NASPI Work Group Virtual Meeting

Forced Oscillation Localization in ERCOT System through Synchrophasors

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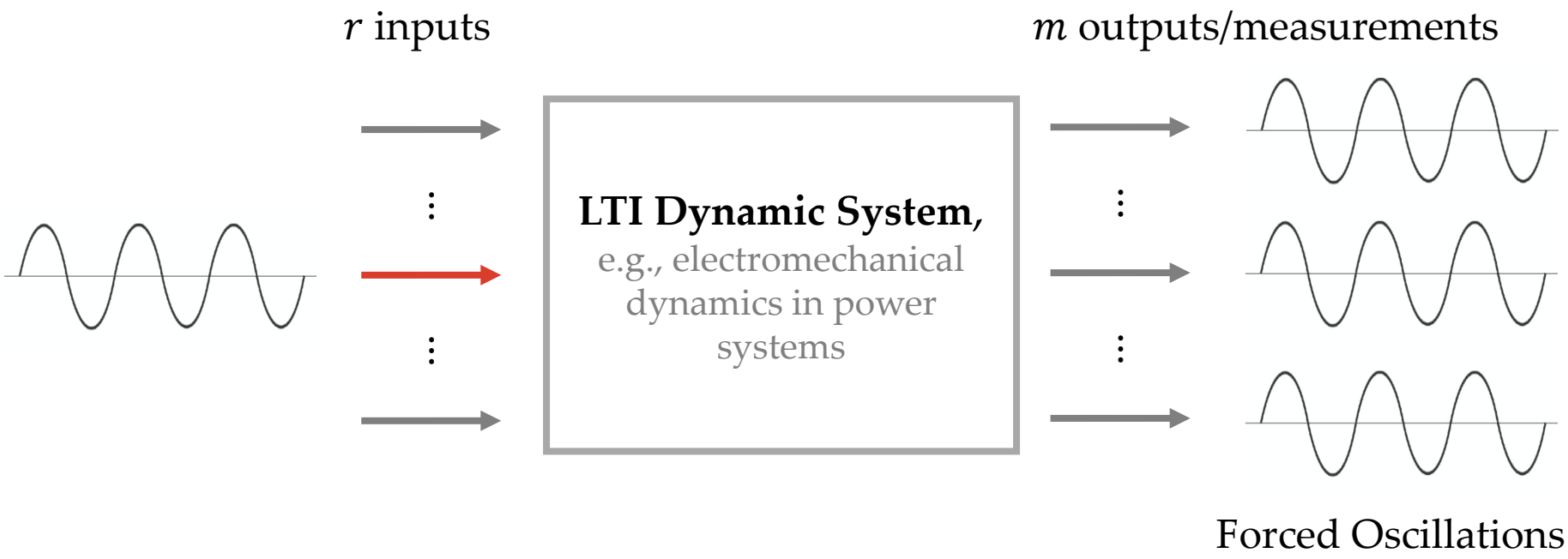
Joint work with Diran Obadina, Nemica Kadel, Jian Ma, Patrick Gravois, and Prabhu Gnanam at ERCOT and Prof. Le Xie at Texas A&M

Outline

- Forced Oscillation Localization (FOL)
- FOL Challenge
- Approach: Robust Principal Component Analysis
- Case Studies
- Physical Interpretation

Forced Oscillation Localization

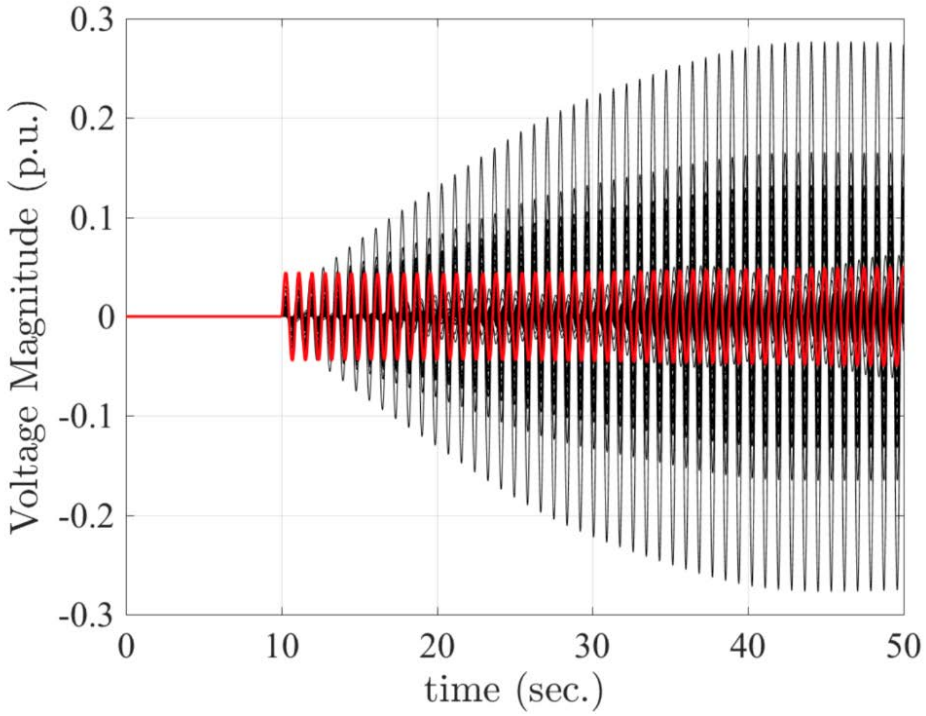


- Oscillation *source*: the input with periodic signal.
- Different measurements have different geographic locations.
- FOL: How to find the measurement near the source only by outputs?

T. Huang, N. Freris, P. R. Kumar and L. Xie, "A Synchrophasor Data-driven Method for Forced Oscillation Localization under Resonance Conditions," *IEEE Transactions on Power Systems, 2020*.

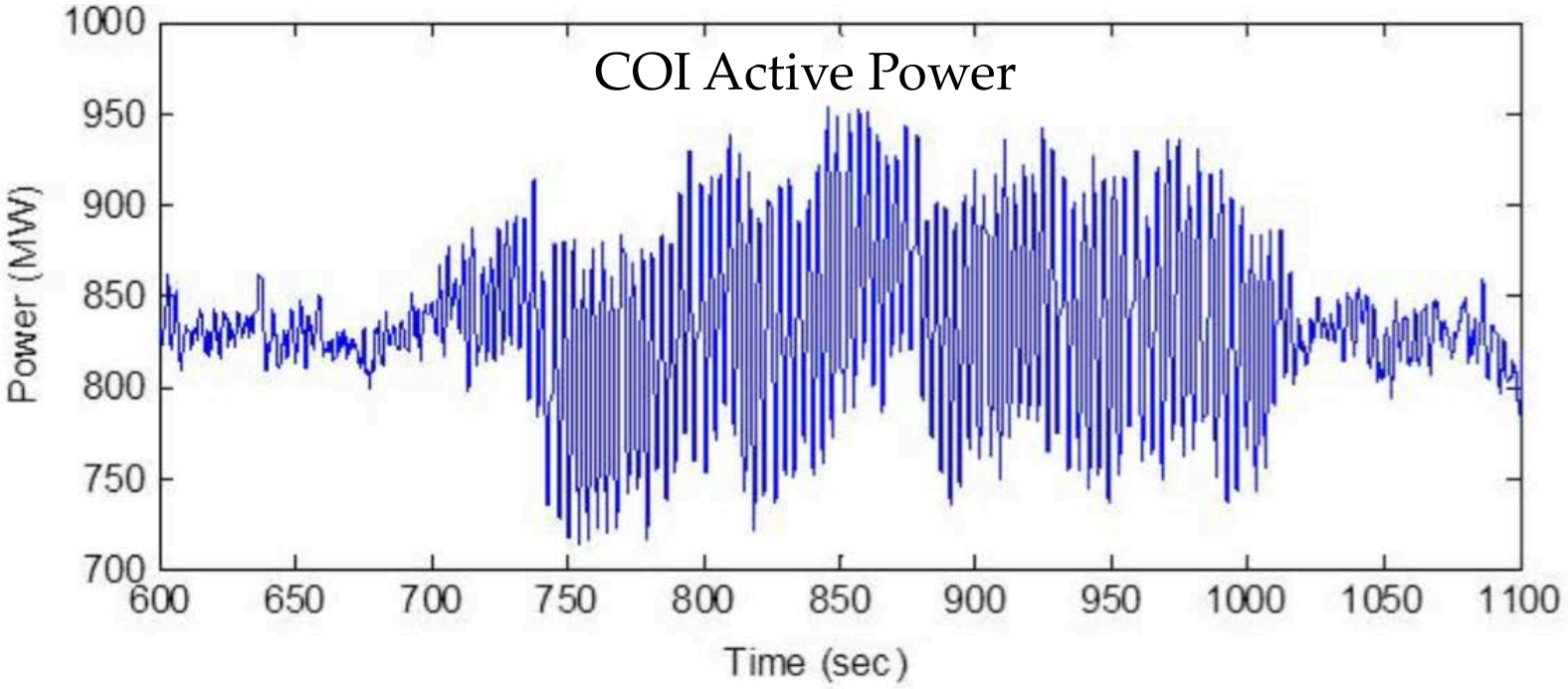
The Challenge of Source Localization

Challenges come when the injection frequency is near one of natural frequencies of the system, i.e., the resonance phenomena is triggered.



A resonance case: *source* measurement (**red**); the rest measurements (black)

Forced Oscillation under Resonance Condition in the Real-world Power System



- One power plant at Nova Joffre (source) has 20 MW (peak-to-peak) oscillations
- The California-Oregon Intertie (COI) has 200 MW oscillations, causing system islanding and blackout!
- The distance between these two places is 1100 miles

http://www.nerc.com/pa/RAPA/rg/ReliabilityGuidelines/Reliability_Guideline_-_Forced_Oscillations_-_2017.pdf

The Challenge of Source Localization

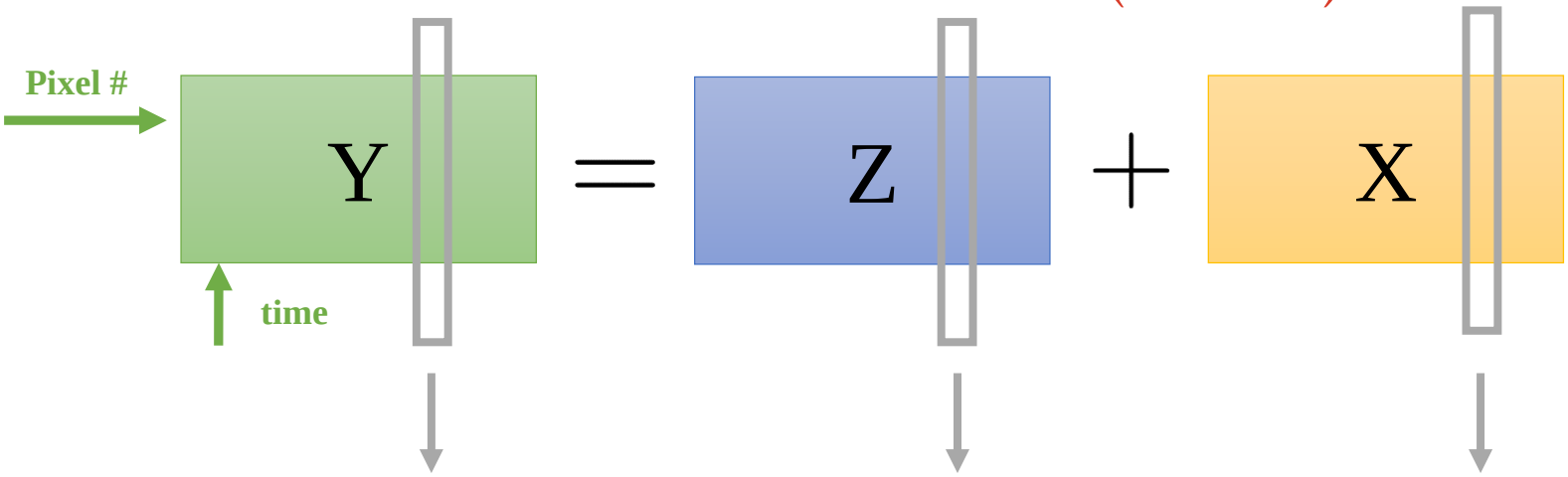
We need to develop an approach that can locate the oscillation source even when *resonance* happens!

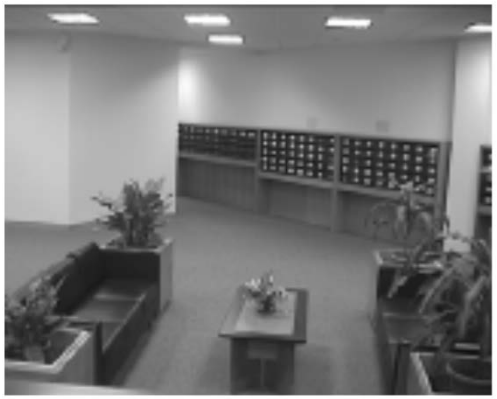
A Similar Problem: Background Modeling from Surveillance Video

A frame of the video

E. J. Cande`s, X. Li, Y. Ma, and J. Wright, "Robust Principal Component Analysis?" Journal of the ACM (JACM), vol. 58, no. 3, p. 11.

A Similar Problem: Background Modeling from Surveillance Video (Cont.)



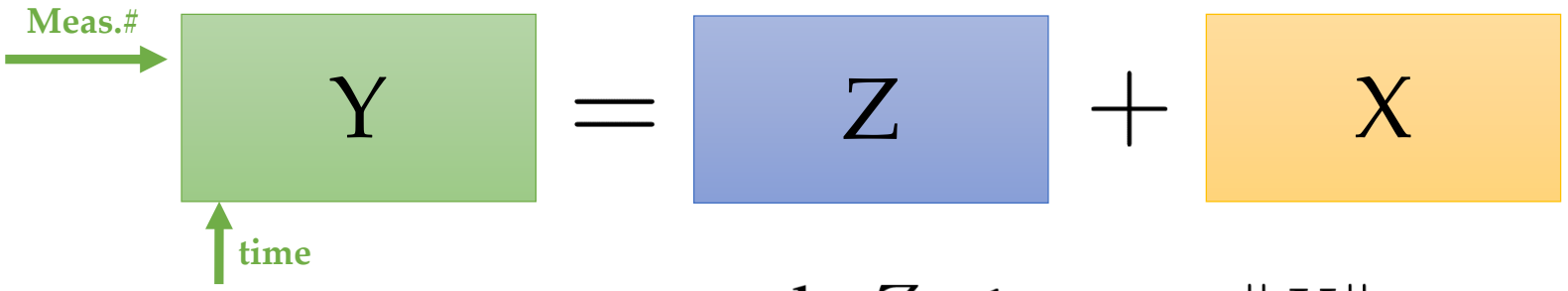


Background

Foreground

E. J. Cande`s, X. Li, Y. Ma, and J. Wright, "Robust Principal Component Analysis?" Journal of the ACM (JACM), vol. 58, no. 3, p. 11.

Localization of Oscillation: Observations

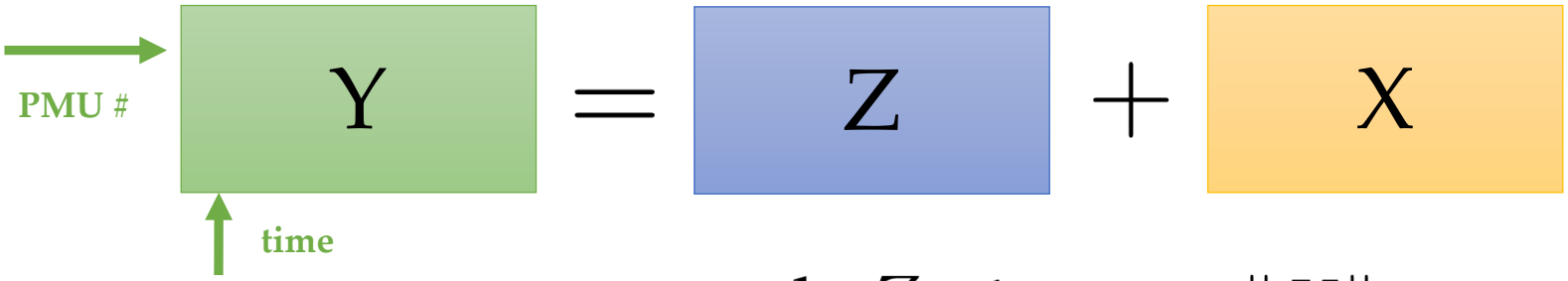


- Measurements should be correlated with each other and exhibit a *"general trend"*.
- The measurement near the source should *deviate most* from the *"general trend"*.

T. Huang, N. Freris, P. Kumar, and L. Xie, "Localization of Forced Oscillation in the Power Grid under Resonance Conditions," *52th CISS*, 2018

Problem Formulation

How to decompose a measurement matrix Y into a *low-rank* matrix Z and a *sparse* matrix X?



Problem Formulation: Robust PCA

How to decompose a measurement matrix Y into a *low-rank* matrix Z and a *sparse* matrix X?

$$Y = Z + X$$

$$\operatorname{rank} Z \leq r$$

$$\|X\|_0 \leq p$$

- Non-convex
- r and p are unknown

$$\min_X \|Y - X\|_\star + \lambda \|X\|_{1,1}$$

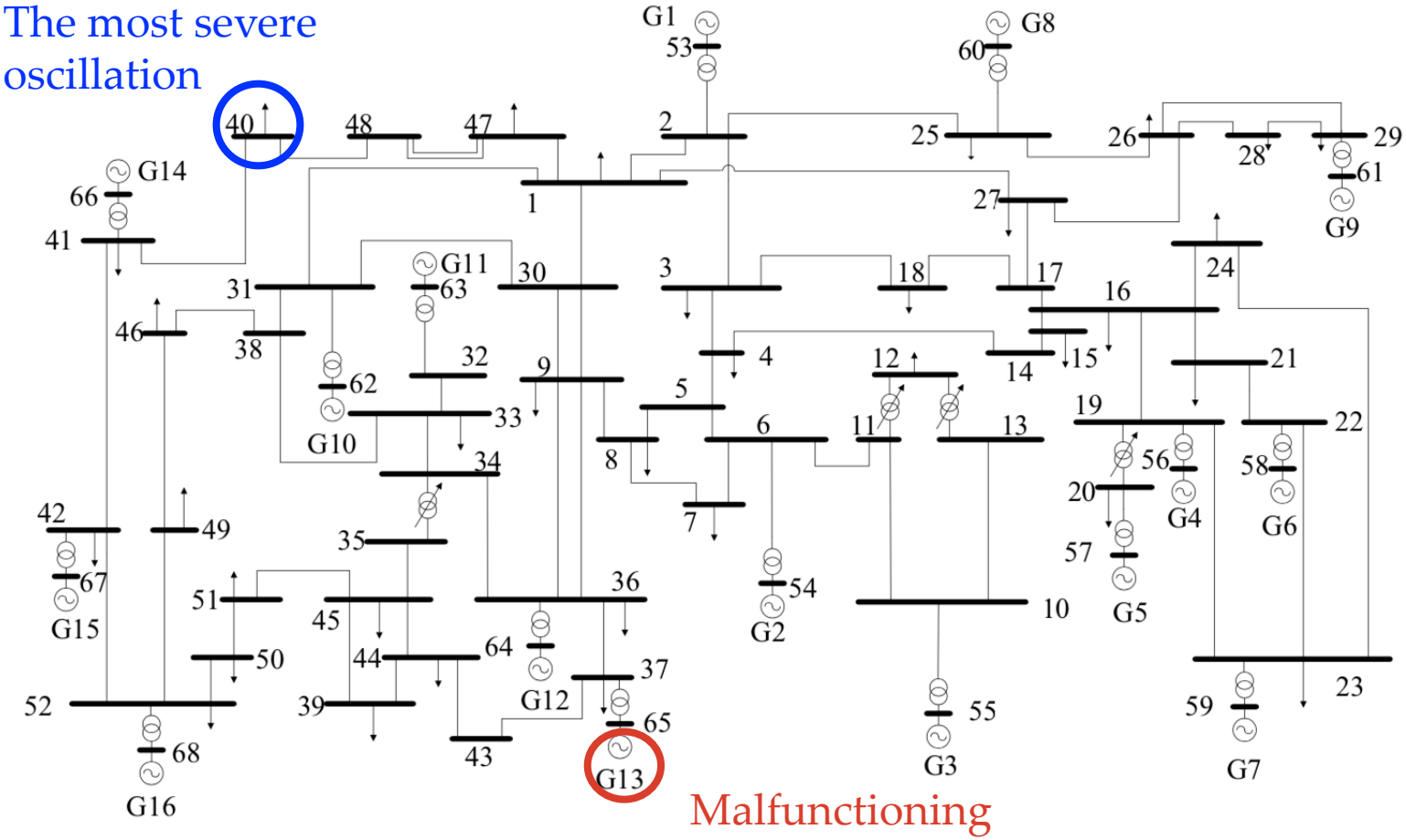
- *Convex* optimization
- No need to know r and p
- Efficient Algorithms to solve it
- $\lambda = 1/\sqrt{n_0}$, where n_0 is col. #of Y

PCA: Principal Component Analysis
Augment Lagrange Multiplier (ALM)
http://perception.csl.illinois.edu/matrix-rank/sample_code.html

T. Huang, N. Freris, P. R. Kumar and L. Xie, "A Synchrophasor Data-driven Method for Forced Oscillation Localization under Resonance Conditions," *IEEE Transactions on Power Systems, 2020* (accepted).

FO Localization in the Power Grid

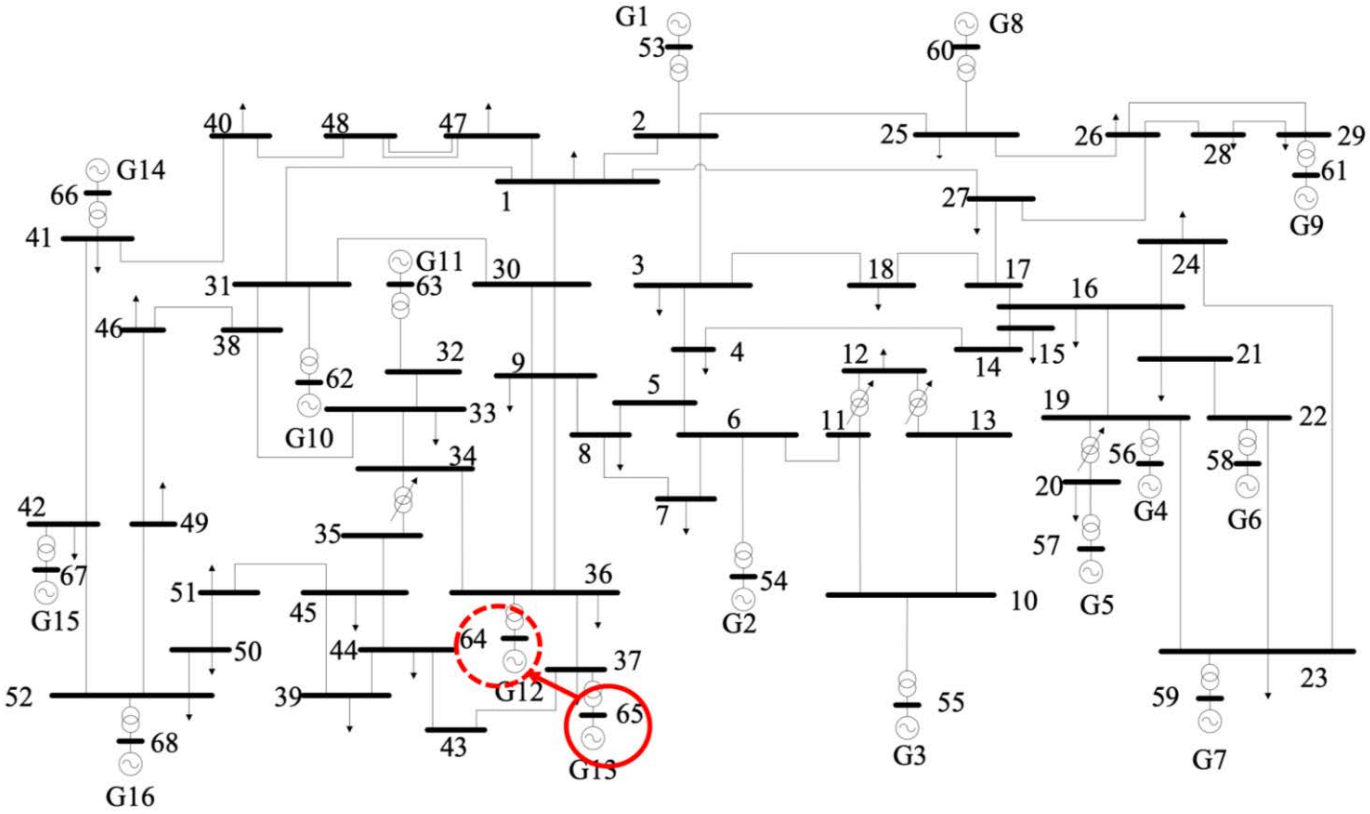
The most severe oscillation



Malfunctioning Generator

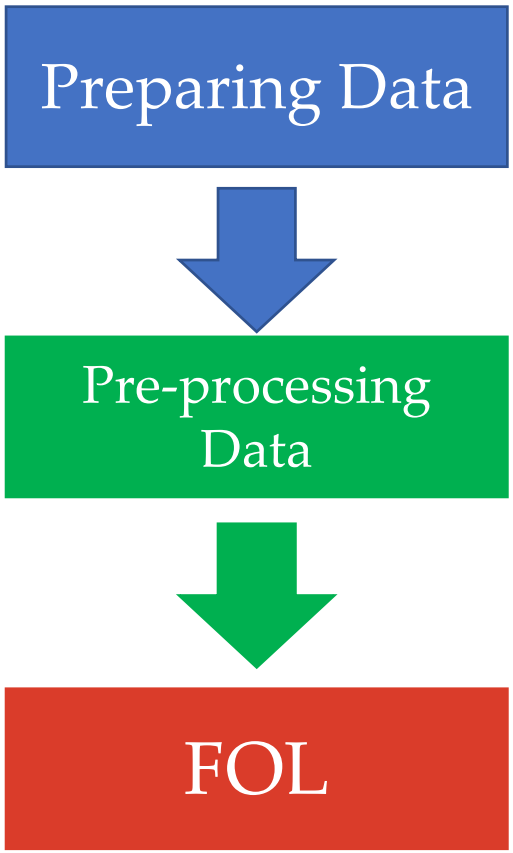
- 44 *counter-intuitive* cases

Performance in the 68-bus Systems



- Over ***97.73%*** (43/44) accuracy even under the *resonance* cases;
- The seemingly wrong results can effectively narrow the searching space.

ERCOT FOL Tool: Overview

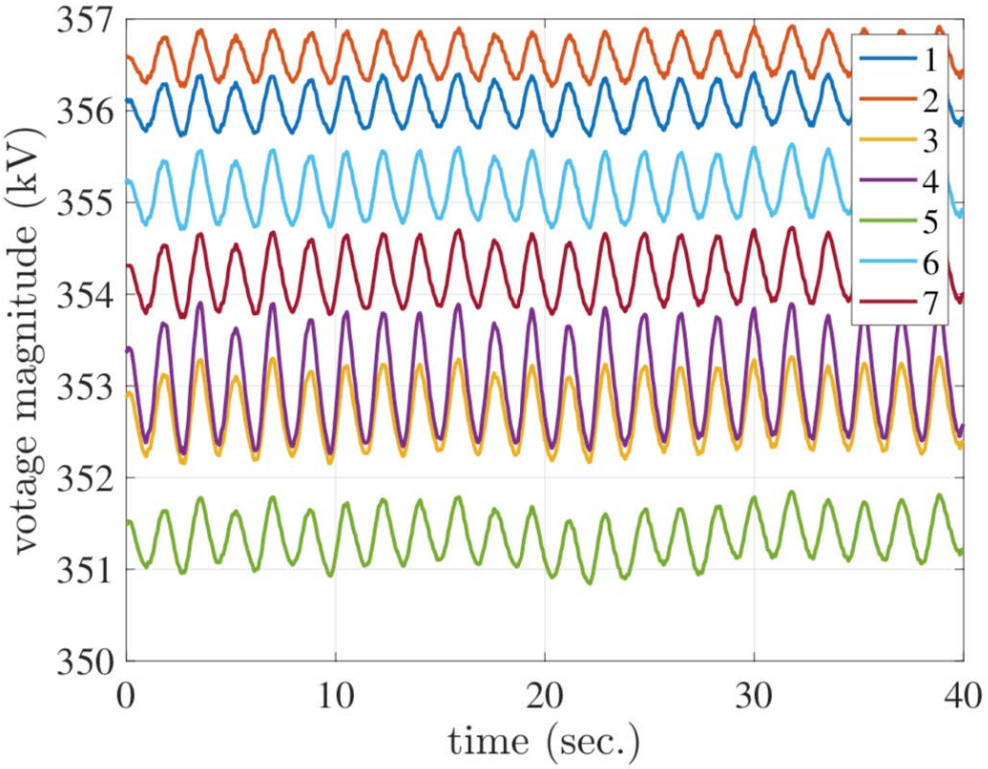


Convert PMU data into matrix form

Select data of interest
Filtering

FOL based on RPCA

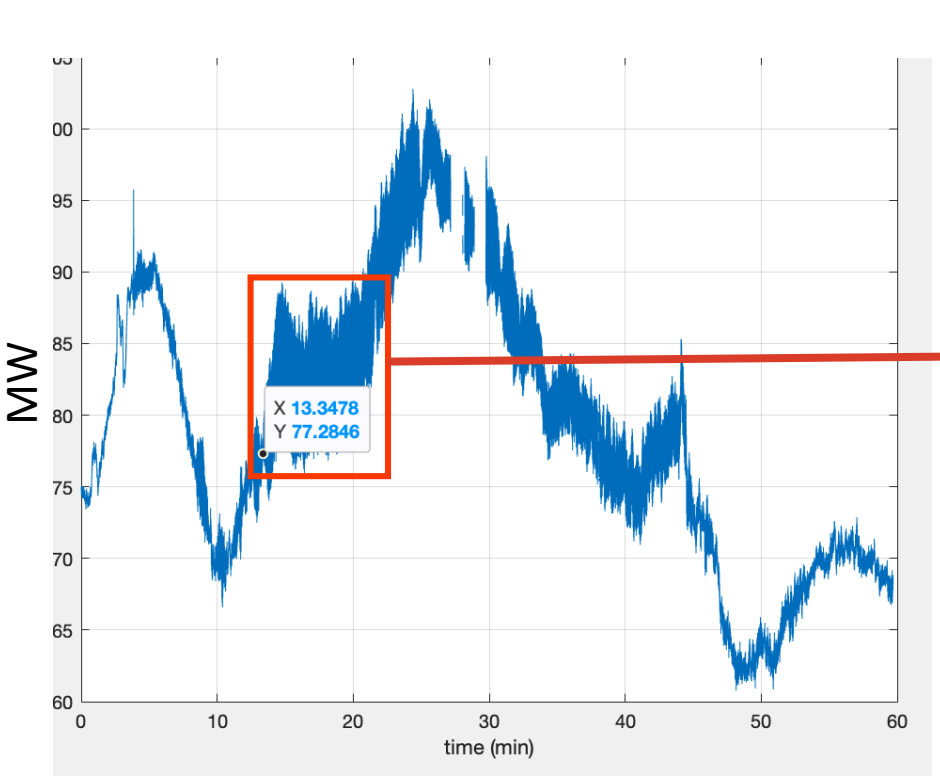
Case Study: ERCOT Event 1

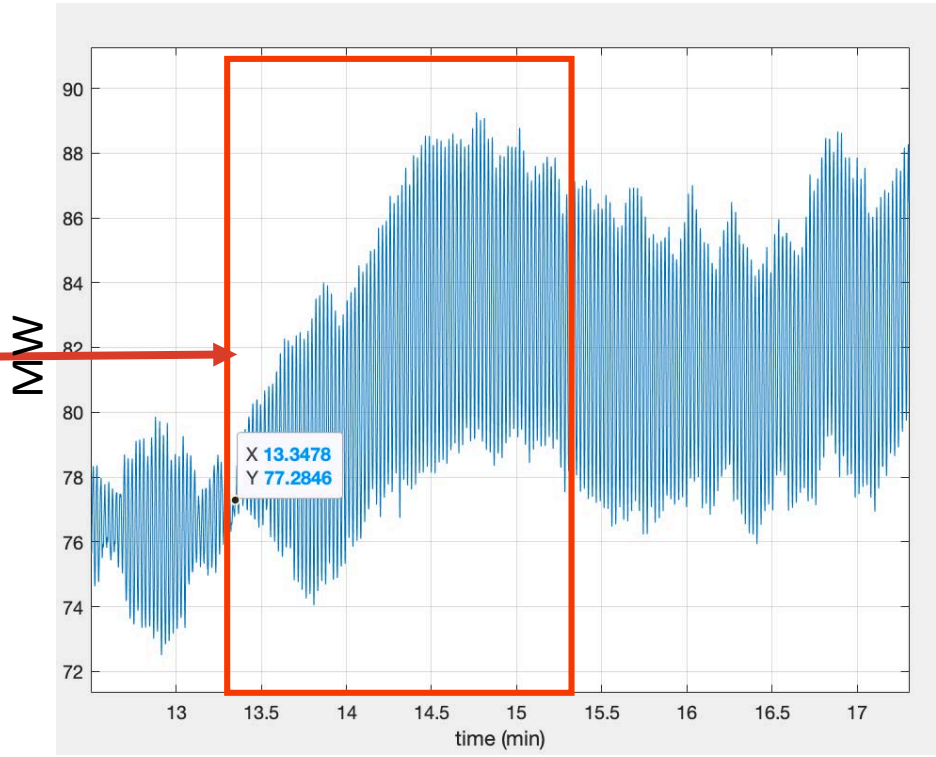


- We use a 20-second time window of raw data provided by ERCOT
- A band-pass filter (0.1-2Hz) is applied
- The algorithm suggests PMU 4 is the one near the source

T. Huang, N. Freris, P. R. Kumar and L. Xie, "A Synchrophasor Data-driven Method for Forced Oscillation Localization under Resonance Conditions," *IEEE Transactions on Power Systems, 2020* (accepted).

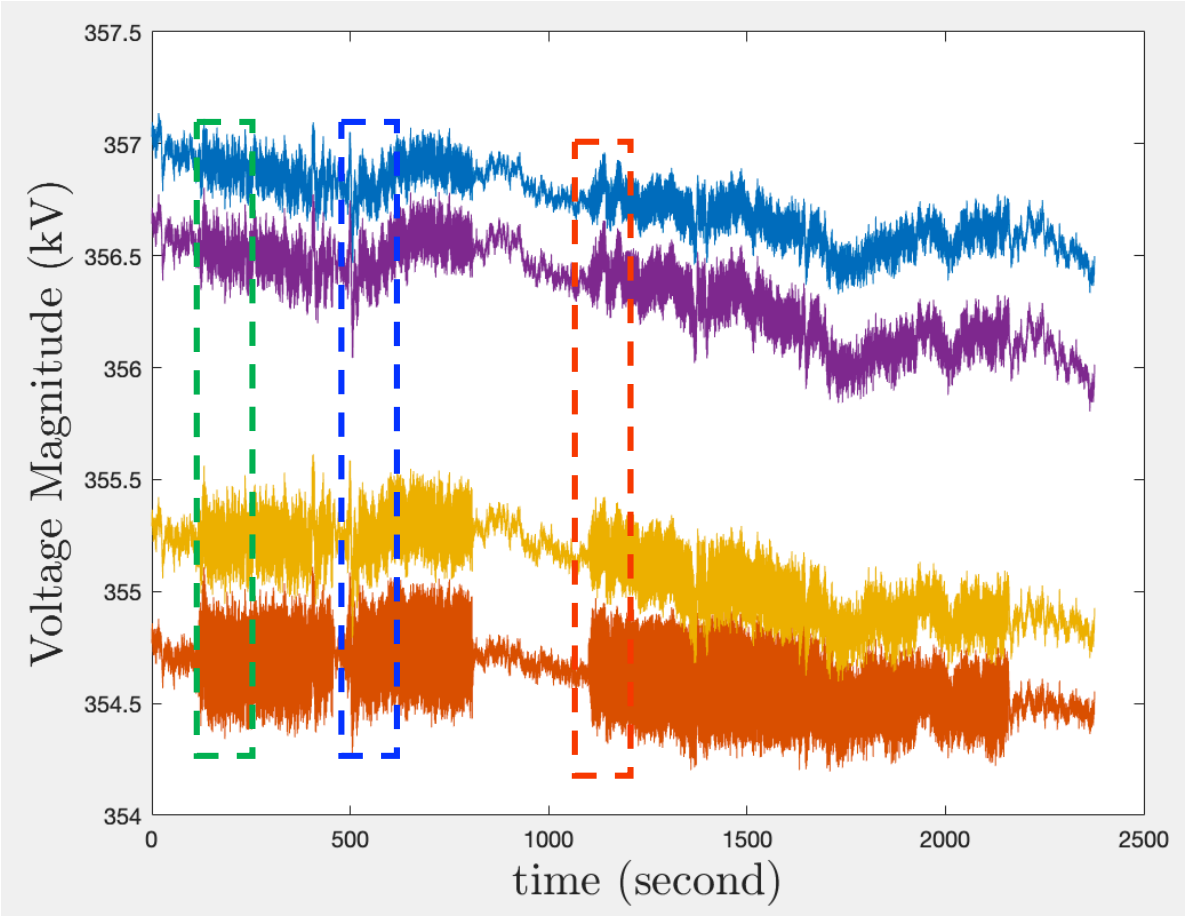
Case Study: ERCOT Event 2

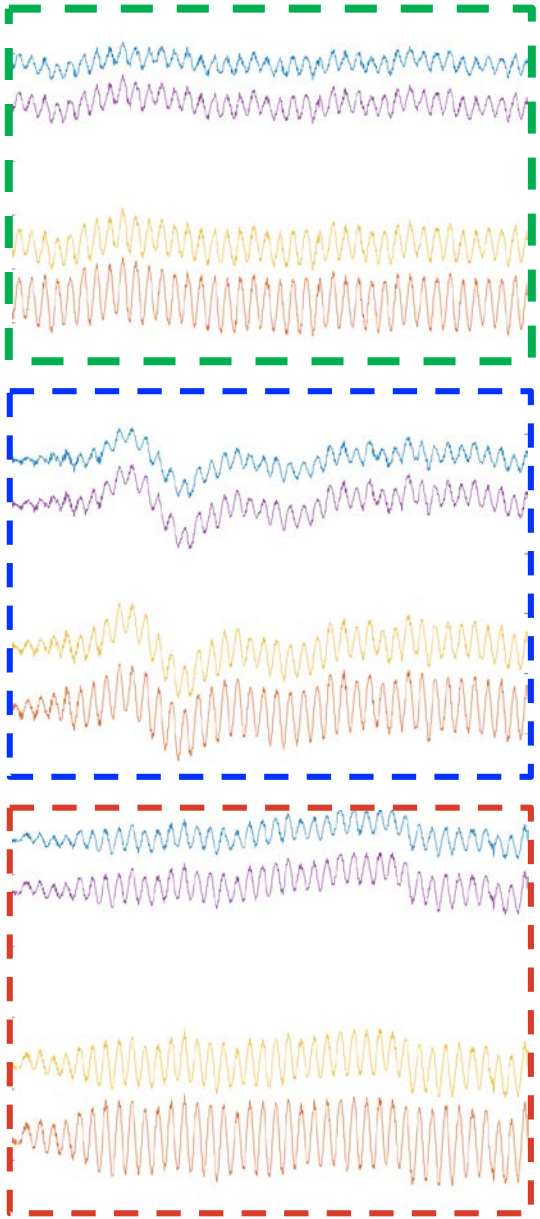




- Using real power measurement from 14 PMU
- A band-pass filter (0.1-2Hz) is applied
- The algorithm can identify the source

Case Study: ERCOT Event 3

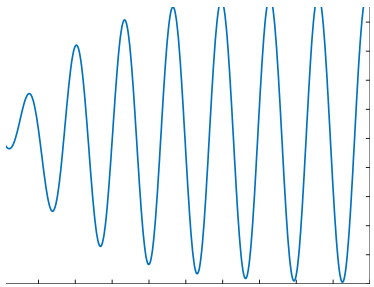




FO Localization: One Possible Interpretation

Physical Analysis

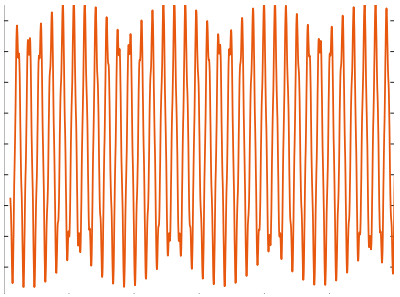
$$y_k(t) =$$



Resonance

"Rank 2"

$+$



Resonance-free

Source location info.

Theorem: *For a linear time-invariant dynamical system, the resonance matrix has rank 2.*

T. Huang, N. Freris, P. R. Kumar and L. Xie, "A Synchrophasor Data-driven Method for Forced Oscillation Localization under Resonance Conditions," *IEEE Transactions on Power Systems, 2020* (accepted).

FO Localization: One Possible Interpretation

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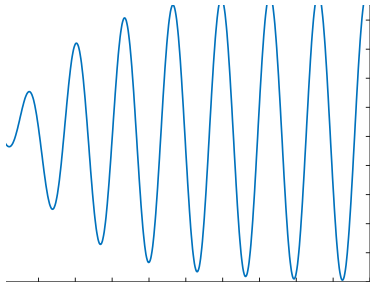
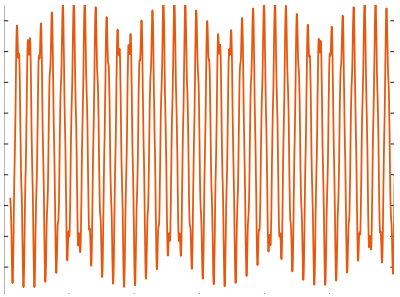


Resonance

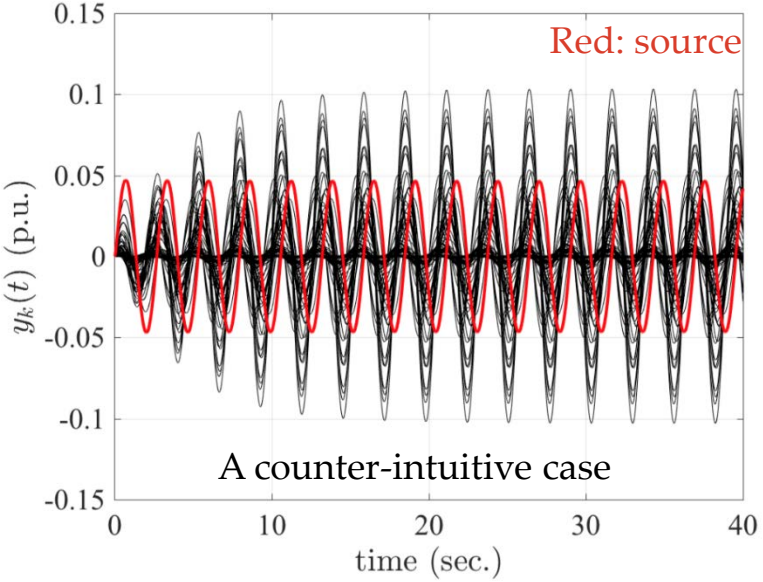
"Rank 2"

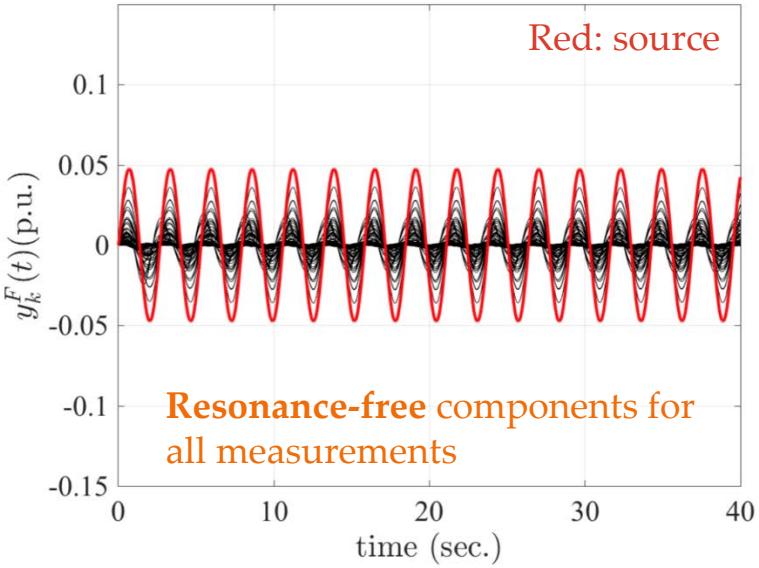
+



Resonance-free

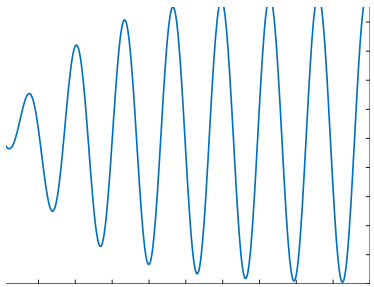
Source location info.





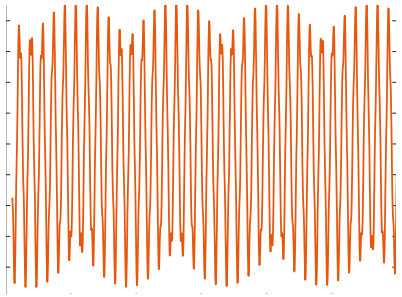
FO Localization: One Possible Interpretation

$$y_k(t) =$$



Resonance

$+$



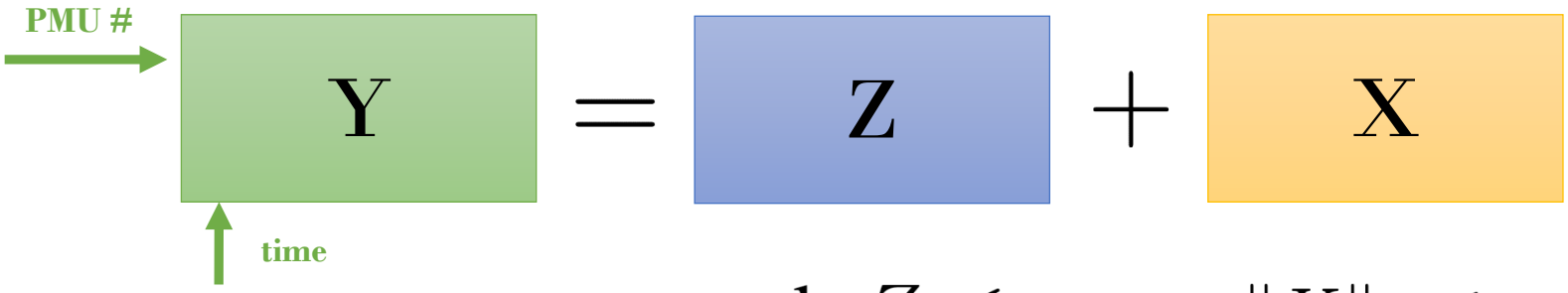
Resonance-free

Physical Analysis

"Rank 2"

Source location info.

Purely Data-driven method



$\text{rank } Z \leq r$ $\qquad$ $\|X\|_0 \leq p$

Conclusion

- A data-driven approach to forced oscillation localization
- FOL tool development in ERCOT
- Algorithm test using realistic events in ERCOT system
- Physical interpretation of the algorithm
- Future work will test the tool in conjunction with event detection/classification algorithms.

Acknowledgement

We would like to thank Diran Obadina, Nemica Kadel, Jian Ma, Patrick Gravois, and Prabhu Gnanam at ERCOT for offering test cases and valuable suggestions.

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