NTNU
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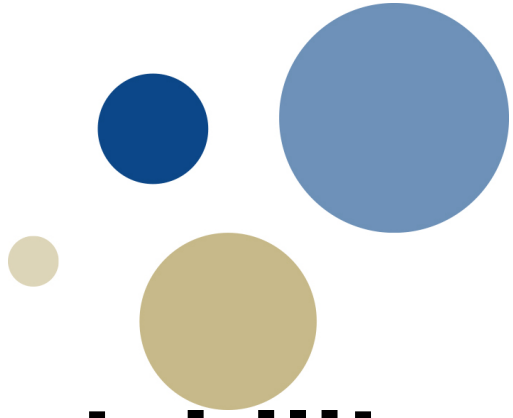

Frequency control and stability requirements on hydro power plants

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October 8, 2019

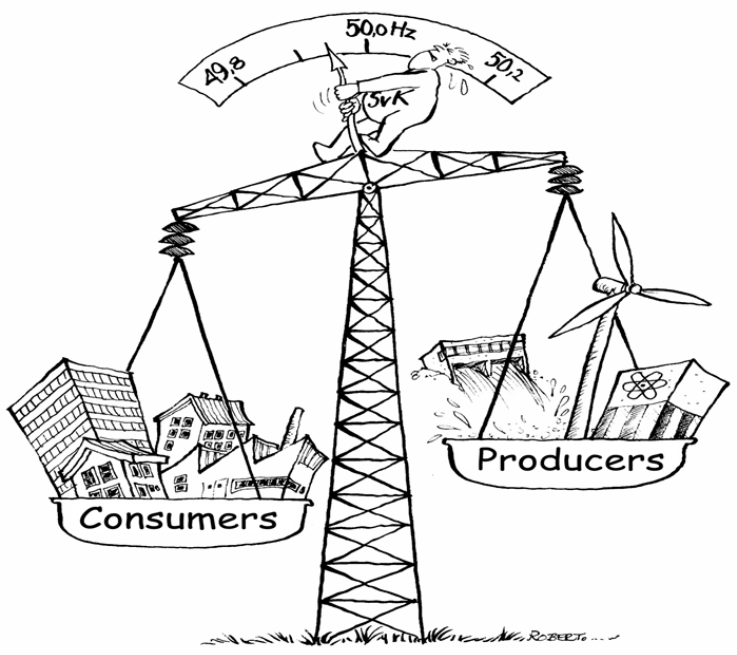
Outline

Problem

Paper I

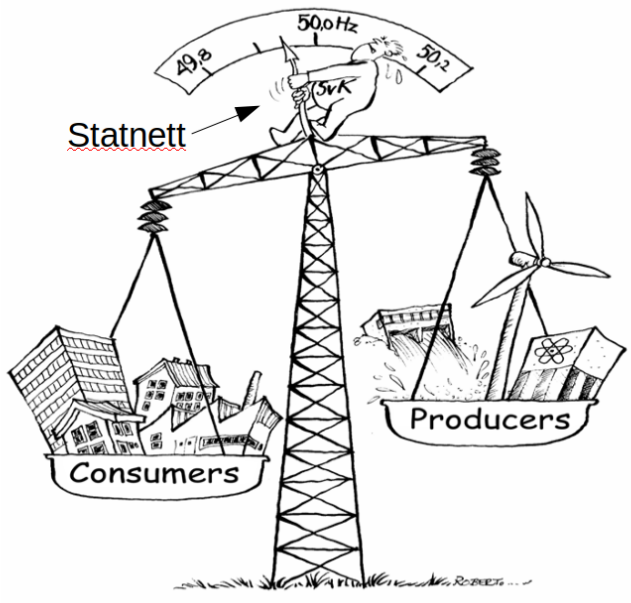
Load and production balancing

— The power system frequency measures the power balance.



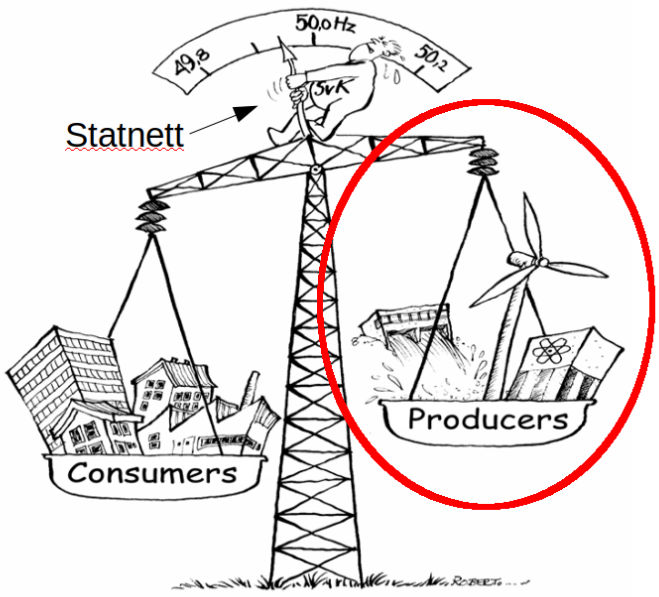
Load and production balancing

- The power system frequency measures the power balance.
- It is the responsibility of Statnett to control the frequency.



Load and production balancing

- The power system frequency measures the power balance.
- It is the responsibility of Statnett to control the frequency.
- However, it is the power plant owners who can control the frequency.



Buying frequency control

— Statnett pays all power plant owners to provide frequency control.

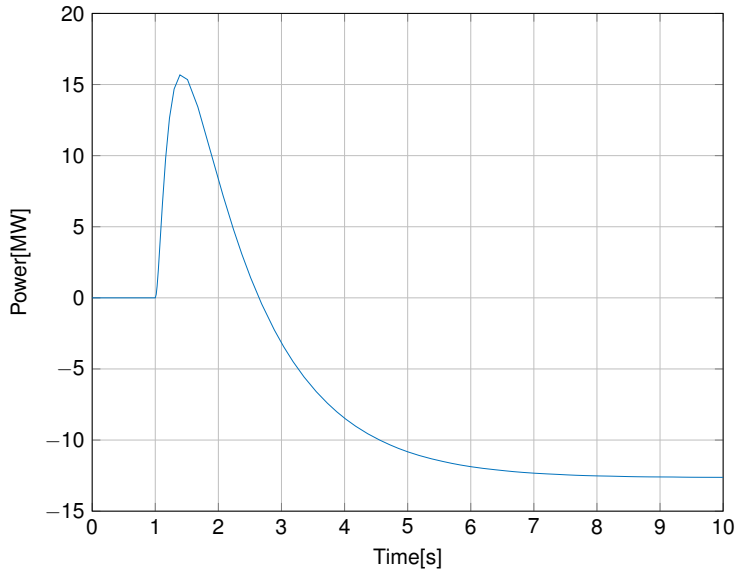


Figure: Frequency control response to step change in frequency

Buying frequency control

- Statnett pays all power plant owners to provide frequency control.
- However, they don't provide the same quality of service.

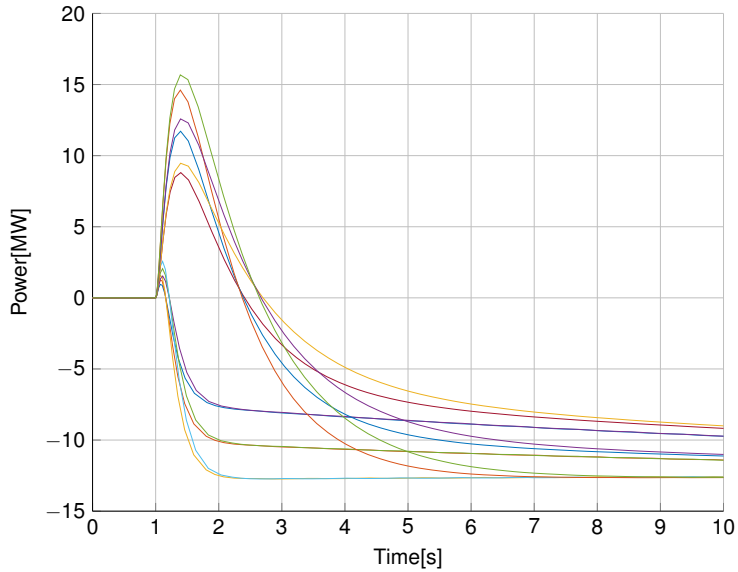


Figure: Frequency control response to step change in frequency

Buying frequency control

- Statnett pays all power plant owners to provide frequency control.
- However, they don't provide the same quality of service.
- Renewable energy sources such as wind and solar don't contribute.

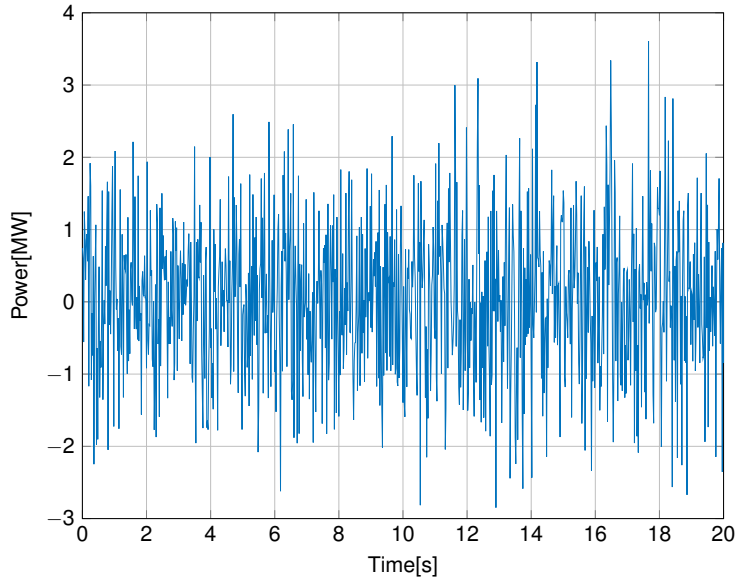


Figure: Frequency control response to step change in frequency

Future of frequency control

- Power plants have to pass tests to get paid to provide frequency control.
- Only those who pass the tests get paid for the service.

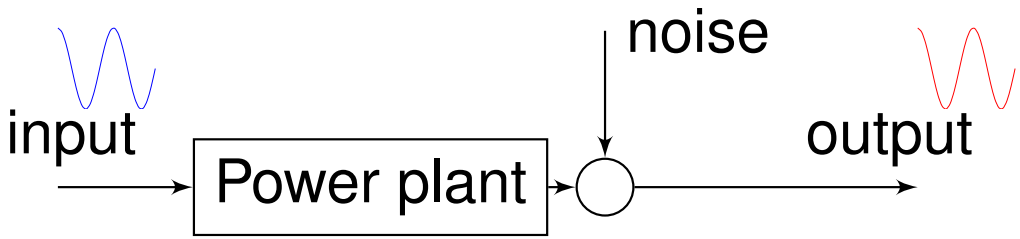
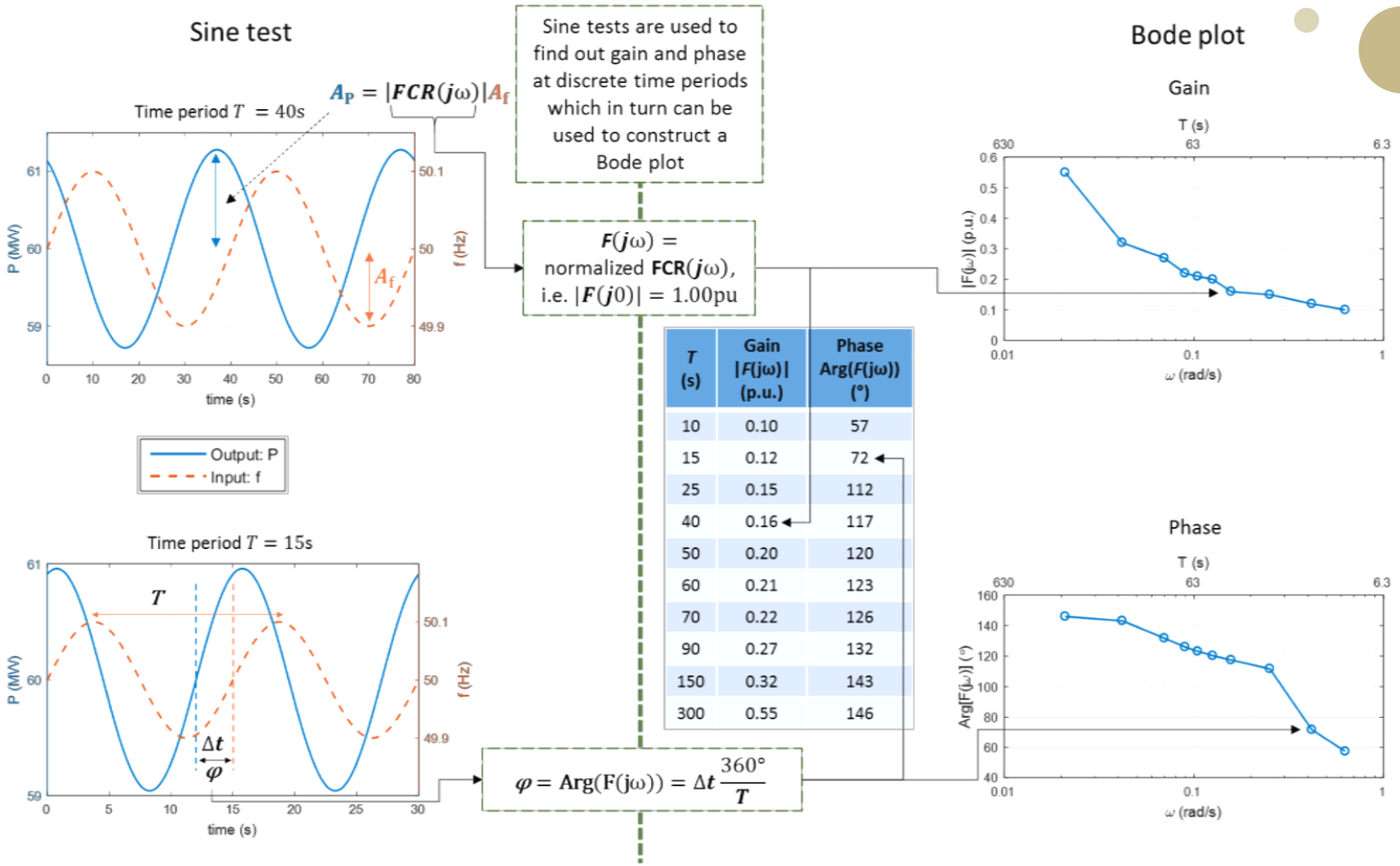


Figure: Test of power plant

Tests proposed by the industry

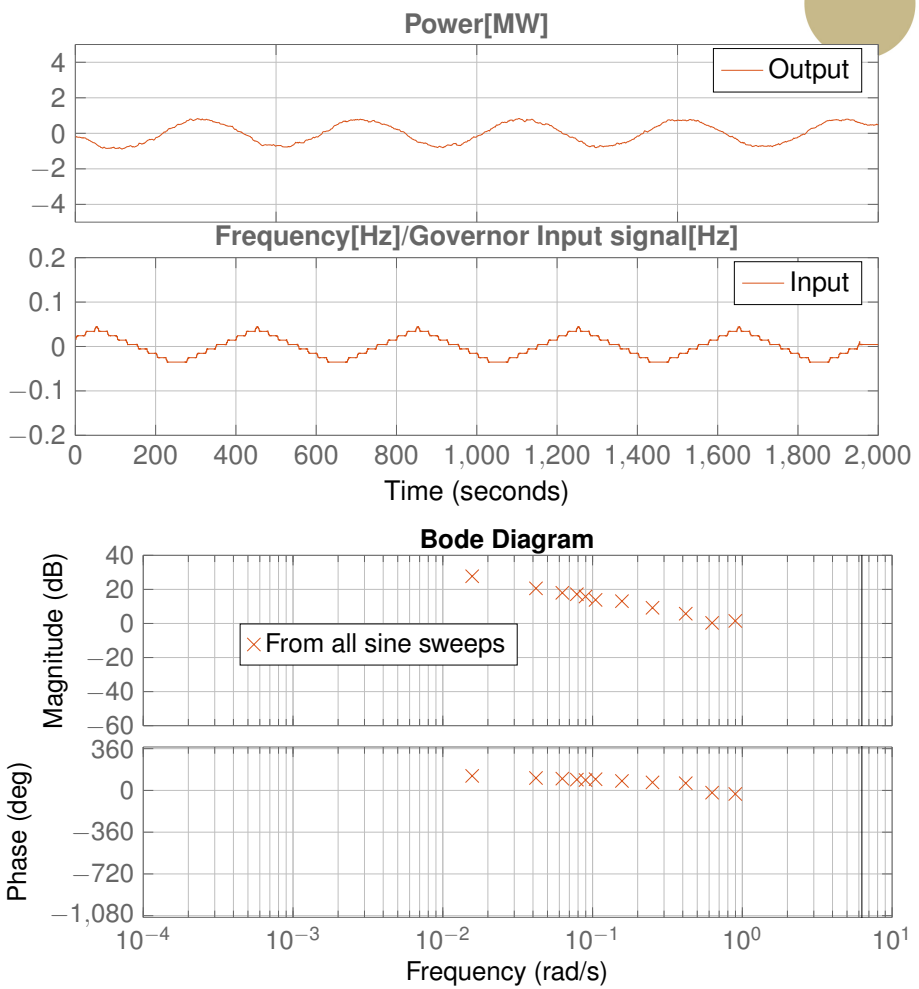


T (s)	Gain $\lvert F(j\omega)\rvert$ (p.u.)	Phase Arg($F(j\omega)$) (°)
10	0.10	57
15	0.12	72
25	0.15	112
40	0.16	117
50	0.20	120
60	0.21	123
70	0.22	126
90	0.27	132
150	0.32	143
300	0.55	146

Figure: Testing procedure [source:ENTSO-E]

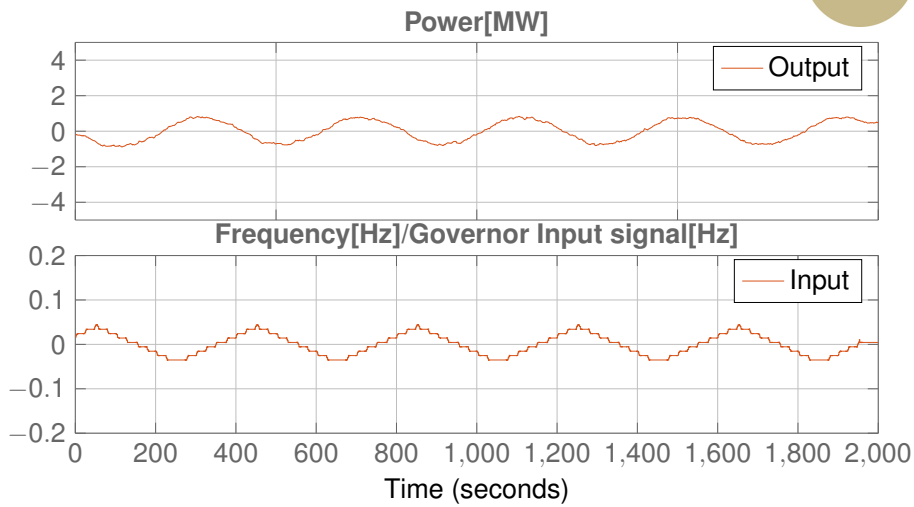
Example from real tests

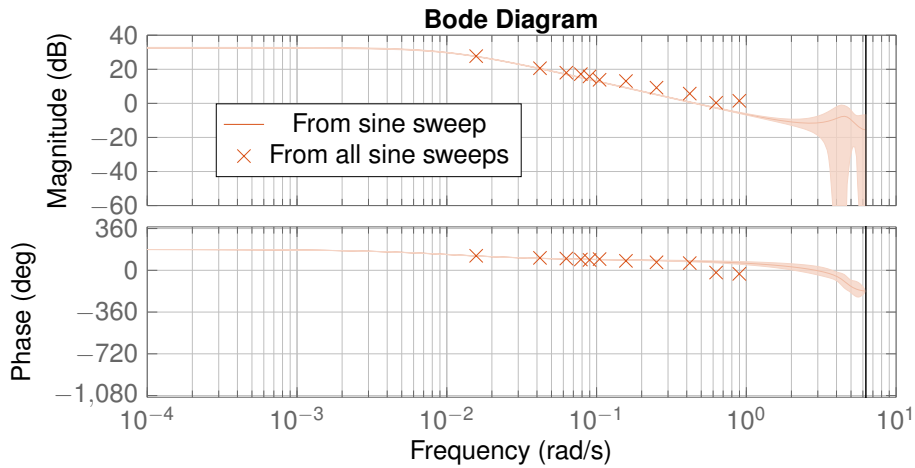
- The power plant needs to be disconnected
- Takes up to 20 hours.



Example from real tests

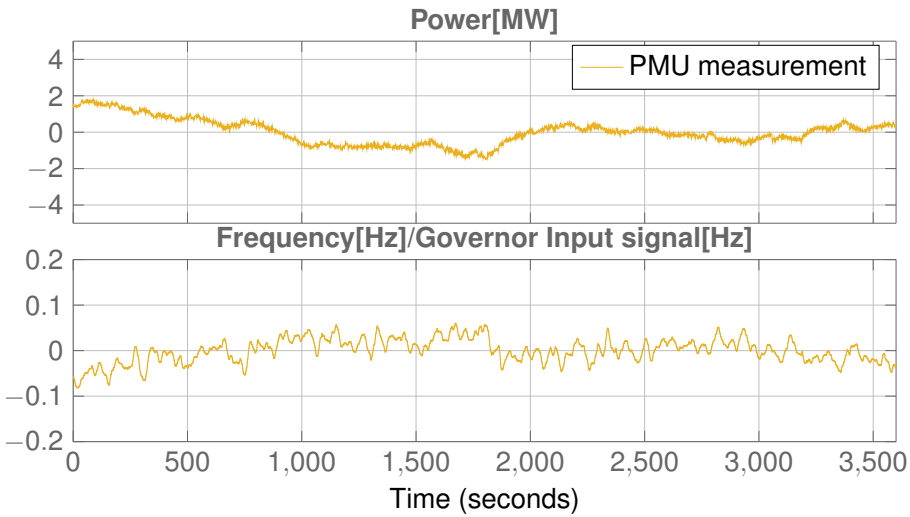
- The power plant needs to be disconnected
- Takes up to 20 hours.
- Only one sine test needed with model learning.





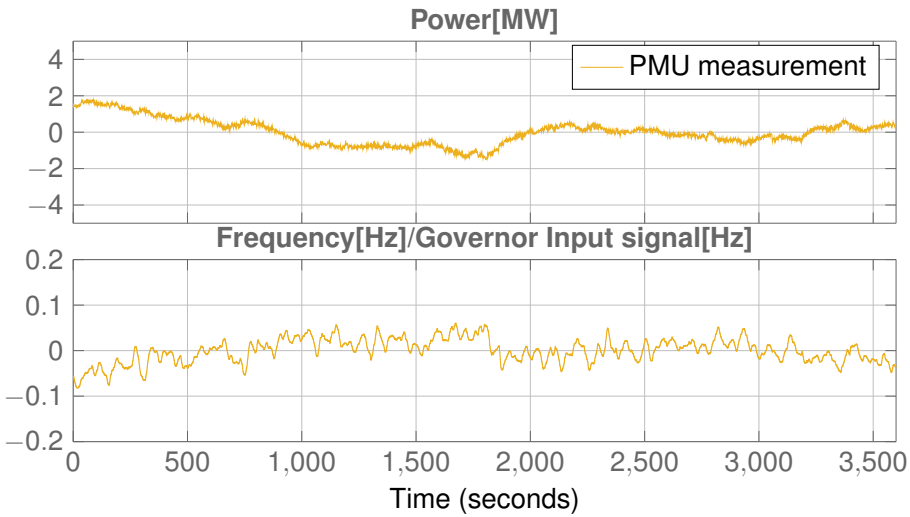
Motivation

— The power system is never really in steady state.



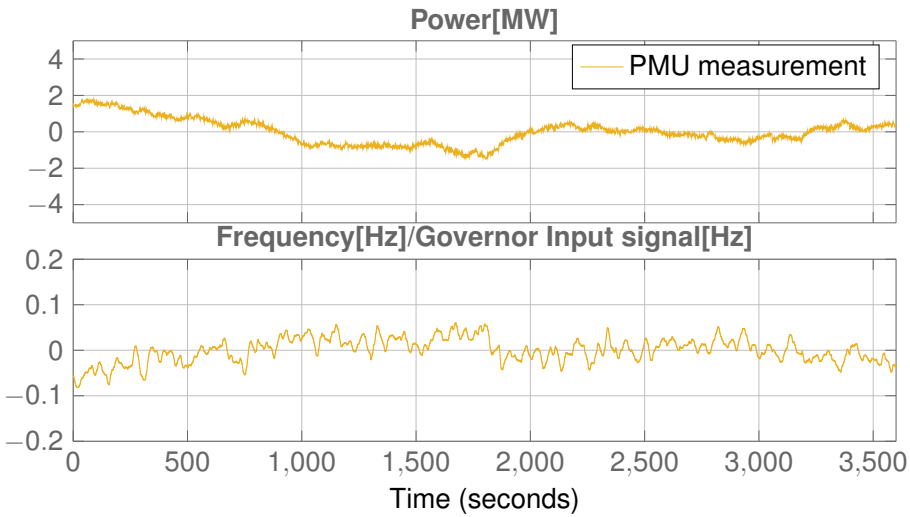
Motivation

- The power system is never really in steady state.
- Can the power plant dynamics be identified from normal operation measurements?



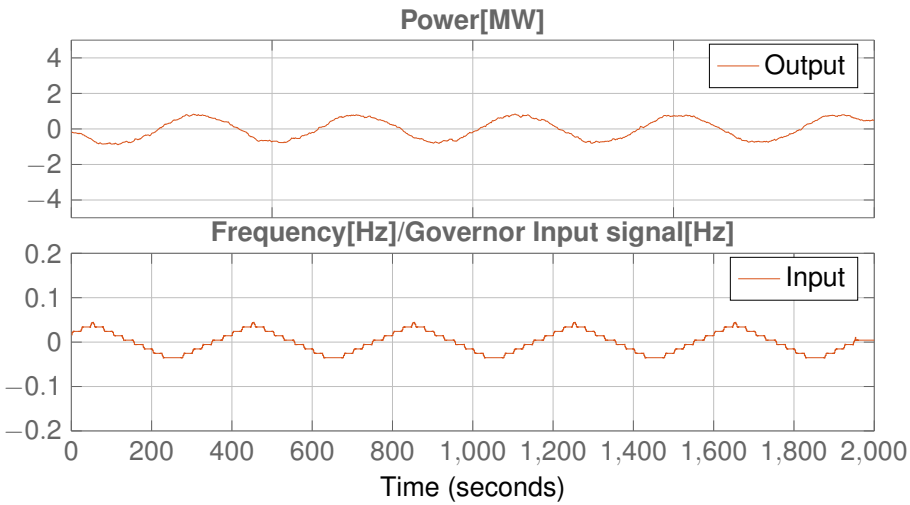
Research questions

— Can power plant dynamics be identified using a PMU?



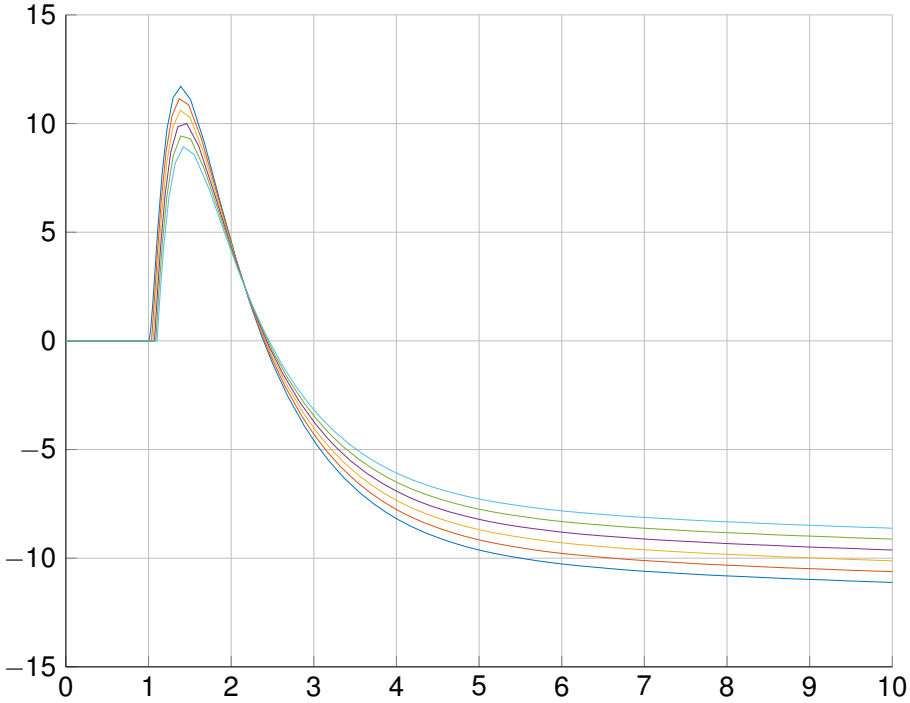
Research questions

- Can power plant dynamics be identified using a PMU?
- Can power plant dynamics be identified using control system measurements without disturbing the operation of the plant?



Research questions

- Can power plant dynamics be identified using a PMU?
- Can power plant dynamics be identified using control system measurements without disturbing the operation of the plant?
- What is the effect of nonlinearities on the identification?



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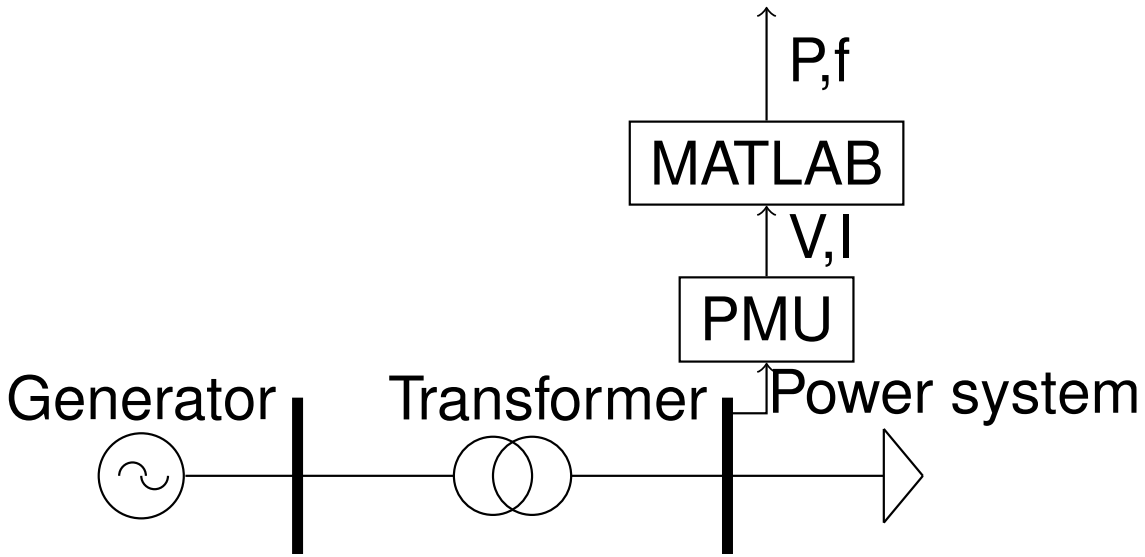
Background

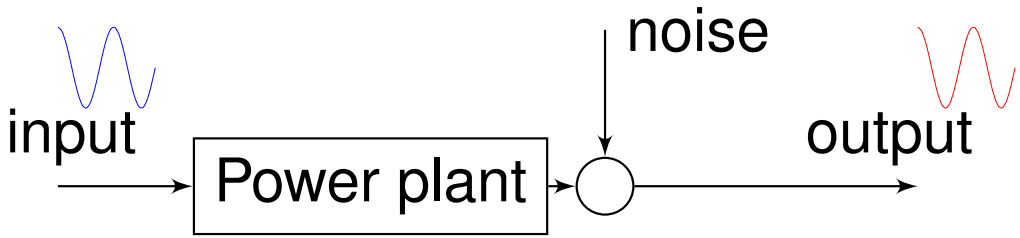
— Idea from[1] can the power plant dynamics be identified using PMUs



[1] Dinh Thuc Duong et al. “Estimation of Hydro Turbine-Governor’s Transfer Function from PMU Measurements”. In: IEEE PES General Meeting. Boston: IEEE, July 2016

Background

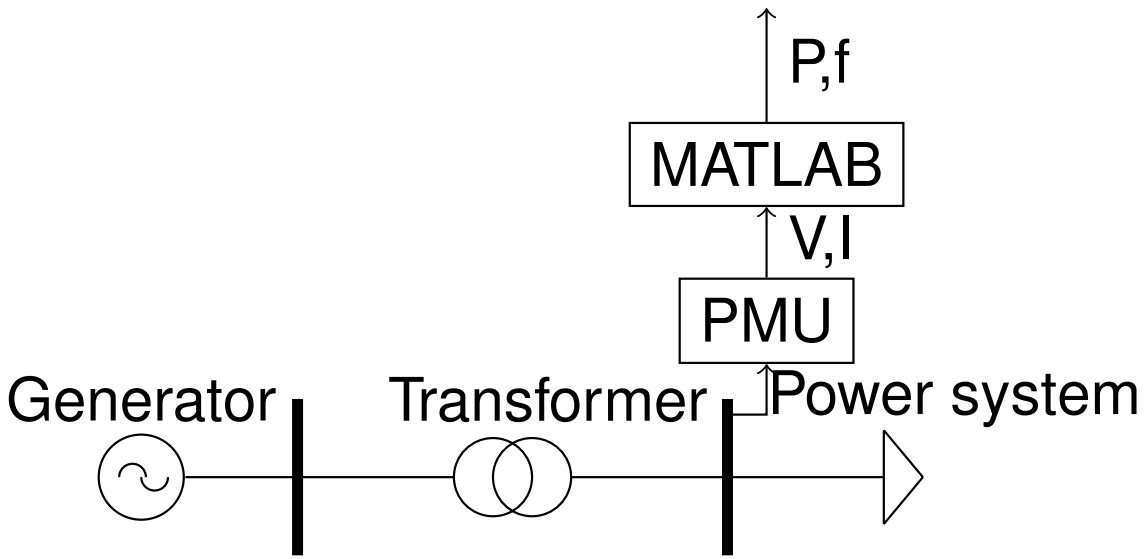
- Idea from[1] can the power plant dynamics be identified using PMUs
- Uses the same input and output measurements as in the requirements:
  - Input: Power system frequency.
  - Output: Electric power.



[1] Dinh Thuc Duong et al. “Estimation of Hydro Turbine-Governor’s Transfer Function from PMU Measurements”. In: IEEE PES General Meeting. Boston: IEEE, July 2016

Methodology

- Collect several datasets from PMUs.
- Calculate power and frequency from the measurements.
- Identify dynamics using vector fitting.
- Compare models.



Vector fitting basics

$$Y(s) = H(s) \cdot U(s) \qquad (1)$$

— Vector fitting fits a transfer function to measured input and output data

Vector fitting basics

$$Y(s) = H(s) \cdot U(s) \tag{1}$$

$$H(s) = d + \sum_{i=1}^{n_p} \frac{r_i}{s - p_i} \tag{2}$$

- Vector fitting fits a transfer function to measured input and output data
- It assumes the system to have the following structure.

Vector fitting basics

- Vector fitting fits a transfer function to measured input and output data
- It assumes the system to have the following structure.
- In time domain it is.

$$Y(s) = H(s) \cdot U(s) \tag{1}$$

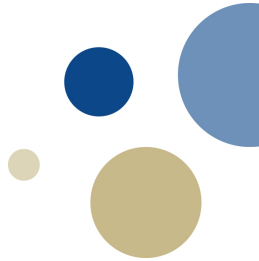
$$H(s) = d + \sum_{i=1}^{n_p} \frac{r_i}{s - p_i} \tag{2}$$

$$y(t) \approx \tilde{d}x(t) + \sum_{i=1}^{n_p} \tilde{r}_i x_i - \sum_{i=1}^{n_p} \tilde{k}_i y_i \tag{3}$$

$$x_i = \int_0^t e^{\tilde{p}_i(t-\tau)} x_i(\tau) d\tau \tag{4}$$

$$y_i = \int_0^t e^{\tilde{p}_i(t-\tau)} y_i(\tau) d\tau \tag{5}$$

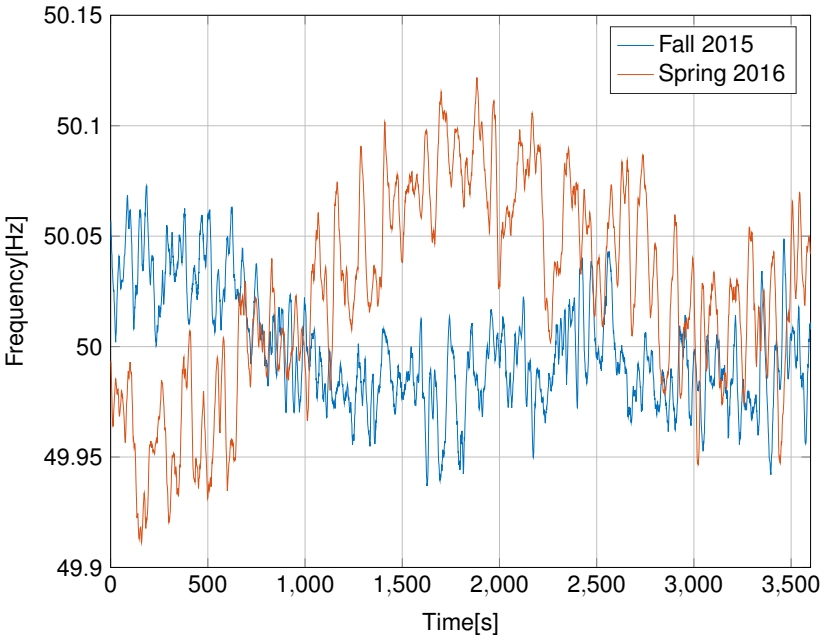
Vector fitting basics ctd.

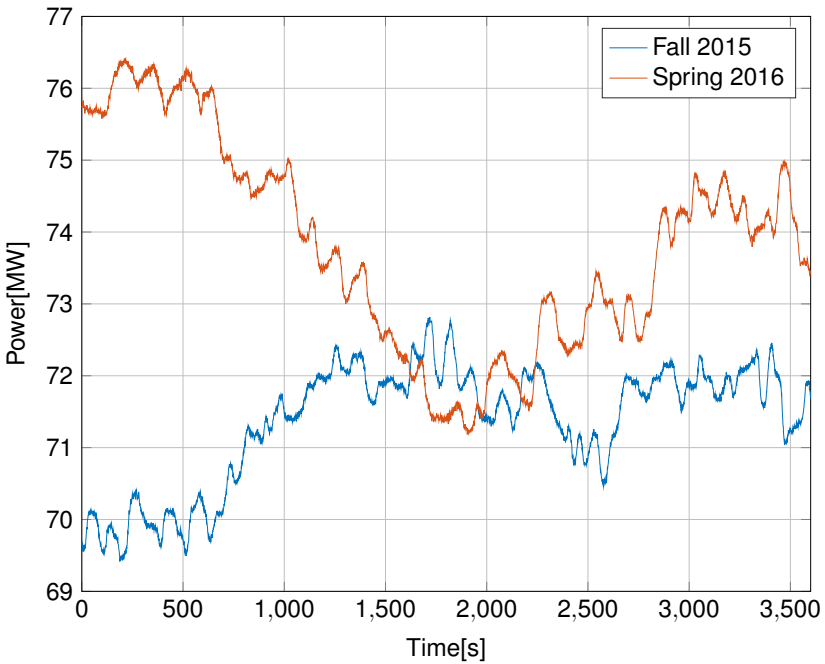


— Find $\tilde{d}$, $\tilde{r}_i$ and $\tilde{k}_i$ to minimize:

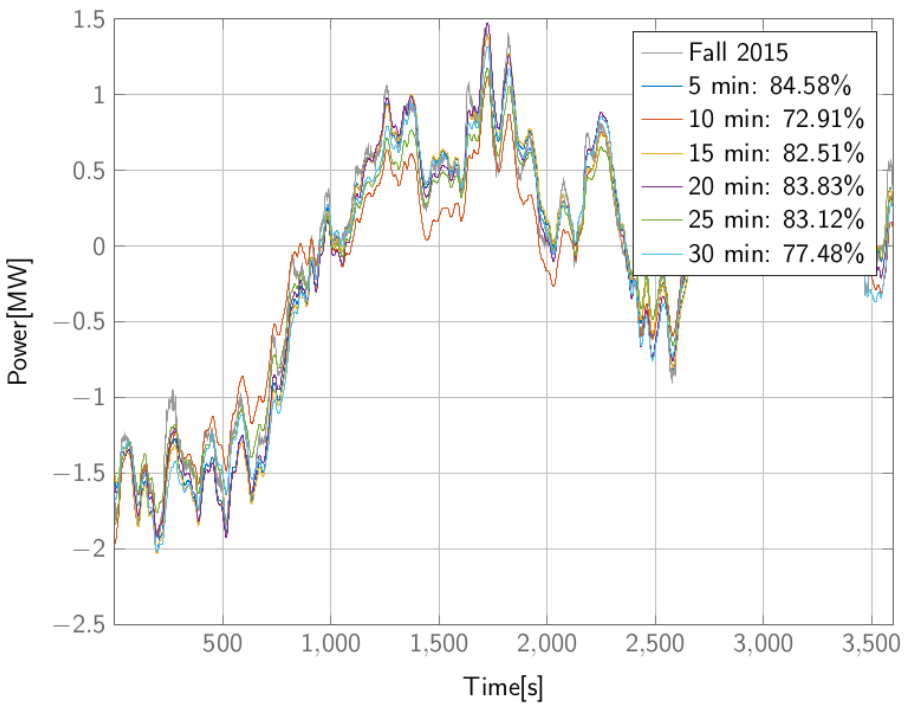
$$y(t) - (\tilde{d}x(t) + \sum_{i=1}^{n_p} \tilde{r}_i x_i - \sum_{i=1}^{n_p} \tilde{k}_i y_i) \tag{6}$$

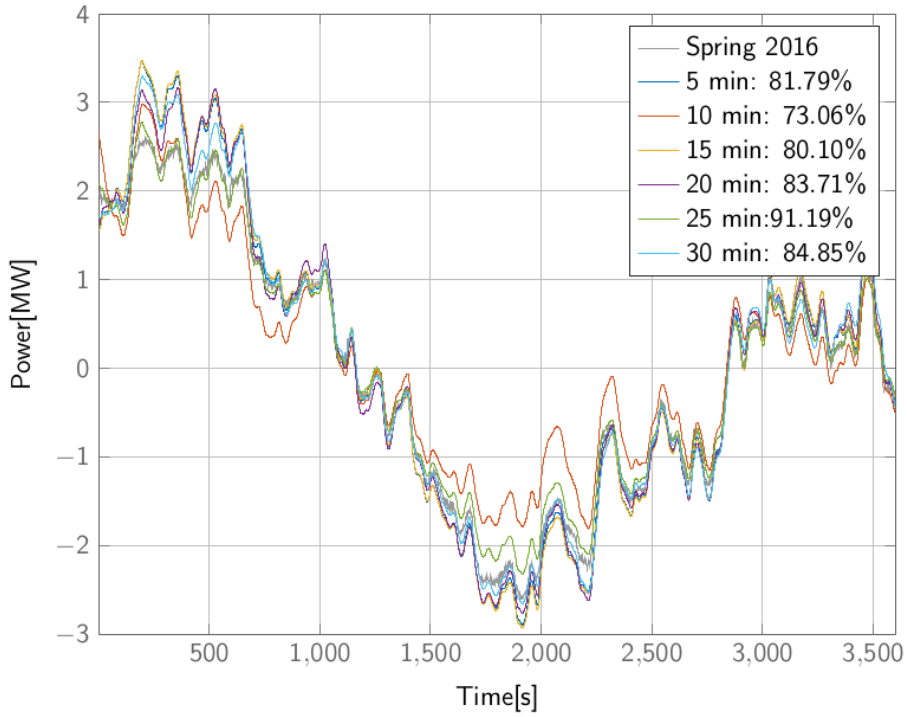
Cross validation using distant data sets



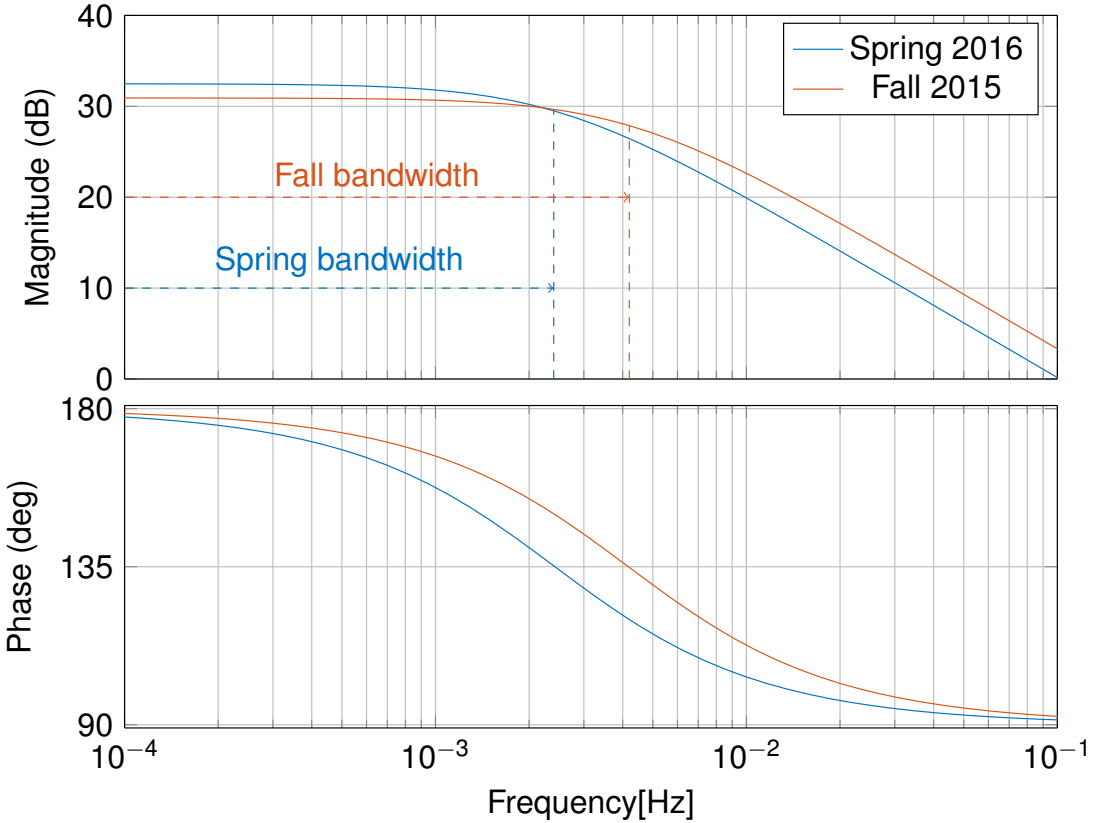


Cross validation using distant data sets





Estimated droop and bandwidth



Dataset	Droop[%]	B
Fall 2015	10	
Spring 2016	8	