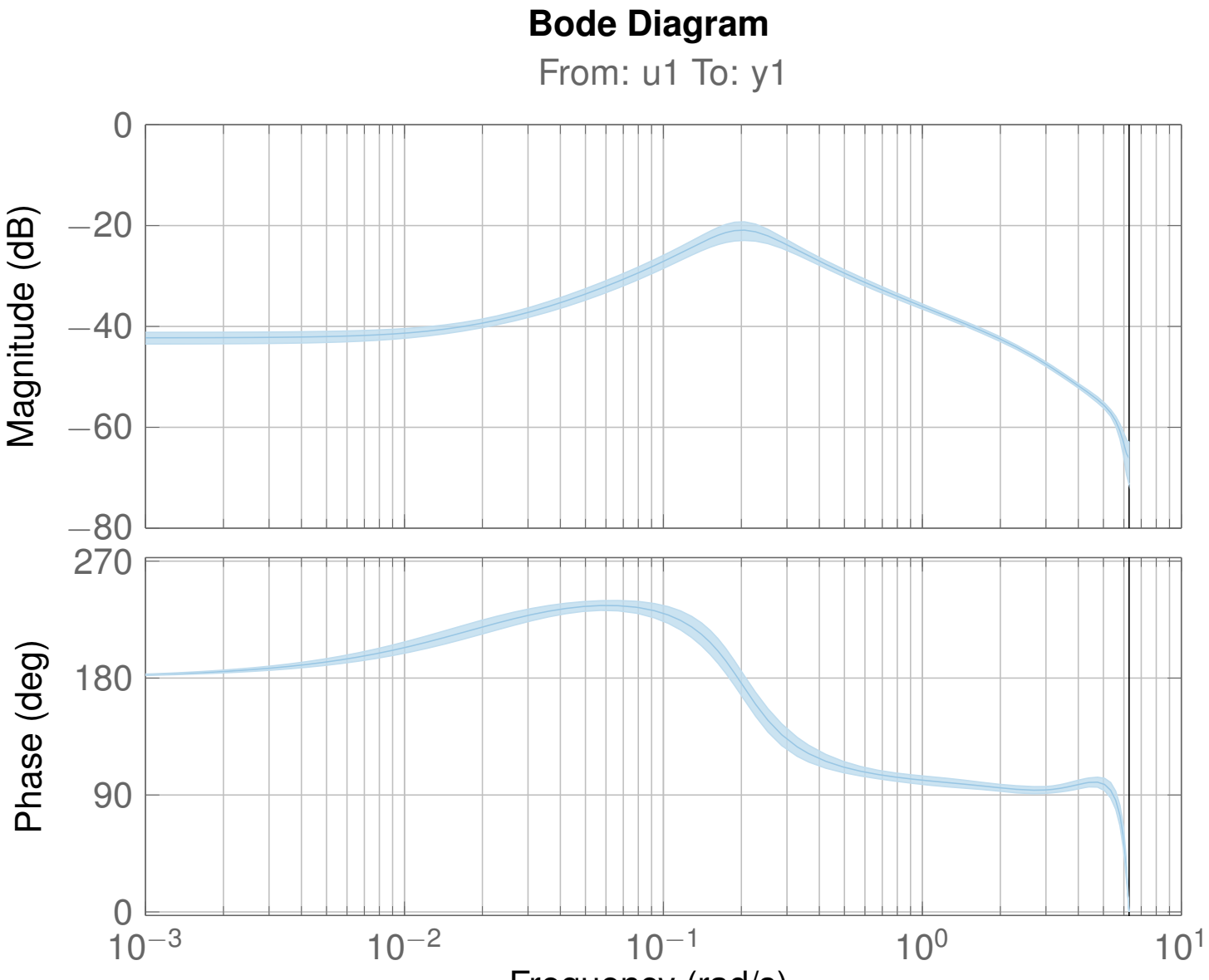


Results

Results from the power system



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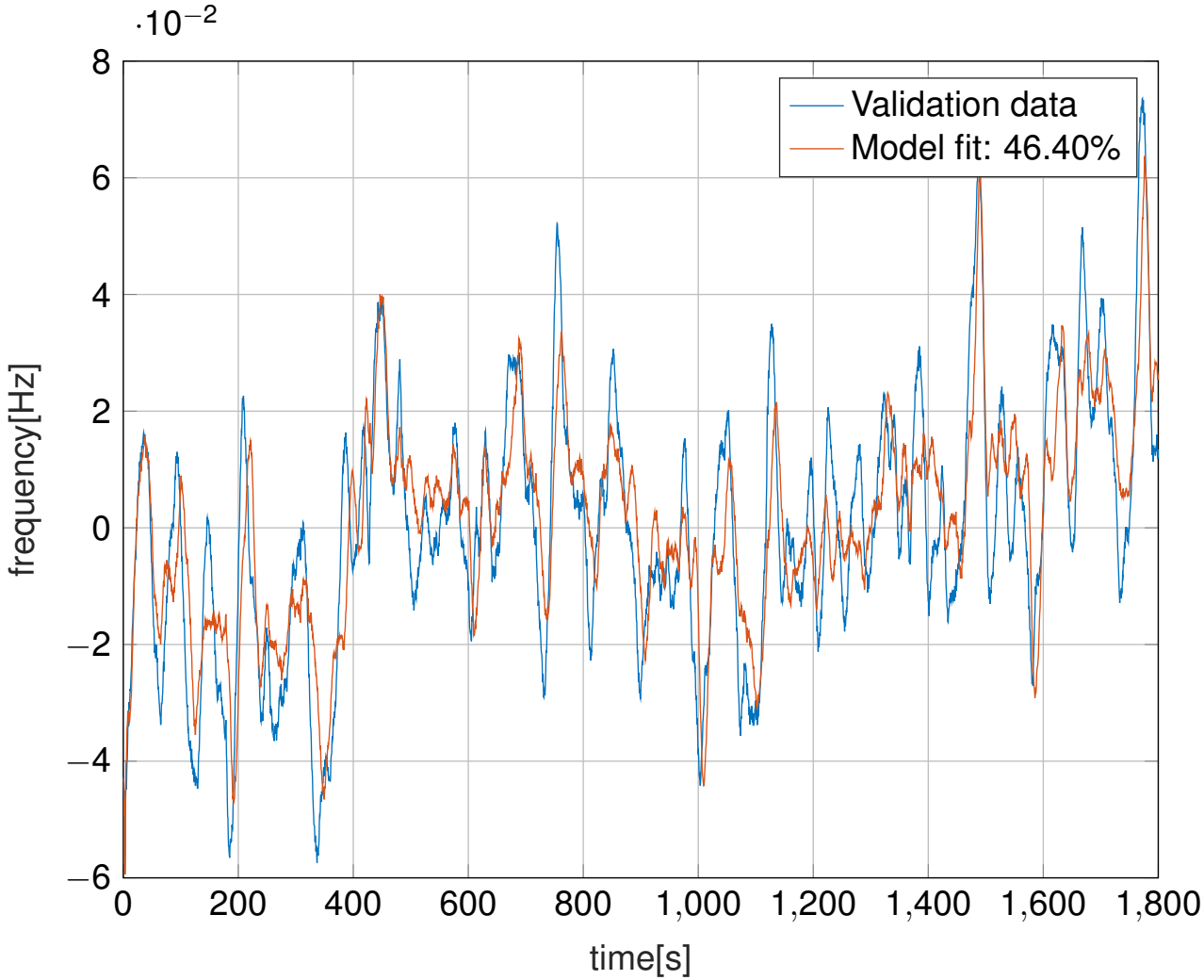

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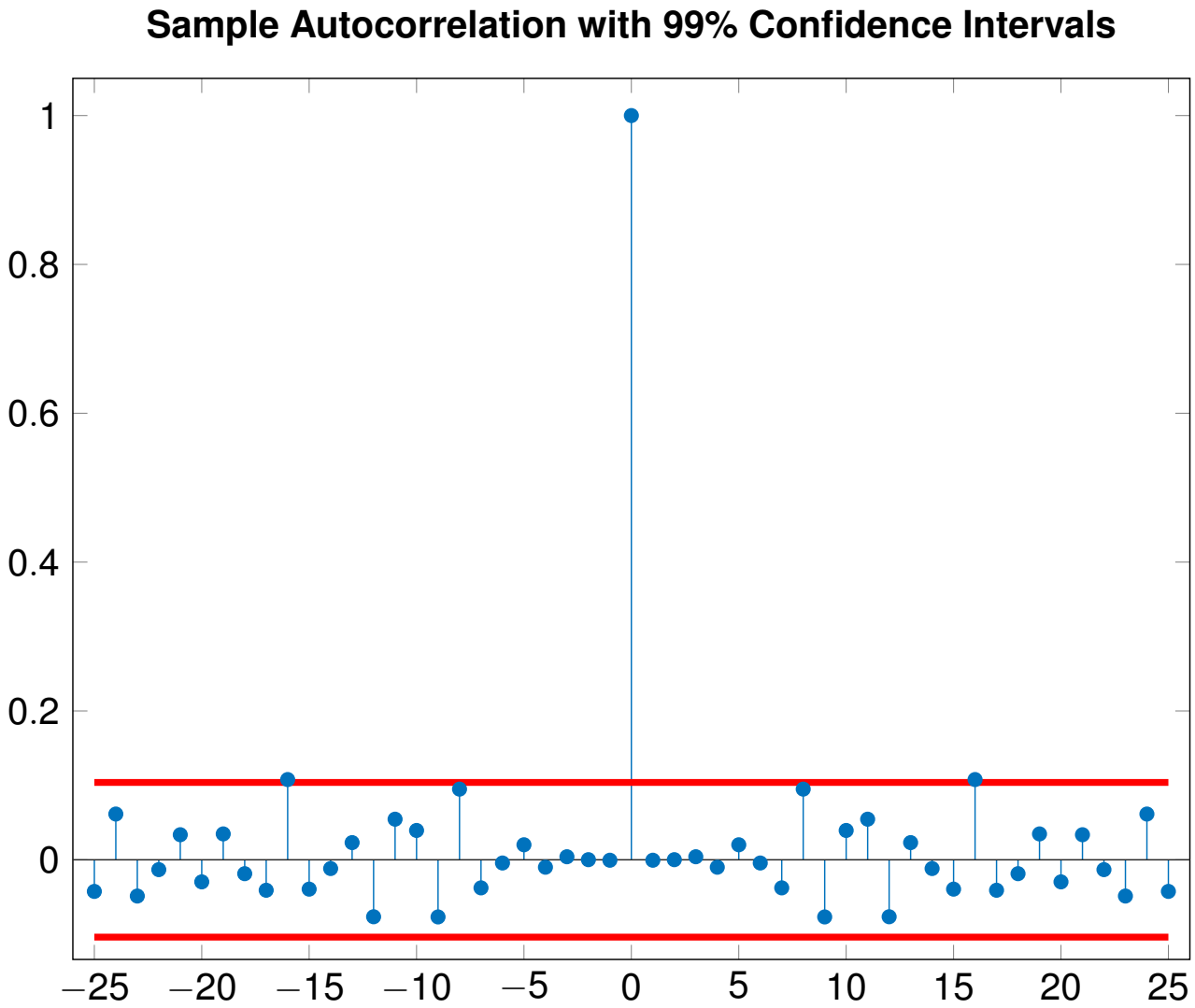

Conclusions and further work

- It is indeed possible to identify the turbine dynamics(closed loop with electromechanical dynamics) using PMU measurements.
- Look into the assumptions