COHERENCE FUNCTION ESTIMATION WITH A DERIVATIVE CONSTRAINT FOR POWER GRID OSCILLATION DETECTION

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Motivation

- Oscillations with growing amplitudes can cause serious problems

  1- system break-ups and large-scale outages

  2- negatively affect the life expectancy of equipment

  3- flickering light which is annoying to human eyes

- To ensure the **stability** and **reliability** of a power grid, it is important to **accurately detect** the oscillations.

Background

- Oscillations in a power grid:

  1- Free oscillations : the results of internal interaction among the system equipment. (Studied well in last 20 years)

  2- Forced oscillations are caused by external inputs. (Recently gained a lot of attention)

Background

- **Coherence spectrum,** a.k.a the magnitude squared coherence **(MSC)** function, is widely used for oscillation detection.
- The MSC function can be estimated by many different spectral estimation methods such as:
  - Welch’s method
  - ARMA method
  - Minimum variance distortionless response (MVDR) method, a.k.a Capon method

MVDR (Capon) Method

- Advantages:
  - Real-time applicability
  - Multi-channel data adaptability
  - Low risk of false alarm
  - High estimation accuracy.
- Drawbacks:
  - Estimated MSC does not cover all the frequencies. **“blind spots”**

Generalized MVDR (Capon) Method

$$x(t) = f(t) + q(t)$$

f(t) forced oscillations
q(t) noises

$$\gamma^2_{x_1x_2}(\omega) = \frac{|S_{x_1x_2}(\omega)|^2}{S_{x_1}(\omega)S_{x_2}(\omega)},$$

γ^2_{x1x2} (MSC function)
S_{x1x2} cross spectrum between two signals
S_{x1} and S_{x2} Power spectral density

$$\begin{cases} \min\limits_{\mathbf{w}_k} & S_x(\omega_k) = \mathbf{w}_k^H \mathbf{R}_x \mathbf{w}_k \\ \text{s.t.} & \mathbf{c}_k^H \mathbf{w}_k = 1 \end{cases}$$

w_K **k**th sub filter of the filter bank
R_x Covariance matrix

$$\mathbf{c}_k = [1, e^{j\omega_k}, \cdots, e^{j\omega_k(L-1)}]^T/\sqrt{L}.$$

$$S_x(\omega_k) = \mathbf{w}_{k,opt}^H \mathbf{R}_x \mathbf{w}_{k,opt} = \frac{1}{\mathbf{c}_k^H \mathbf{R}_x^{-1} \mathbf{c}_k}.$$

Derivative Constrained MVDR (capon) Method

New optimization problem

$$\begin{cases} \min\limits_{\mathbf{w}_k} & S_x(\omega_k) = \mathbf{w}_k^H \mathbf{R}_x \mathbf{w}_k \\ \text{s.t.} & \mathbf{C}_k^H \mathbf{w}_k = \mathbf{h} \end{cases}$$

$$\mathbf{C}_k = \begin{bmatrix} \mathbf{c}_k & \frac{d\mathbf{c}_k}{d\omega_k} \end{bmatrix}, \qquad \mathbf{h} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

New MSC function

$$\gamma^2_{x_1 x_2}(\omega_k) = \frac{\left|\mathbf{h}^H \boldsymbol{\zeta}_{1,k} \mathbf{C}_k^H \mathbf{R}_{x_1}^{-1} \mathbf{R}_{x_1 x_2} \mathbf{R}_{x_2}^{-1} \mathbf{C}_k \boldsymbol{\zeta}_{2,k} \mathbf{h}\right|^2}{(\mathbf{h}^H \boldsymbol{\zeta}_{1,k} \mathbf{h})(\mathbf{h}^H \boldsymbol{\zeta}_{2,k} \mathbf{h})}$$

$$\boldsymbol{\zeta}_{i,k} = (\mathbf{C}_k^H \mathbf{R}_{x_i}^{-1} \mathbf{C}_k)^{-1}, i = 1, 2.$$

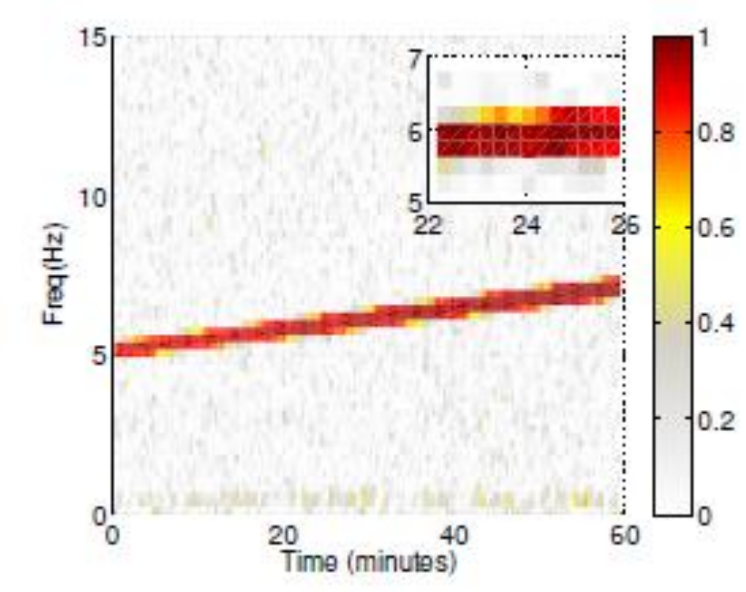
Simulation

- Simple Chirp signal SNR= -10dB, f_0 = 5 Hz to f_1 = 7Hz

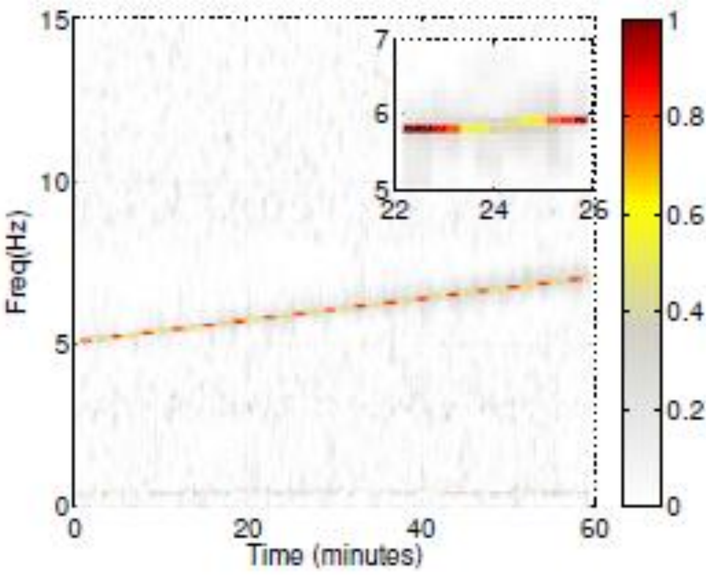
Wide peak → Low Freq resolution
High Mag other Freq → High rate of false alarm

Blind spots → High rate of miss detection

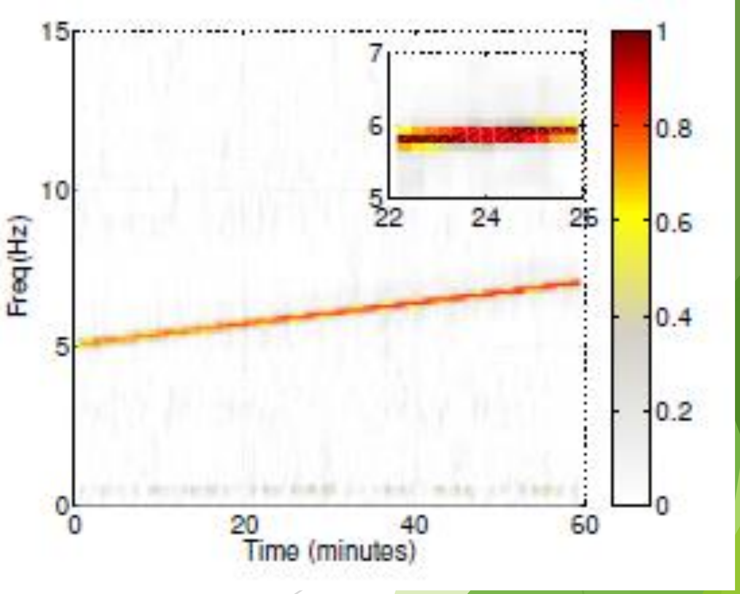
High Freq resolution
Low rate of false alarm
Low rate of miss detection



Welch method



Generalized MVDR



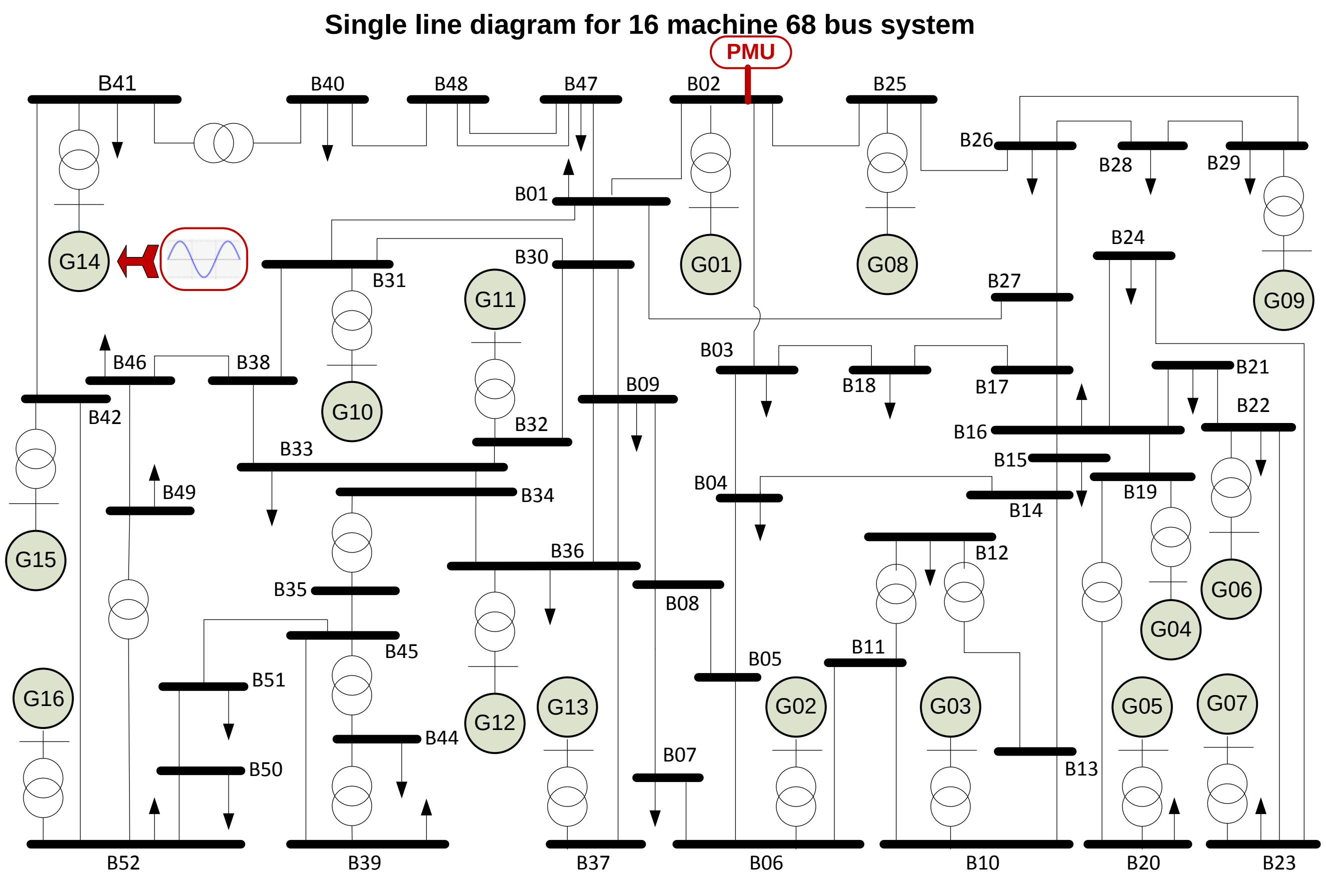
Derivative constraint MVDR

Power system Simulation

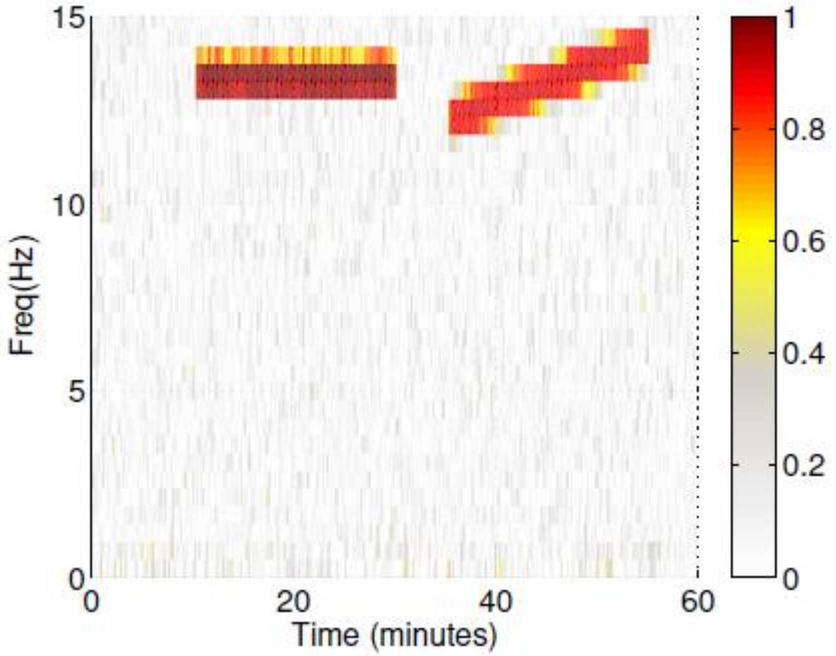
Source: Generator 14
Forced oscillations:

> ***1-Sinosuidal signal Freq=*** 13.125Hz from the 10th minute to 30th minute
>
> ***2-*** chirp signal of 12 to 14Hz from the 35th minute to 55th minute

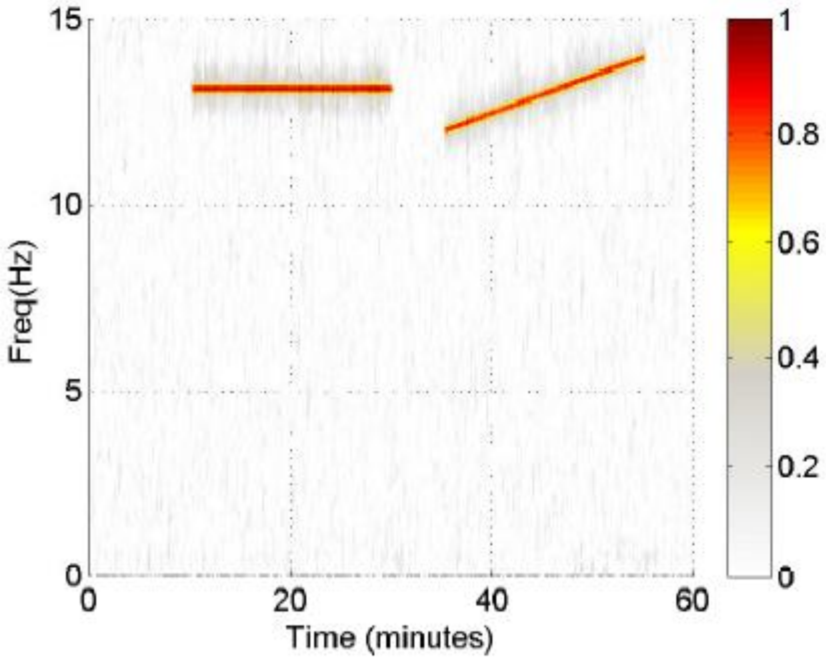
PMU location: bus 2



Power system Simulation



Welch method



Derivative constraint MVDR

Conclusion

- Proposed method
  - Narrow peak ⇨ **Higher** Frequency **resolution**
  - Low Mag at other Frequency ⇨ **Lower** rate of **false alarm**
  - Can avoid the “blind spots” problem ⇨ **Lower** rate **of miss detection**
- thus increase the oscillation detection accuracy.

Thank you for your attention.