

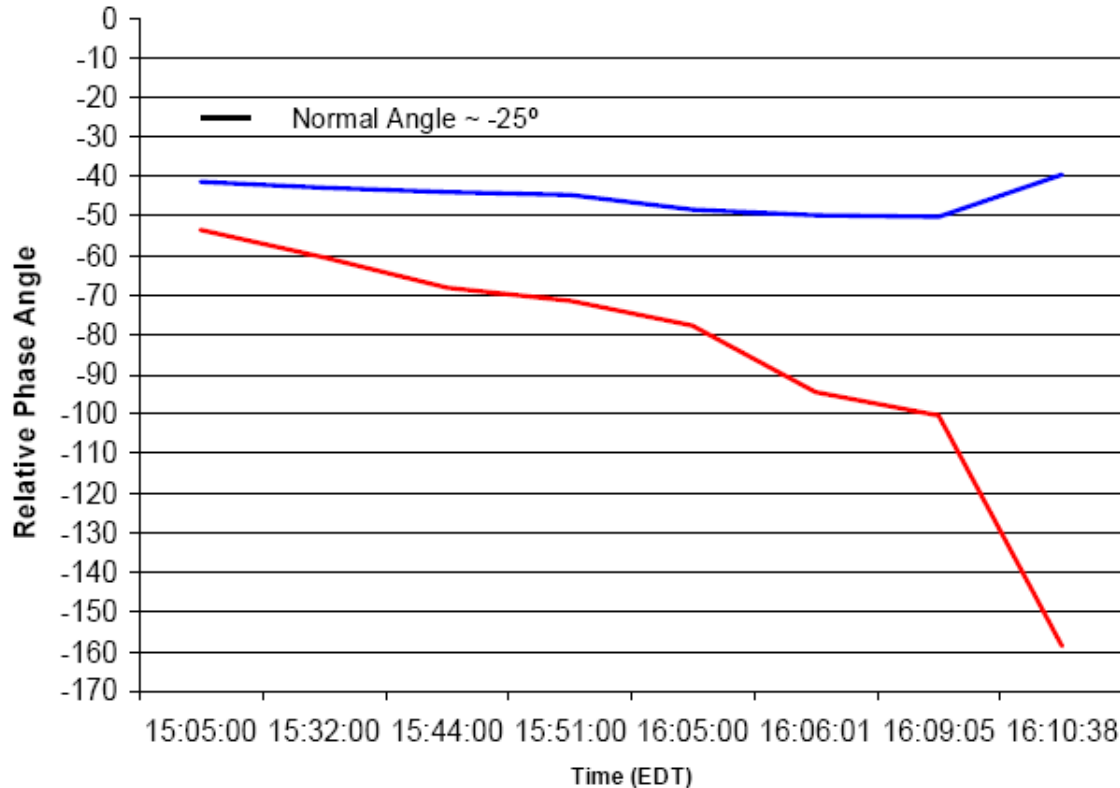
Issues Associated with the Visualization and Significance of Bus Phase Angles for the Eastern Interconnect



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A Motivation: 8/14/03 Angle Separation



Reference:

Browns Ferry

— Cleveland — West MI

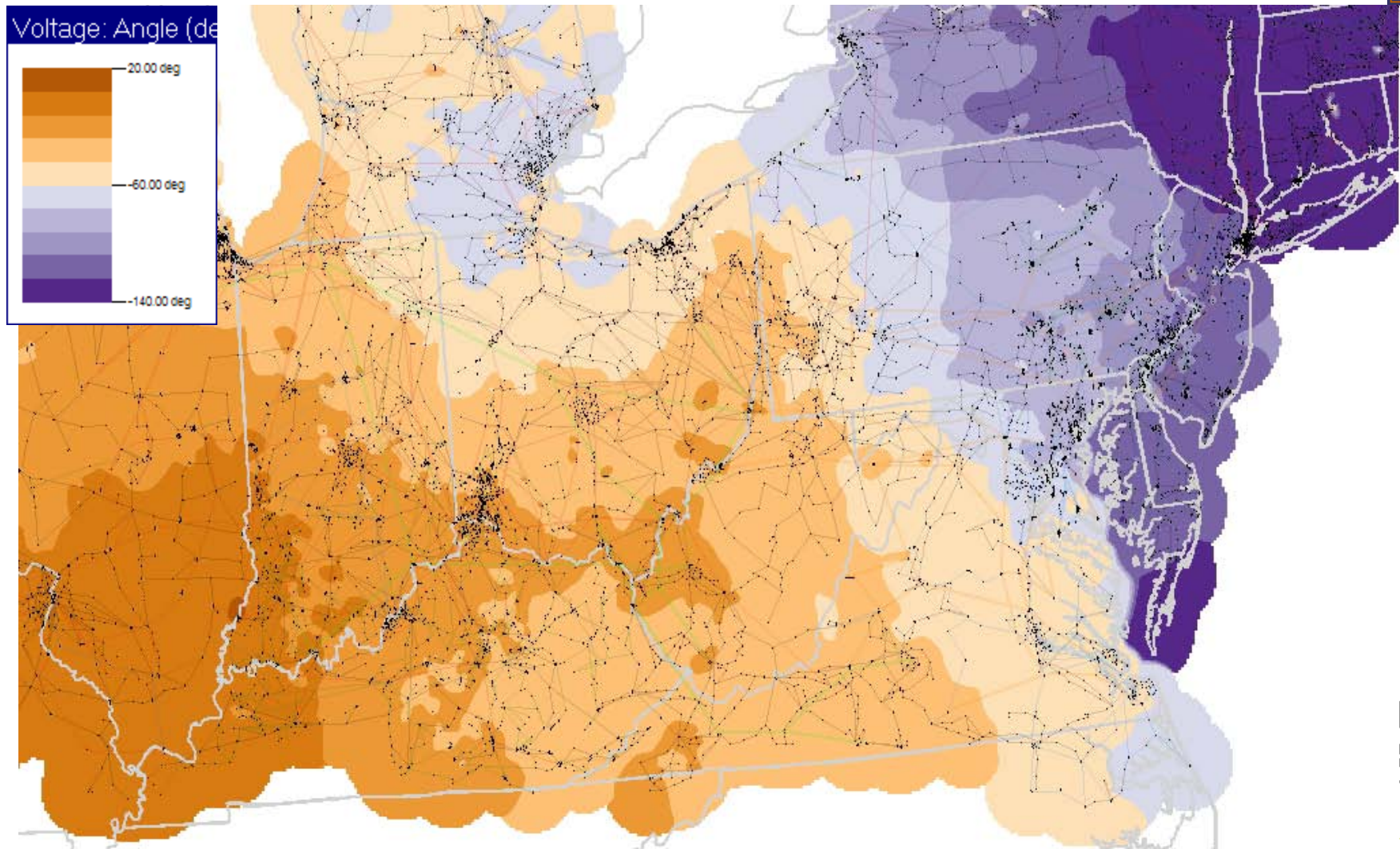
Slide source: Robert Cummings (NERC) November 29, 2007
PMU Overview and Update Presentation

Slide at left indicates that during the 8/14/03 event there was a significant angle separation between Cleveland and Western MI. But it also raises some interesting research questions

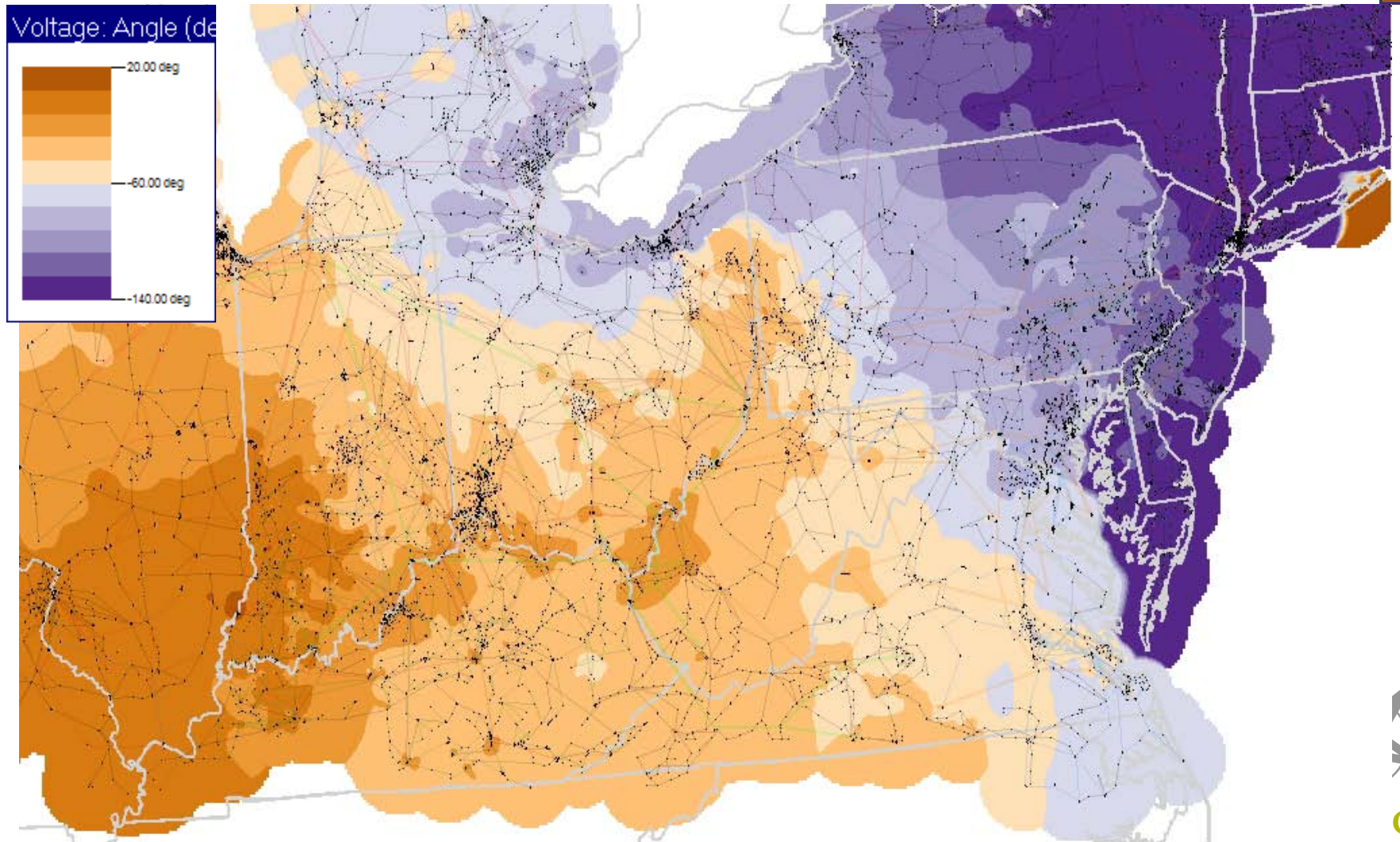


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Bus Angle Visualization: 8/14/03 Day Ahead Model



Bus Angle Visualization: 8/14/03 16:05 EDT (Reconstructed)



What Does A Bus Angle Indicate?

- Straightforward (if we allow for a dc power flow approximation): $\theta = \mathbf{B}^{-1} \mathbf{P}$
 - Incremental variations similar for full ac case
- The equation indicates that the angle at a particular bus is the vector product of a row of the inverse of the B matrix with the net power injection vector \mathbf{P} .
- While the B matrix is sparse, its inverse is not.
- Angles are given with respect to a system reference, Brown's Ferry here (18137)



Example: In NERC 2008 Summer Case Angle at 36406 (Wempleton 345 in Northern IL) is -25.2°

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Impact on 36406

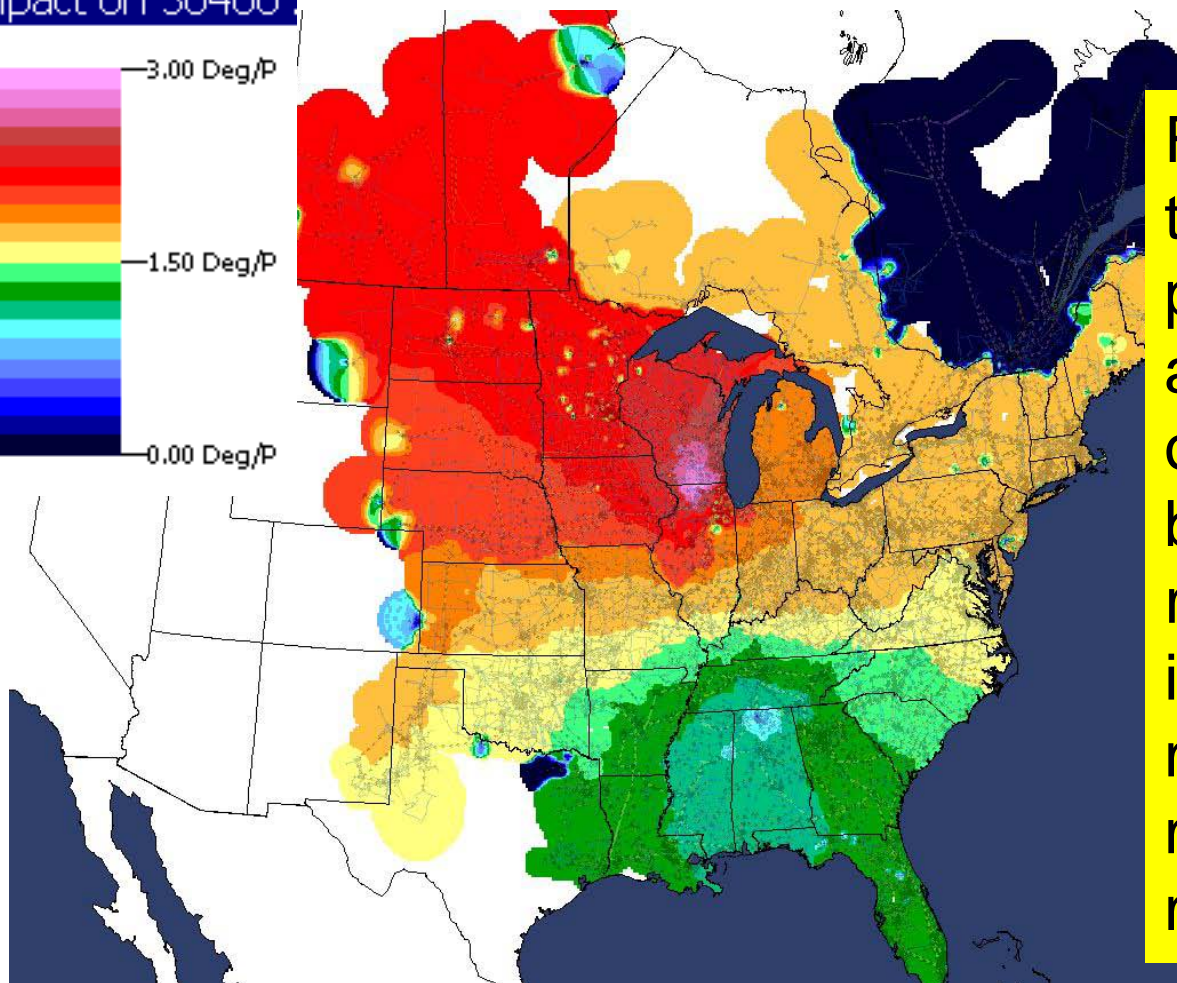
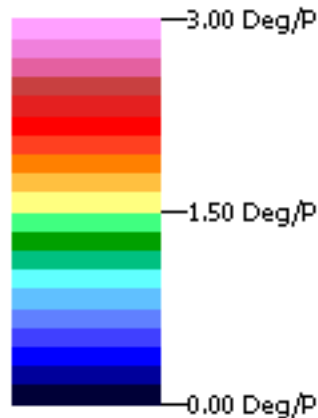


Figure contours the impact of power injections at different locations on the angle at bus 36406 (i.e., a row from the inverse of the B matrix). Note most locations matter!

Angle Difference Between Wempleton and Burnham 345 kV

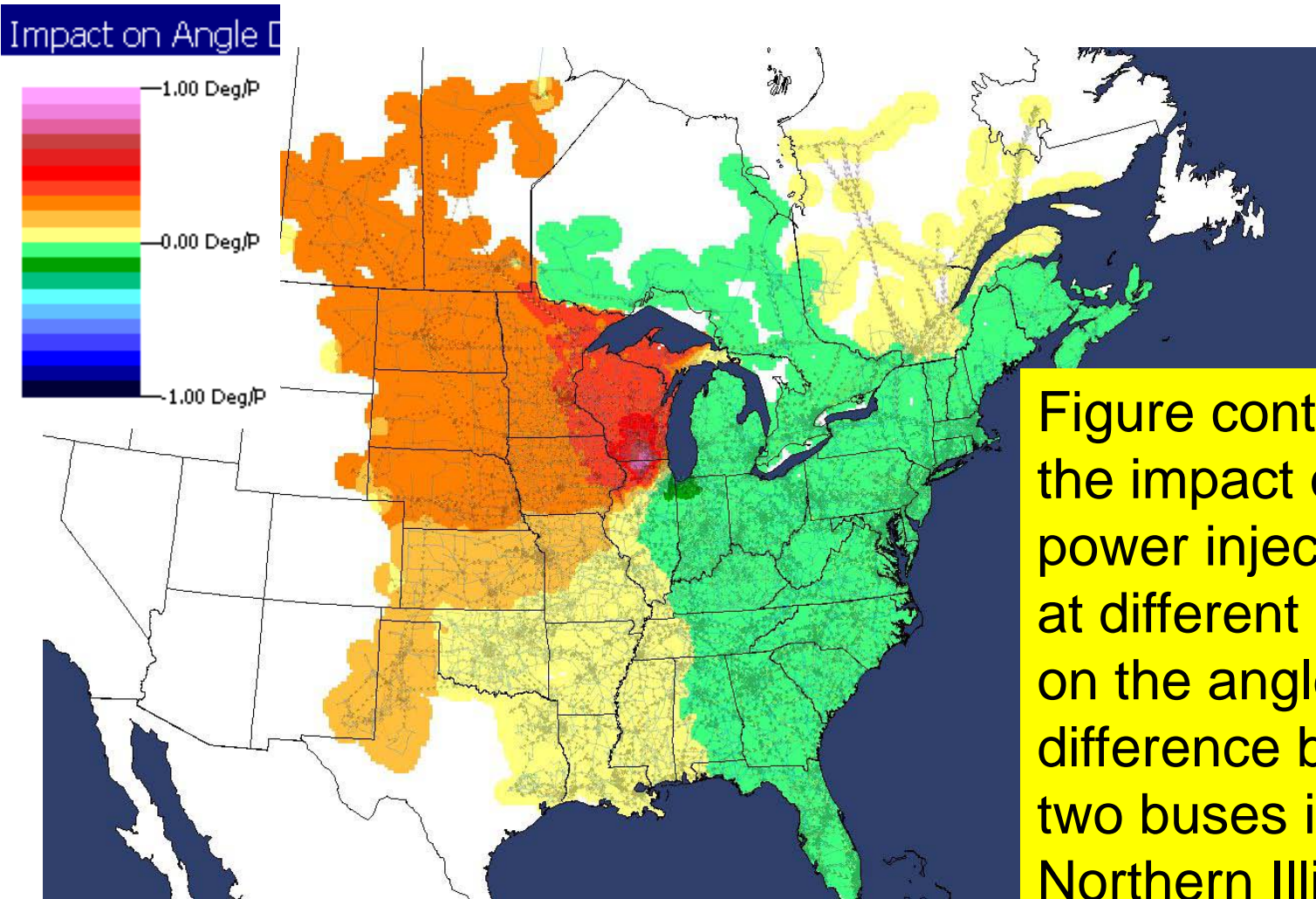
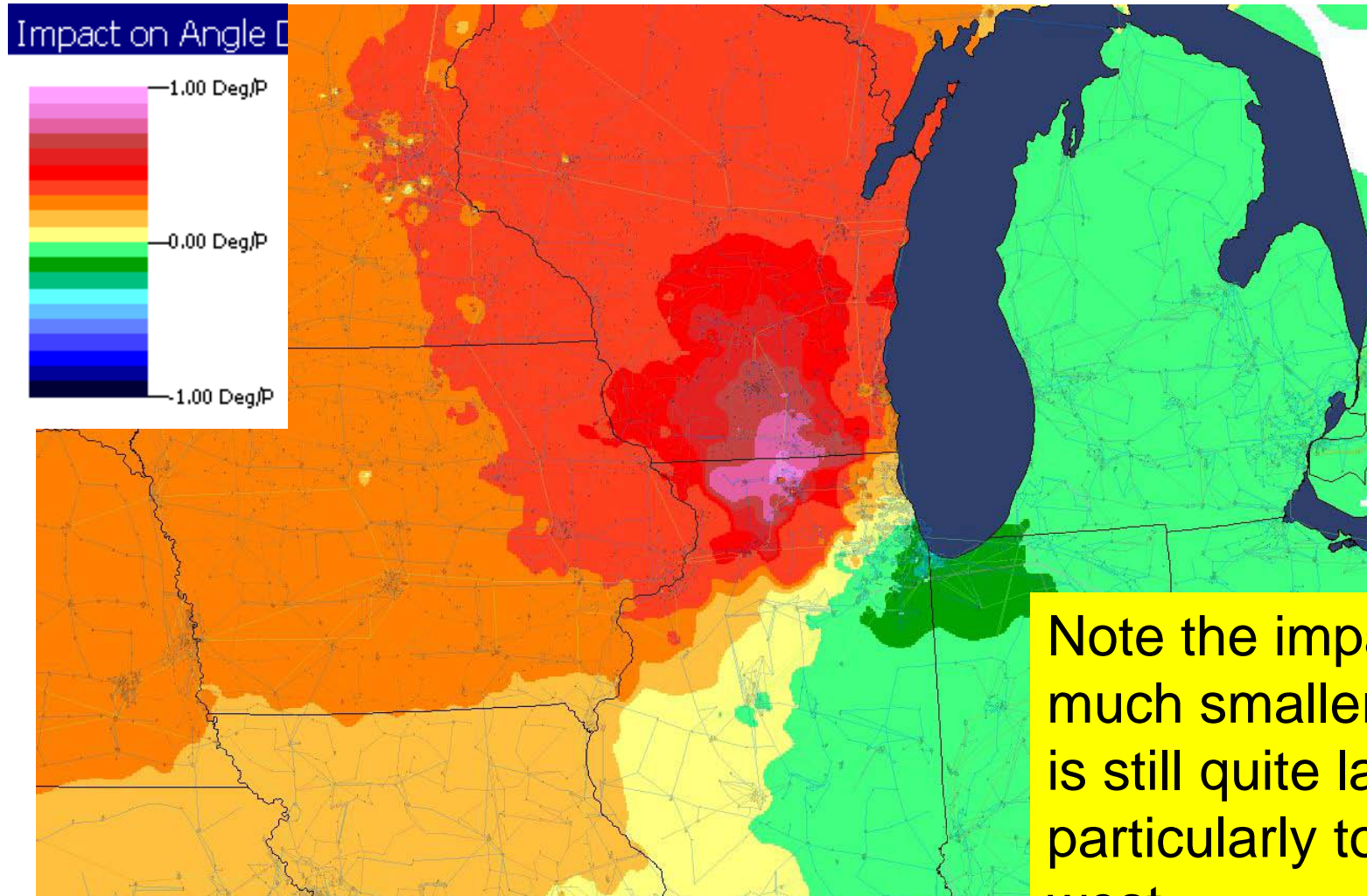


Figure contours the impact of power injections at different locations on the angle difference between two buses in Northern Illinois.

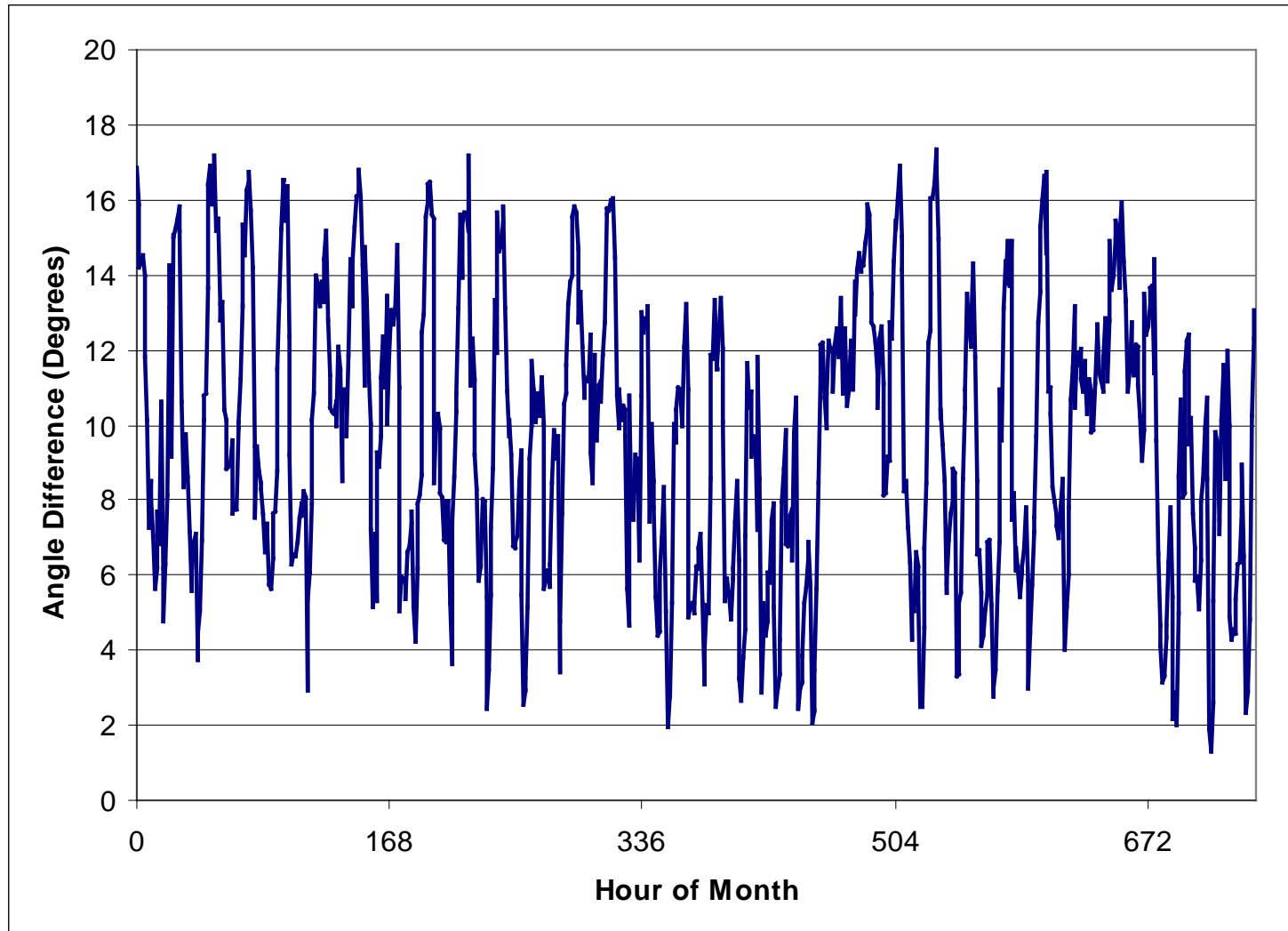


Zoomed View of Midwest



Note the impact is much smaller, but is still quite larger, particularly to the west.

Variation in Angle across Northern Illinois (One Month SCOPF Simulated Data)

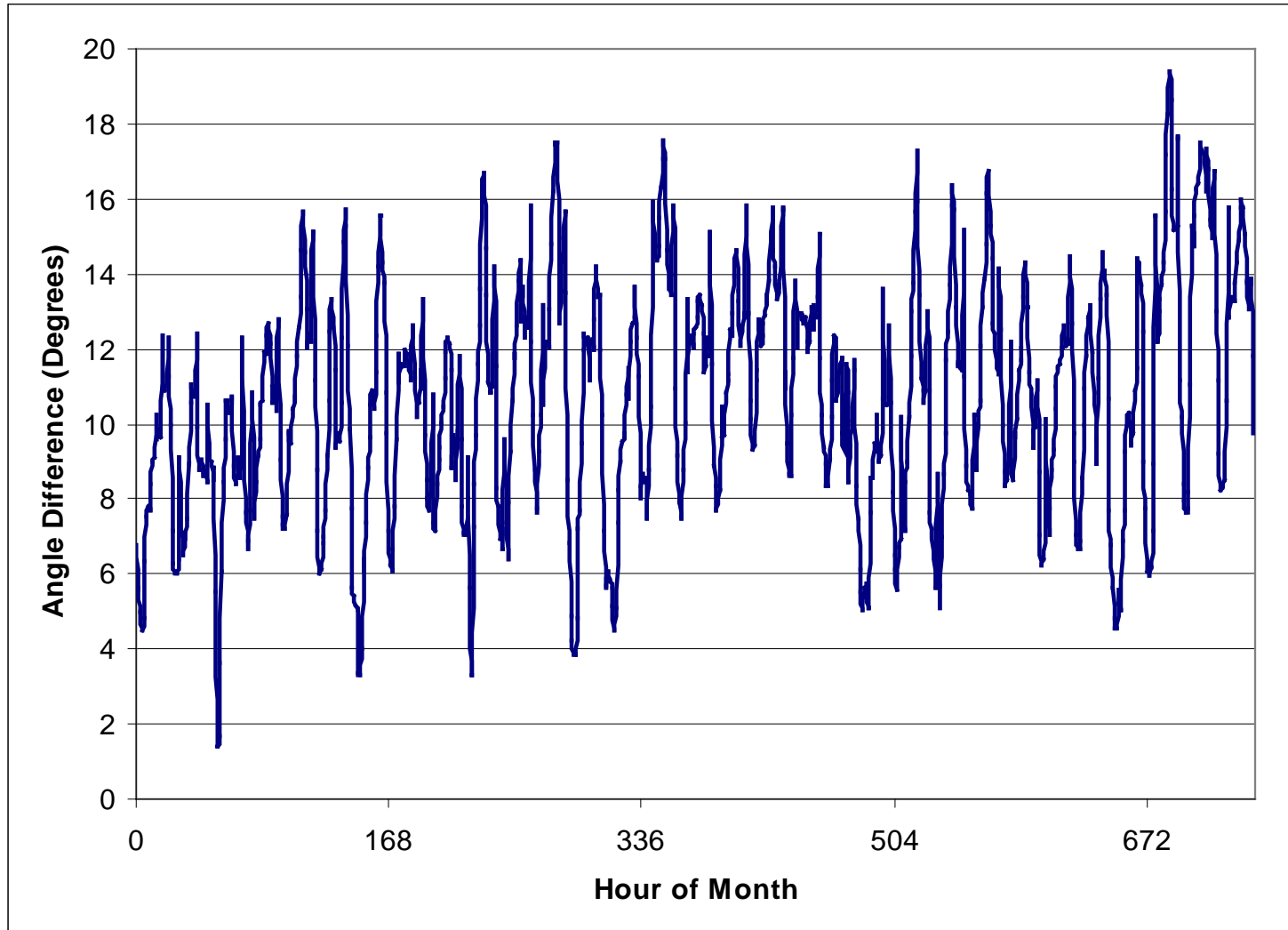


Graph shows hourly variation in angles between Wempton 345 kV and Burnham 345 kV buses



Average = 9.6 degrees, standard deviation = 3.8 degrees **PSERC**

Variation in Angle from W. MI to Central OH (One Month SCOPF Simulated Data)



Graph shows variation in angles between DC Cook 345 kV and S. Canton 345 kV buses

Average = 10.7 degrees, standard deviation = 3.1 degrees



Summary and Future Work

- In the Eastern Interconnect the significance of individual bus angles or bus angle differences across different regions is not fully understood.
- We would like to suggest future work in which the theoretical and practical issues associated with the interpretation of phase angle differences are studied.
- Useful input data would be a set of state estimator cases to give actual operating conditions coupled with associated PMU measurements.
- Results would (hopefully) be interpretations and visualizations of this data

