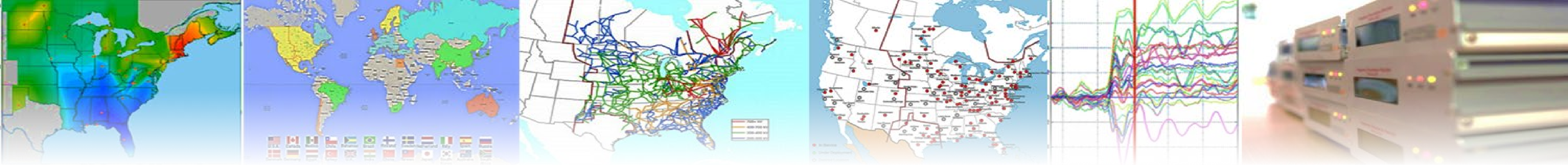

Locate the Source of Resonance-Involved Forced Oscillation in Power Systems Based on Mode Shape Analysis

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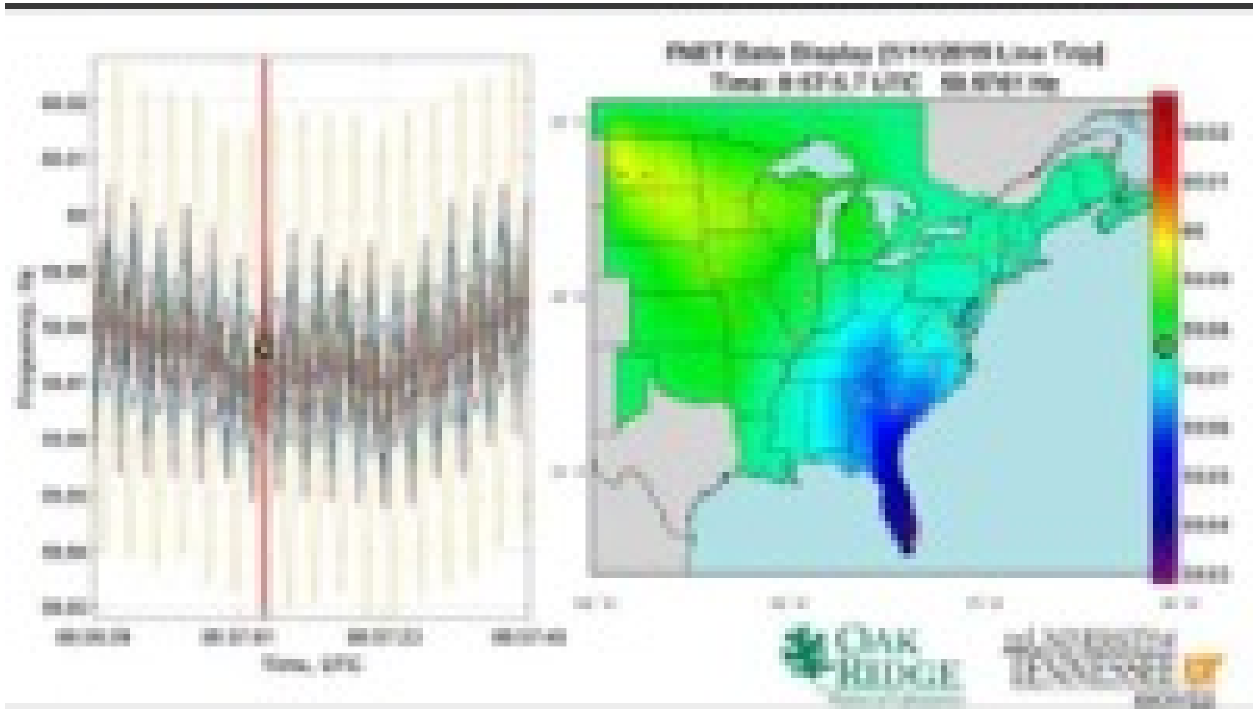
Locate the Source of Resonance-Involved Forced Oscillations

- This study proposed a new method to locate the source of forced oscillation that involves resonance with natural oscillation modes.
  - The new method is based on **comparing the oscillation mode shape of the forced oscillation with that of the natural oscillation** that the forced oscillation resonates with.
  - The oscillation source is the location that has the largest angle difference between the forced oscillation mode and the natural oscillation mode.
  - Two oscillation cases in the actual U.S. EI system verified this approach.

Forced Oscillation

- Forced oscillations are usually caused by malfunctions of controls. They are typical shown as persistent oscillations in system with nearly zero damping.
- Locating the source of forced oscillations may be challenging, because in some cases, the location with the largest oscillation amplitude is not the actual oscillation source.
  - This phenomenon is more common if the oscillation driving force has an oscillatory frequency close to the natural oscillation mode of a system, which often involves resonance.



Jan 11, 2019 EI oscillation video

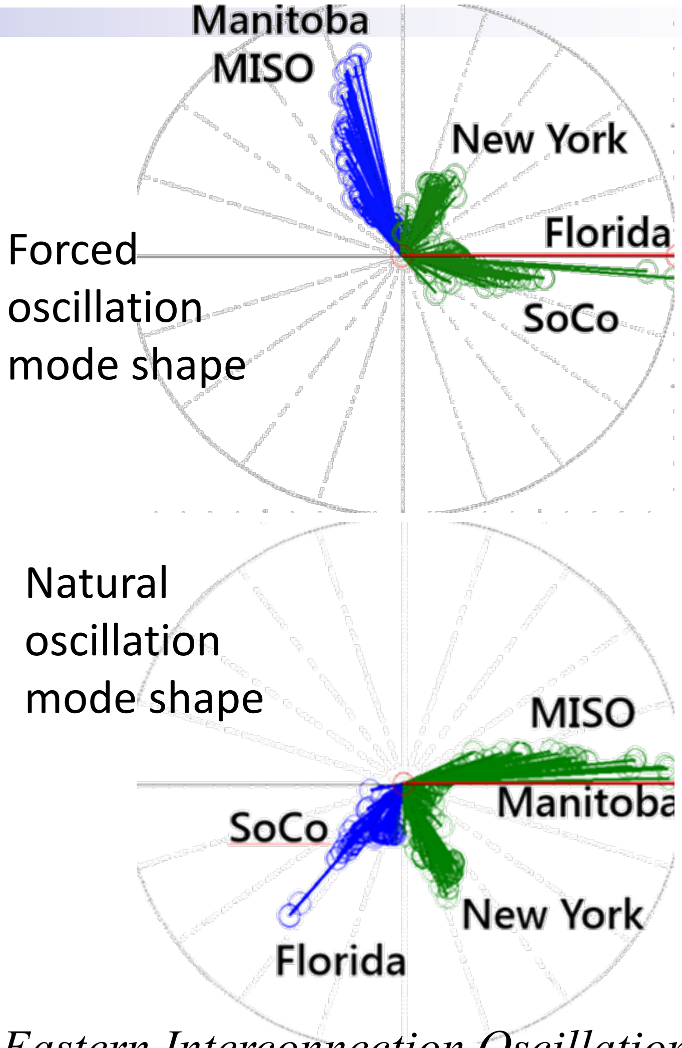
Resonance-Involved Forced Oscillations

- Resonance-involved forced oscillations are oscillations that have a driving force to make the system oscillate around natural oscillation modes. The driving force frequency of such forced oscillations is close to the frequency of a natural oscillation.

- Intuitive theoretical foundation for the proposed method.
  - Their (forced and natrual) oscillation mode shapes would also be very similar, except for that the mode phase angle near the driving force location will be leading its original angle (in the natural oscillation) due to the driving force that consistently feeds energy to sustain oscillation.

Locate the Source of Resonance-Involved Forced Oscillations Based on Mode Shape Analysis

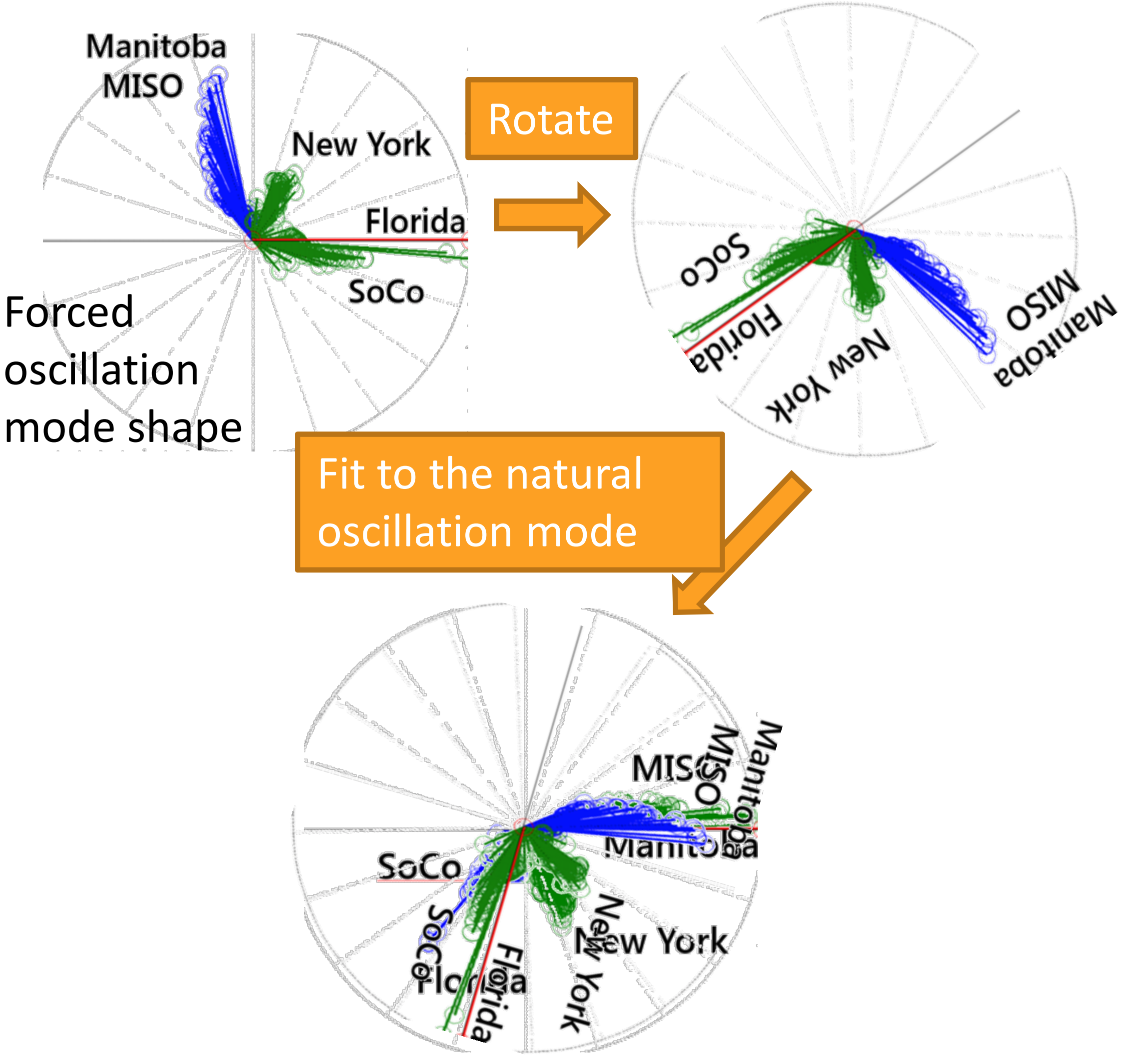
- Approach – Use Jan 11, 2019 EI forced oscillation as an example.
  1. Plot the oscillation mode shape based on measurement from multiple PMUs at different locations.
  2. Set a threshold of the magnitude to select the PMU frequency data that have relatively large oscillation magnitudes.



Ref. [1]. NERC, *Eastern Interconnection Oscillation Disturbance -- January 11, 2019 Forced Oscillation Event*. December 2019.

Locate the Source of Resonance-Involved Forced Oscillations Based on Mode Shape Analysis

3. The mode shape angles of the selected PMUs in the forced oscillation are <u>rotated by a constant angle to maximize its fitness with the mode shape angles of the natural oscillation that the forced oscillation resonates against</u>.



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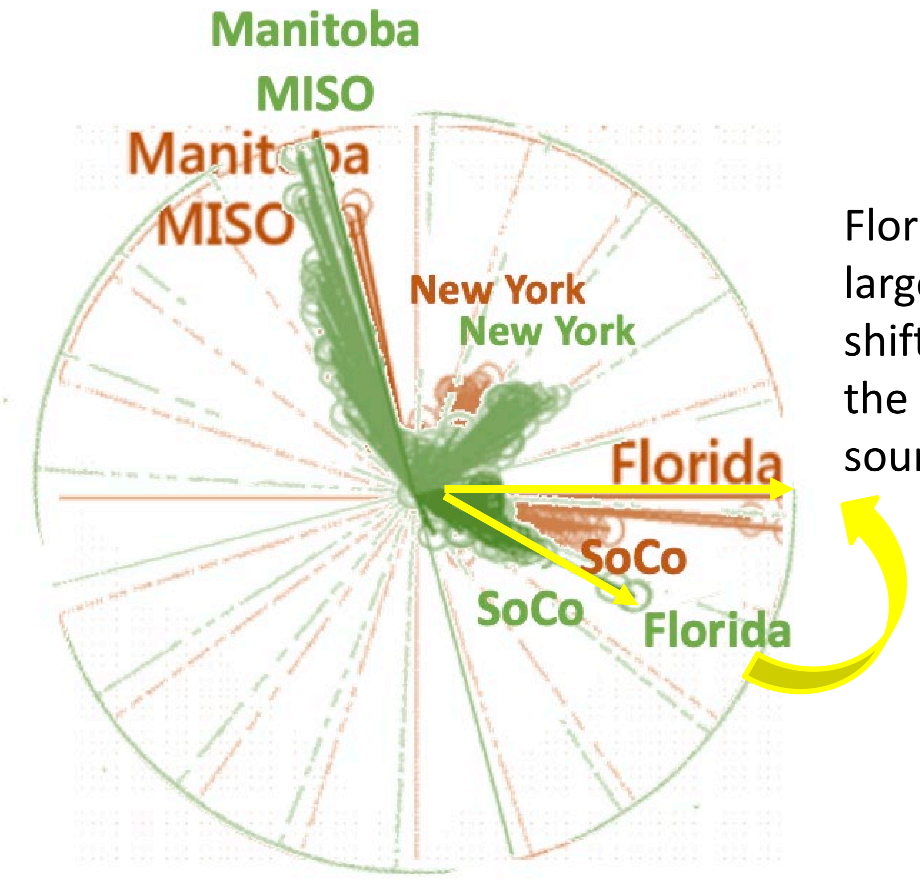
Locate the Source of Resonance-Involved Forced Oscillations Based on Mode Shape Analysis

4. Check large angle differences between the forced oscillation and the natural oscillation mode shapes.

- <u>If one angle difference is significantly larger than the rest, then the location of this PMU data is the location of the oscillation source</u>.
- If several locations have comparable angle differences among the largest, then the forced oscillation source can be obtained using a triangulation method based on the angle difference values.



Florida has the largest angle shift, indicating the oscillation source.

Compare forced oscillation and natural oscillation mode shapes

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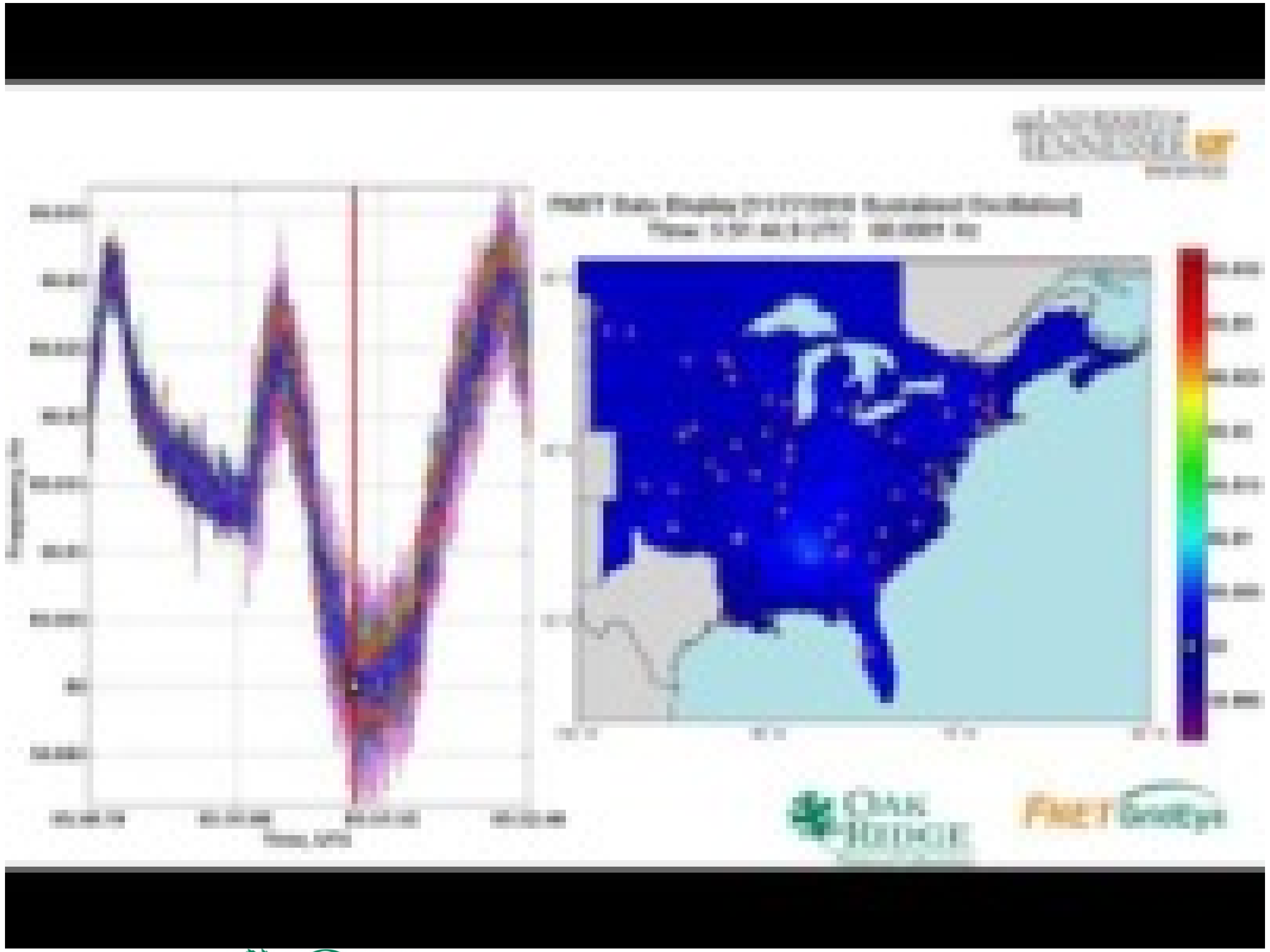
Case Study 2 -- EI Forced Oscillation on Nov 27, 2016

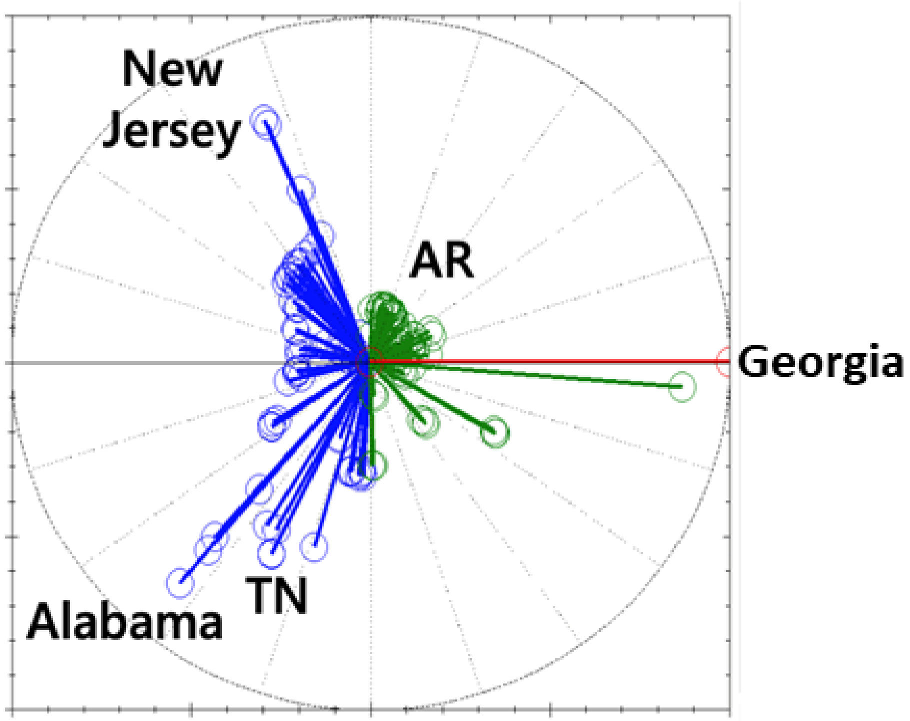
- The EI forced oscillation event happened on Nov 27, 2016. (~0.7Hz).



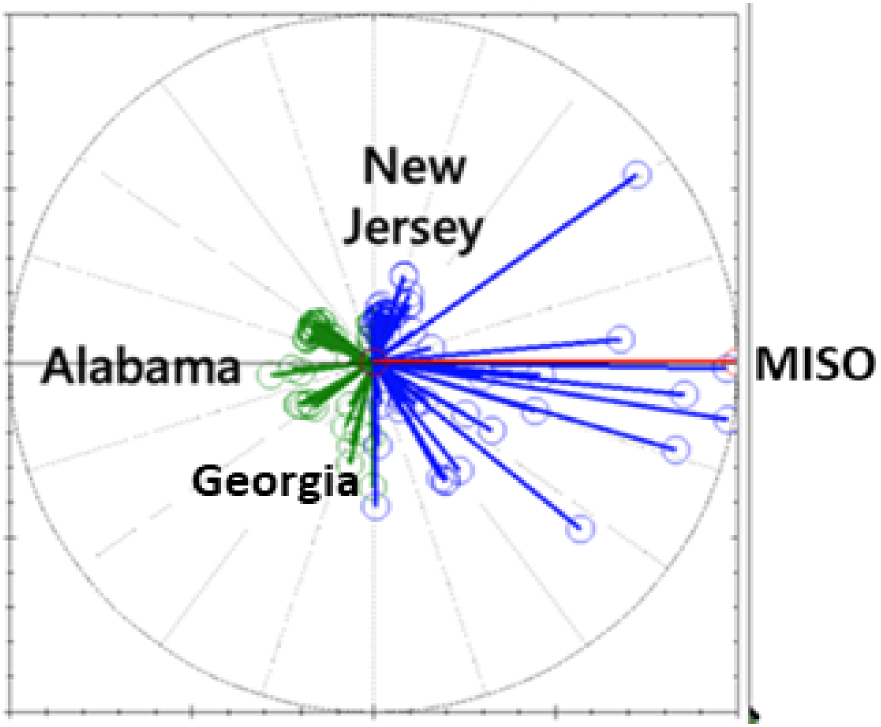
Video of EI Forced Oscillation Nov 27, 2016

Case Study 2 -- EI Forced Oscillation on Nov 27, 2016

- Oscillation mode shapes of forced and natural oscillations



The **forced** oscillation mode shape at ~0.7 Hz

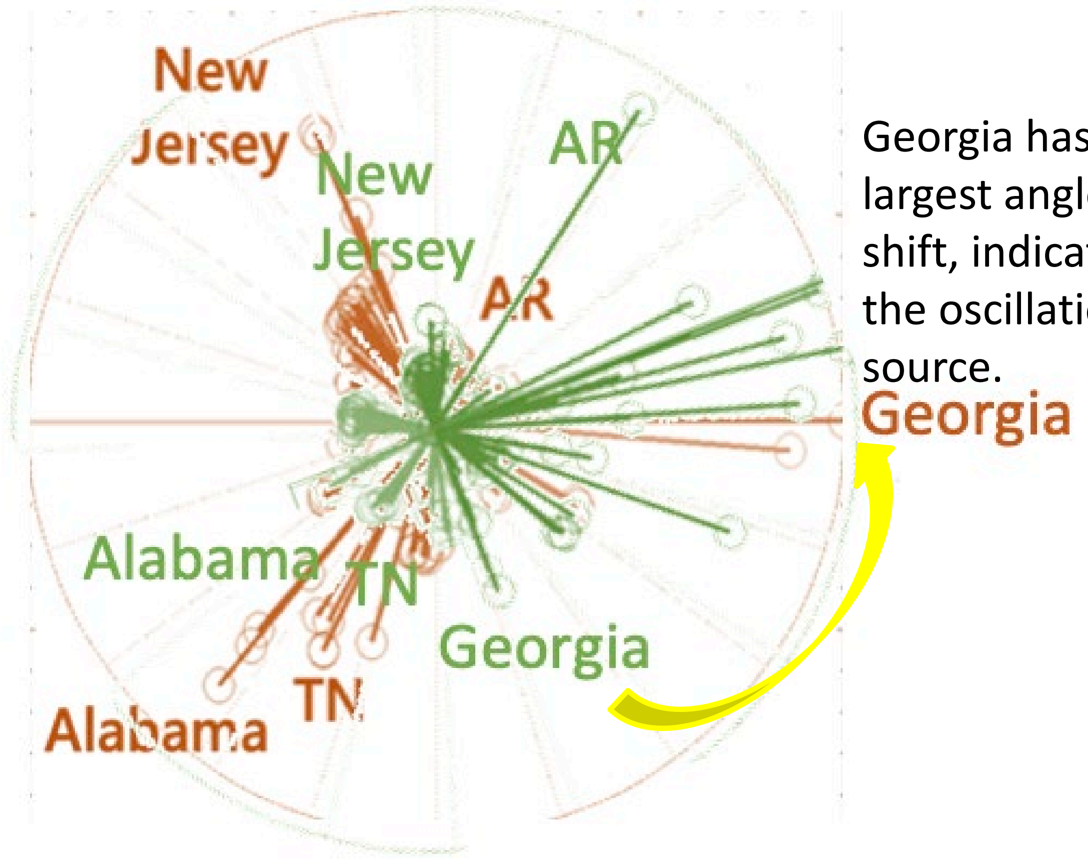


The **natural** oscillation mode shape at ~0.7 Hz

Ref [2]. Venkatasubramanian, M., *Analysis of November 27, 2016 Eastern Interconnection Event - Preliminary report*. 2017.

Case Study 2 -- EI Forced Oscillation on Nov 27, 2016

- Aligning up the two oscillation modes, Georgia has the largest angle difference between the forced and the natural oscillation mode shapes.
- The utility companies also confirmed that the source of this forced oscillation event was in Georgia.



Georgia has the largest angle shift, indicating the oscillation source.

Summary and future work

- Summary
  - This study proposed an oscillation source location method to find the location of the driving source of a forced oscillation that involves resonance with natural oscillation modes.
  - The method is based comparing the oscillation mode shape of the forced oscillation with that of the natural oscillation.
- Future work
  - More rigorous theoretical and quantitative analysis
  - Improve the accuracy performance by considering system power flow and dynamics.

Thanks !

Q&A