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Net



 π School of Engineering

Locating the Source of Forced Oscillations in Transmission Power Grids

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People



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Power grid dynamics

$$m_j\ddot{ heta}_j + d_j\dot{ heta}_j = P_{\mathrm{m},j} - P_{\mathrm{e},j} = P_j - \sum_k B_{jk}\sin(heta_j - heta_k)$$





J. Machowski, J. W. Bialek, and J. R. Bumby, Power System Dynamics, 2nd ed. (Wiley, Chichester, U.K, 2008).

Forced oscillations



https://www.youtube.com/watch?v=1vuxZJitEJg

Intuitive (but a bit naive) approach: ...



RD, A. Y. Lokhov, M. Tyloo, and M. Vuffray, Phys. Rev. X Energy 2, 023009 (2023).

Intuitive (but a bit naive) approach: the Fourier Transform



RD, A. Y. Lokhov, M. Tyloo, and M. Vuffray, Phys. Rev. X Energy 2, 023009 (2023).

Using the SALO algorithm



RD, A. Y. Lokhov, M. Tyloo, and M. Vuffray, Phys. Rev. X Energy 2, 023009 (2023).

Introduction 000	Source location ○○○●	Results 00000

SALO: System-Agnostic Location of Oscillations

Dynamics: $M\dot{\mathbf{p}} = D\mathbf{p} + B\mathbf{x} + \gamma \mathbf{e}_{\ell} \cos(2\pi ft + \phi) + \boldsymbol{\xi}.$

RD, A. Y. Lokhov, M. Tyloo, and M. Vuffray, Phys. Rev. X Energy 2, 023009 (2023).

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Discretized: $\Delta_{t_j} = A \mathbf{X}_{t_j} + \gamma \mathbf{e}_{\ell} \cos(2\pi k t_j / T + \phi) + \xi_j$.

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$$\Delta_{t_j} = A\mathbf{X}_{t_j} + \gamma \mathbf{e}_{\ell} \cos(2\pi k t_j / T + \phi) + \xi_j$$
.

Least square error:

SALO:
$$\arg\min_{A,\gamma,k,\ell,\phi}\sum_{j=0}^{T-1} \left\|\boldsymbol{\Delta}_{t_j} - A\boldsymbol{X}_{t_j} - \gamma \boldsymbol{e}_\ell \cos(2\pi k t_j/T + \phi)\right\|^2.$$

... and a bit of work.

RD, A. Y. Lokhov, M. Tyloo, and M. Vuffray, Phys. Rev. X Energy 2, 023009 (2023).

Synthetic data



Multiple or hidden sources



Measurement data



M. Escobar, D. Bienstock, and M. Chertkov, in Proc. of the IEEE PowerTech (IEEE, Milano, Italy, 2019).

Measurement data (bis)



The University of Tennessee, Knoxville FNET Server Web Display, https://fnetpublic.utk.edu, accessed: 2022-11-6.

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Refinements to SALO

Relaxation of the amplitude vector:

SALO-relax:
$$\arg\min_{A, \gamma, k, \phi} \sum_{j=0}^{T-1} \left\| \boldsymbol{\Delta}_{t_j} - A \mathbf{X}_{t_j} - \gamma \cos(2\pi k t_j / T + \phi) \right\|^2$$

Use of prior information.

Refinements to SALO

Relaxation of the amplitude vector:

SALO-relax:
$$\arg\min_{A,\gamma,k,\phi}\sum_{j=0}^{T-1} \left\| \boldsymbol{\Delta}_{t_j} - A \mathbf{X}_{t_j} - \gamma \cos(2\pi k t_j/T + \phi) \right\|^2$$

Use of prior information.

Thank you!

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Opimization landscape

1.5

1.0

-1.5

0.0

2.0



6.0

t [s]

8.0

10.0

4.0

Complex cases



00000

Complex cases



Informed SALO



Informed SALO-relax

