



Frequency control and stability requirements on hydro power plants

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Outline



Problem

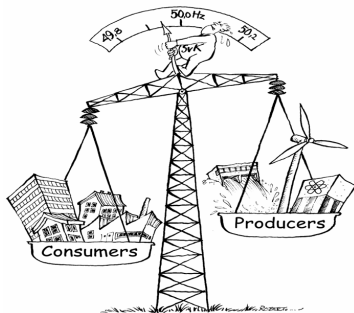
Methodology Paper I

Simple test system Paper II

Conclusions and further work

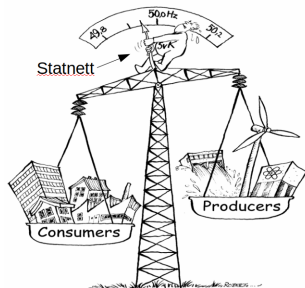
Load and production balancing

- The power system frequency measures the power balance.



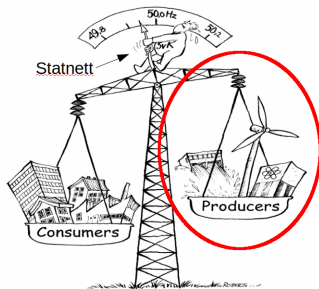
Load and production balancing

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- It is the responsibility of the TSOs to control the frequency.



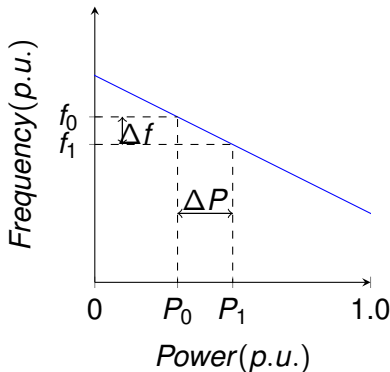
Load and production balancing

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

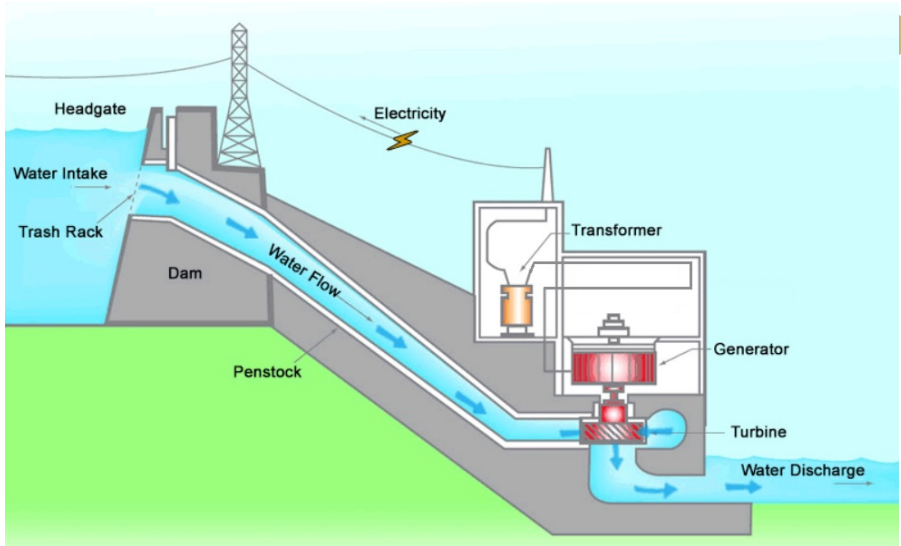


Load and production balancing

- The power system frequency measures the power balance.
- It is the responsibility of the TSOs to control the frequency.
- However, it is the power plant owners who can control the frequency.
- The TSOs pay all power plant owners above a certain size to provide frequency control. (droop $\rho = \Delta f / \Delta P$)

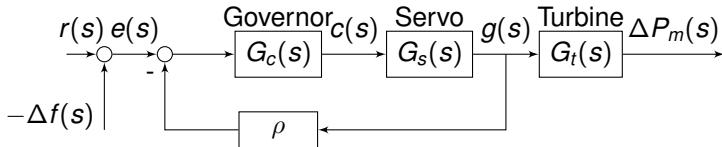


Hydro power plant



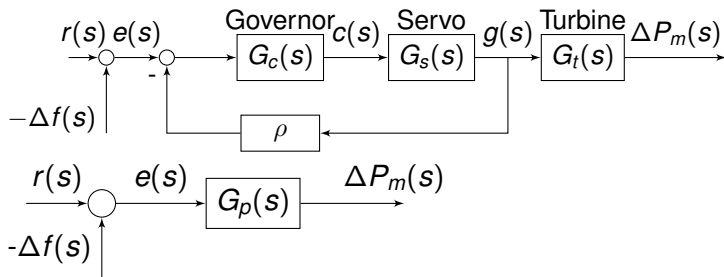
Implementation of the frequency containment process

- $r(s)$ Reference frequency
- $e(s)$ Control error
- $f(s)$ Frequency
- $c(s)$ Control signal
- $g(s)$ Guide vane opening
- $\Delta P_m(s)$ Mechanical power



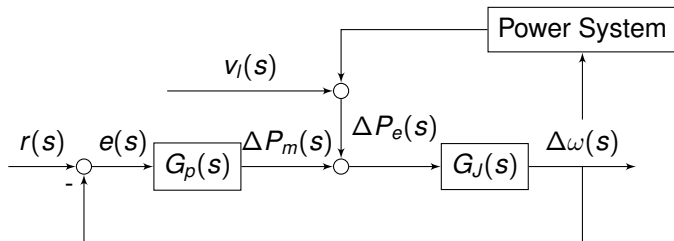
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The frequency containment process $G_p(s)$ in the power system

- $G_J(s)$ represents the swing dynamics of the power plant.
- $v_I(s)$ represents stochastic load.



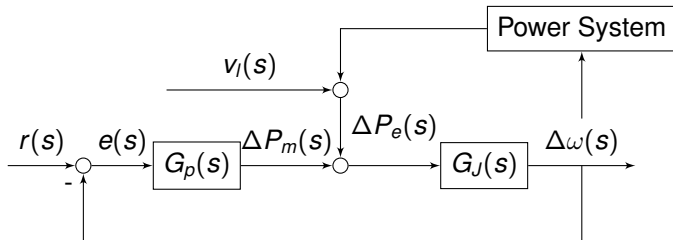
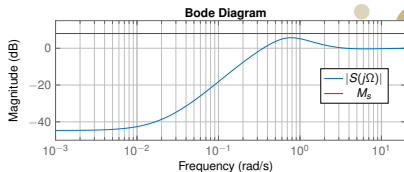
Stability requirements for frequency control

- Stability margin from control theory:

$$\max |S(j\Omega)| < M_s \quad (1)$$

- where:

$$S(s) = \frac{1}{1 + G_p(s)G_J(s)} \quad (2)$$



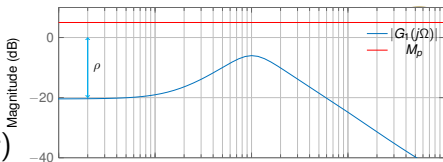
Performance requirements for frequency control

- We want to contain frequency deviations.

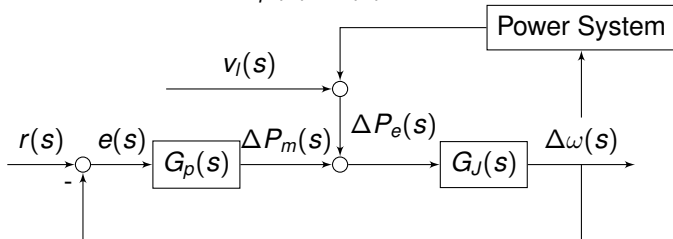
$$\Delta\omega(s) = \frac{G_J}{1 + G_p(s)G_J(s)} \Delta P_e(s) \quad (3)$$

- Define

$$G_1(s) = \frac{G_J}{1 + G_p(s)G_J(s)} \quad (4)$$

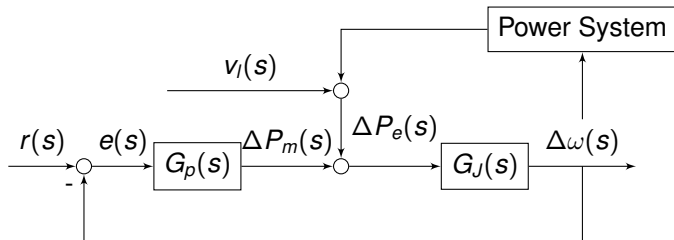


$$|G_1(j\Omega)| < M_p \quad (5)$$



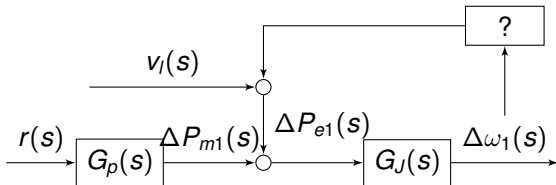
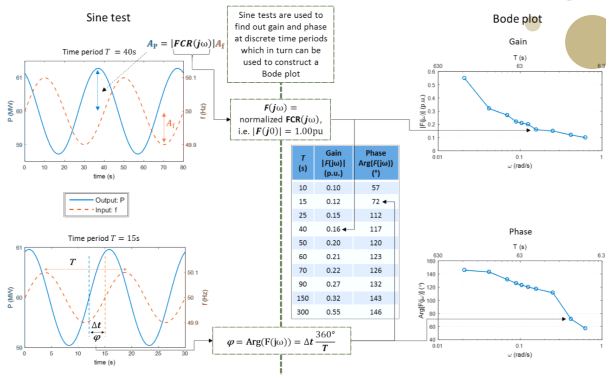
Future of frequency control

- Power plants have to show that they fulfill:
 - Stability requirement $S(s) < M_s$
 - Performance requirement $G_1(s) < M_p$
- To do this they need models of:
 - $G_p(s)$
 - and $G_J(s)$



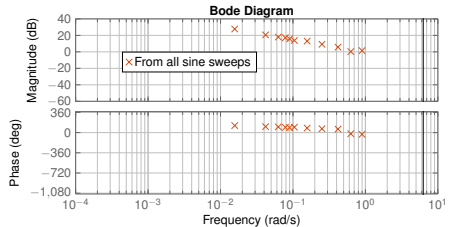
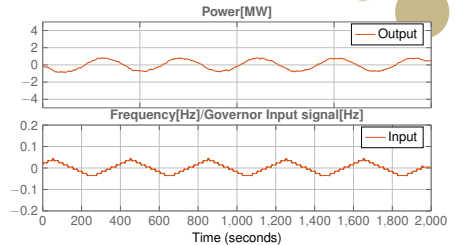
Industry proposed tests

- Time consuming.
- Use system estimate for $G_J(s)$.
- Input $r(s)$
- Output $\Delta P_e(s)$



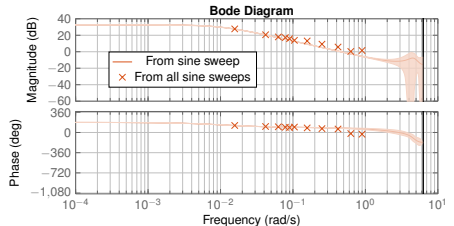
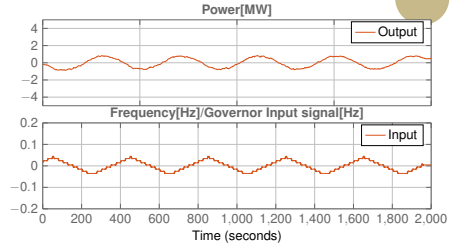
Example from real tests

- 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 system identification.



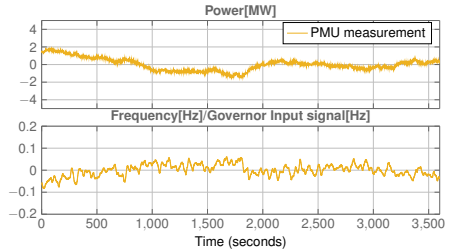
Motivation



— Can we do the tests easier?

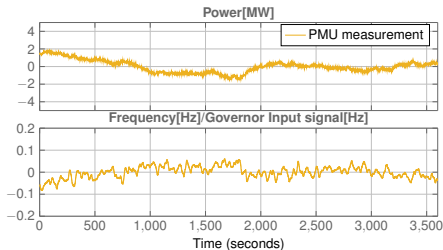
Motivation

- Can we do the tests easier?
- The power system is never really in steady state.



Motivation

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



Outline



Problem

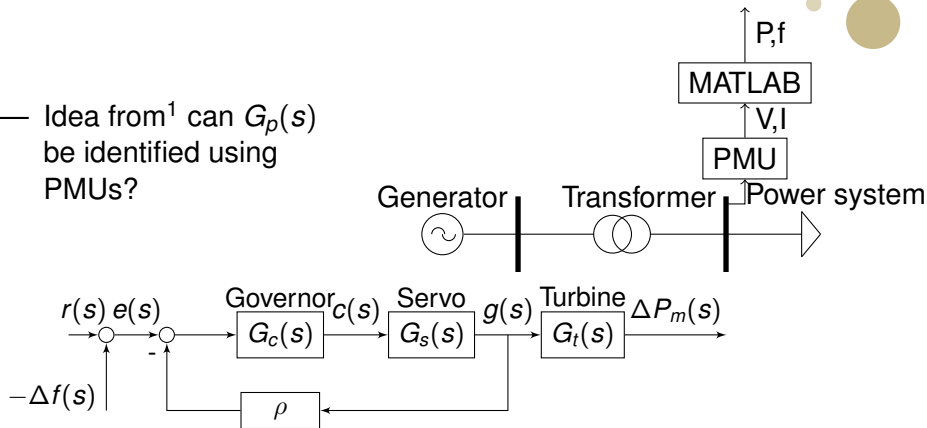
Methodology Paper I

Simple test system Paper II

Conclusions and further work

Background

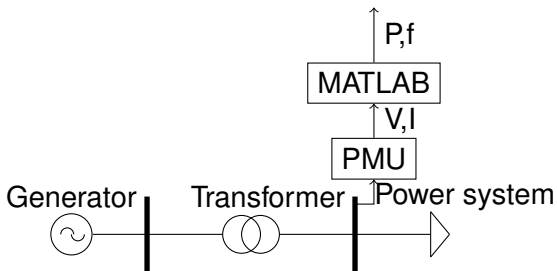
- Idea from¹ can $G_p(s)$ be identified using PMUs?



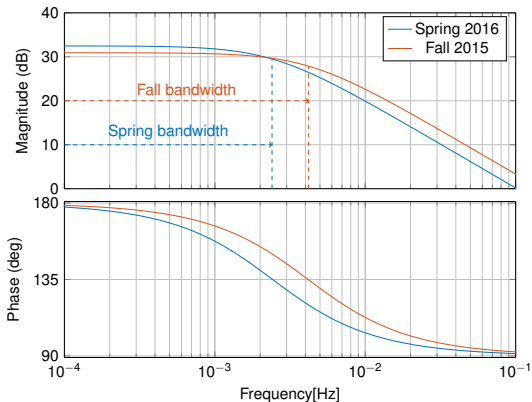
¹Dinh Thuc Duong et al. "Estimation of Hydro Turbine-Governor's Transfer Function from PMU Measurements". In: *IEEE PES General Meeting*. Boston: IEEE, July 2016

Methodology

- Collect data from PMUs.
- Preprocess data.
- Calculate power and frequency from the measurements.
- Identify dynamics.
- Validate models.



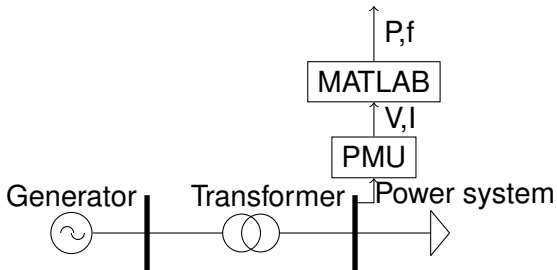
Estimated droop and bandwidth



Dataset	Droop[%]	Bandwidth[mHz]
Fall 2015	10	4.16
Spring 2016	8	2.41

Main contributions to the research questions

- Promising results for 19 datasets.



Main contributions to the research questions

- Promising results for 19 datasets.
- Developed code for interfacing with the PMU data.

The screenshot shows the GitHub repository page for 'Hofsmo / turb_fit'. The repository has 23 commits, 1 branch, 0 releases, and 1 contributor. It is licensed under GPL-3.0. The repository contains several files, including LICENSE, README.md, bode_to_csv.m, create_G0.m, droop_jacobian_bj.m, find_inertia.m, linearize_hygov.m, prepare_case.m, read_top_data.m, read_pmu.m, and read_simulation.m. The README.md file is open, showing the title 'turb_fit' and a description: 'This toolbox provides functions useful for identifying hydro turbines using PMU measurements and signals from the plant.'

Hofsmo / turb_fit

Unwatch 1 Star 0 Fork 0

Code Issues Pull requests Projects Wiki Security Insights Settings

Functions useful for hydro turbine identification

Manage topics

23 commits 1 branch 0 releases 1 contributor GPL-3.0

Branch: master New pull request Create new file Upload files Find file Clone or download

File	Commit Message	Commit Date
LICENSE	Initial commit	2 years ago
README.md	Update README.md	2 years ago
bode_to_csv.m	I added find_inertia and bode to csv	last year
create_G0.m	I added find_inertia and bode to csv	last year
droop_jacobian_bj.m	Added droop Jacobian	last year
find_inertia.m	I added find_inertia and bode to csv	last year
linearize_hygov.m	Commit before pull	last year
prepare_case.m	Added detrend to prepare_case	last year
read_top_data.m	Added function for reading data from top files	last year
read_pmu.m	Added and renamed files from old toolbox	2 years ago
read_simulation.m	Added and renamed files from old toolbox	2 years ago

README.md

turb_fit

This toolbox provides functions useful for identifying hydro turbines using PMU measurements and signals from the plant.

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Problem

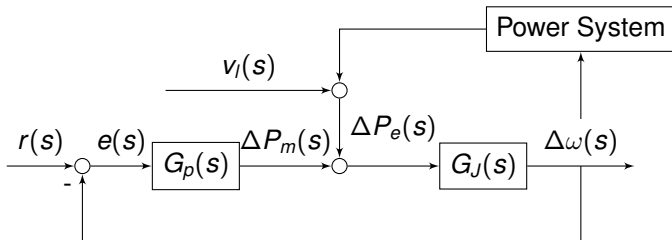
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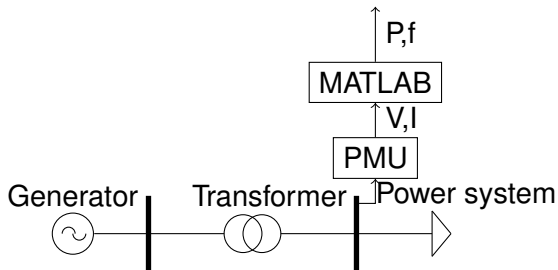
Motivation

- Create a model for analysing the identifiability of hydro power plant dynamics.



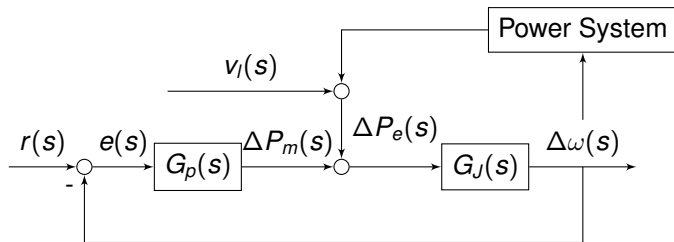
What do we need to model?

- From the PMU we get



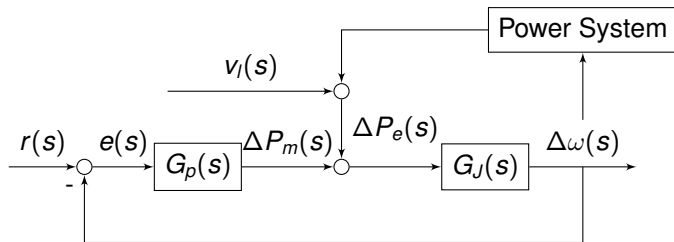
What do we need to model?

- From the PMU we get
 - Power: $\Delta P_e(s)$.



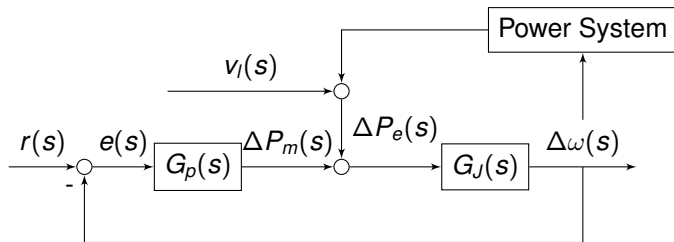
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 - Power: $\Delta P_e(s)$.
 - Frequency: $\Delta f(s) \approx 2\pi\Delta\omega(s)$.



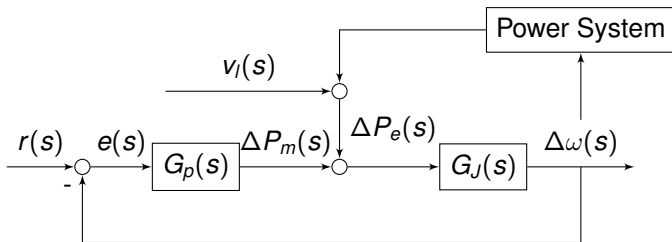
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- From the PMU we get
 - Power: $\Delta P_e(s)$.
 - Frequency: $\Delta f(s) \approx 2\pi\Delta\omega(s)$.
- We need to model how $\Delta P_e(s)$ and $\Delta f(s)$ is related through the power system.



What do we need to model?

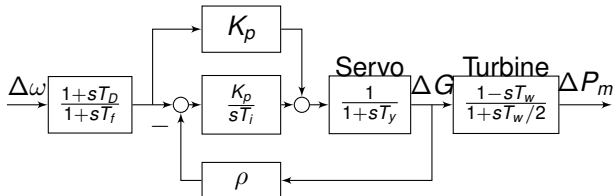
- From the PMU we get
 - Power: $\Delta P_e(s)$.
 - Frequency: $\Delta f(s) \approx 2\pi\Delta\omega(s)$.
- We need to model how $\Delta P_e(s)$ and $\Delta f(s)$ is related through the power system.
- We also need to model the power plant consisting of $G_p(s)$ and $G_J(s)$.



Power plant model

- Model for $G_p(s)$
- Model for $G_J(s)$

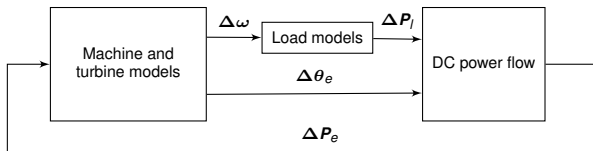
$$G_J(s) = \frac{1}{2Hs + K_d} \quad (6)$$



Power system model



- The frequency and power system angle is related.
- The angle and power is related.
- On matrix form.



$$\Delta\theta(s) = \frac{2\pi f_s}{s} f(s) \quad (7)$$

$$P_k \approx \sum_{m \in \Omega_k} x_{km}^{-1} \theta_{km} \quad (8)$$

$$\mathbf{P} = \mathbf{Y}\theta \quad (9)$$

Test system

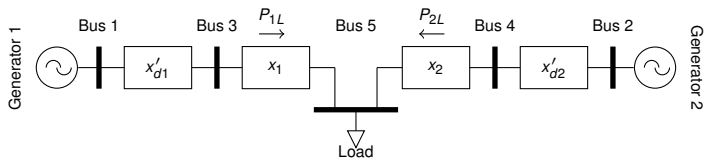
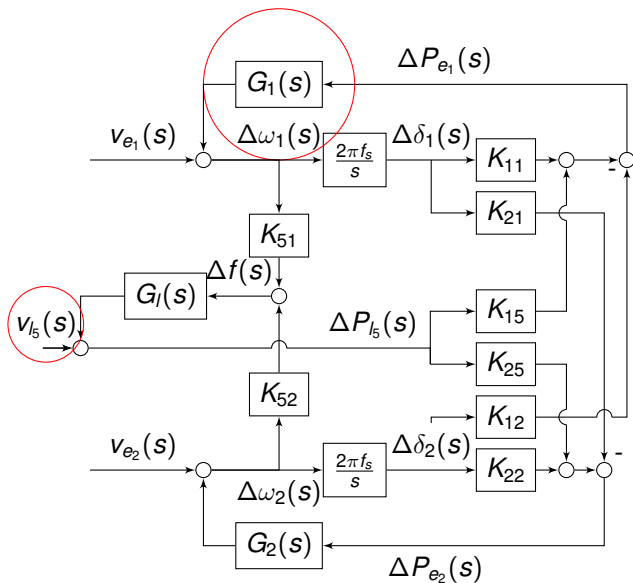


Figure: Single line diagram

Test system



Simulation Result

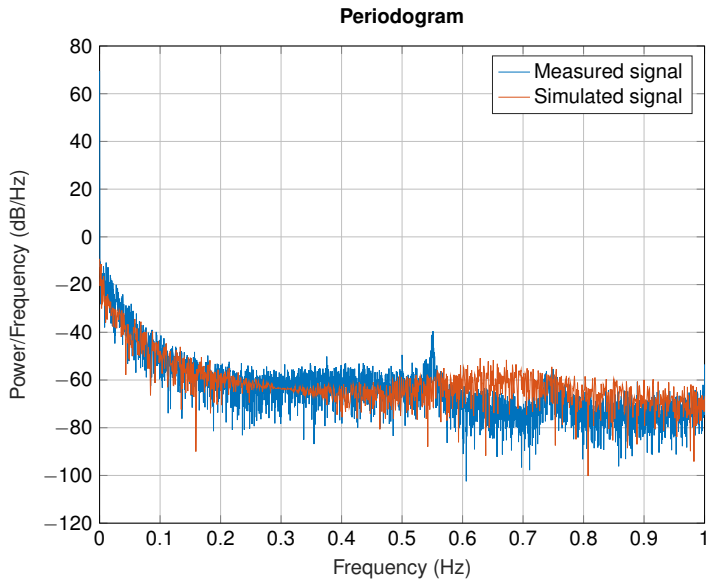


Figure 1 Power spectrum density of measured and simulated frequency

Main contributions



- Developed simple test system for analysing power plant identifiability using PMUs.
- Developed simple test system used in the proceeding papers for simulations.

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Conclusions



- The requirements can be checked using PMU-measurements, however, the results will be biased for faster dynamics.
- The requirements can be checked using control system measurements in normal operation, however, the results may be biased for faster dynamics.
- The requirements can be checked using measurement from normal operation with extra excitation

Further work



- Validate approaches in the lab
- Solve the delay condition.
- Handle backlash.
- Investigate the alternative requirements.