Statistical Analysis of Inter-Area Oscillations in the U.S. Eastern Interconnection: A 2017-2023 Perspective

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Background and Motivation

- **Study Focus:** This study utilizes high-resolution, long-term PMU data to enhance understanding of inter-area oscillations in the U.S. Eastern Interconnection, with data monitored by FNET/GridEye from 2017 to 2023.
- **Objective:** This research builds on previous research to analyze oscillation patterns, frequencies, damping, and excitation mechanisms, aiming to enhance grid resilience.
- **Impact:** The findings reveal new statistical behaviors of inter-area oscillations, crucial for improving network resilience and guiding grid infrastructure development to meet future challenges.

Temporal Patterns in Oscillation Events

- **Cyclical Patterns:** Oscillation rates fluctuate monthly, indicating cyclical effects on stability potentially linked to climate, operations, or demand changes.
- **Seasonal Influences:** Factors influencing oscillations show seasonal patterns.
- **Yearly Changes:** Differences in oscillation rates between years suggest evolving grid dynamics and external impacts.

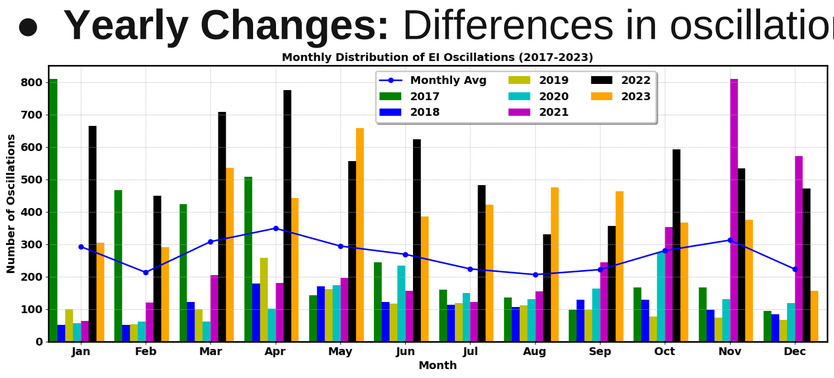

Figure 1. Monthly Occurrence of Inter-area Oscillations in EI

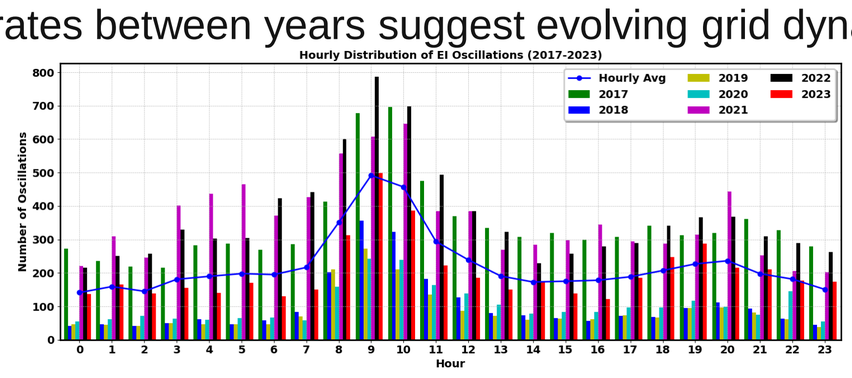

Figure 2. Hourly Occurrence of Inter-area Oscillations in EI

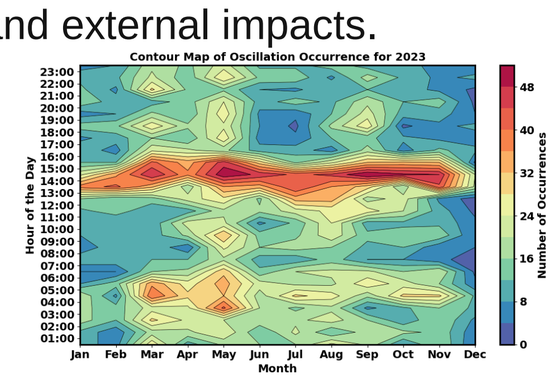

Figure 3. Contour Map of Annual Variations in EI Oscillation Frequency for Year 2023

Types of Excitation Leading to Inter-Area Oscillations

- **Persistent Causes:** Non-obvious events cause oscillations, especially frequent during nighttime and early morning.
- **Load Shedding:** Significant during midday peaks, matching daily oscillation patterns seen in data.
- **2020 Reduction:** Notable oscillation decrease, suggesting an unusual event or operational change.
- **2021 Resurgence:** Increase in oscillations due to Generation Trips, indicating potential weaknesses in power generation.
- **2022-2023 Trends:** Although load shedding and non-obvious events continue, overall oscillation slightly decreases.

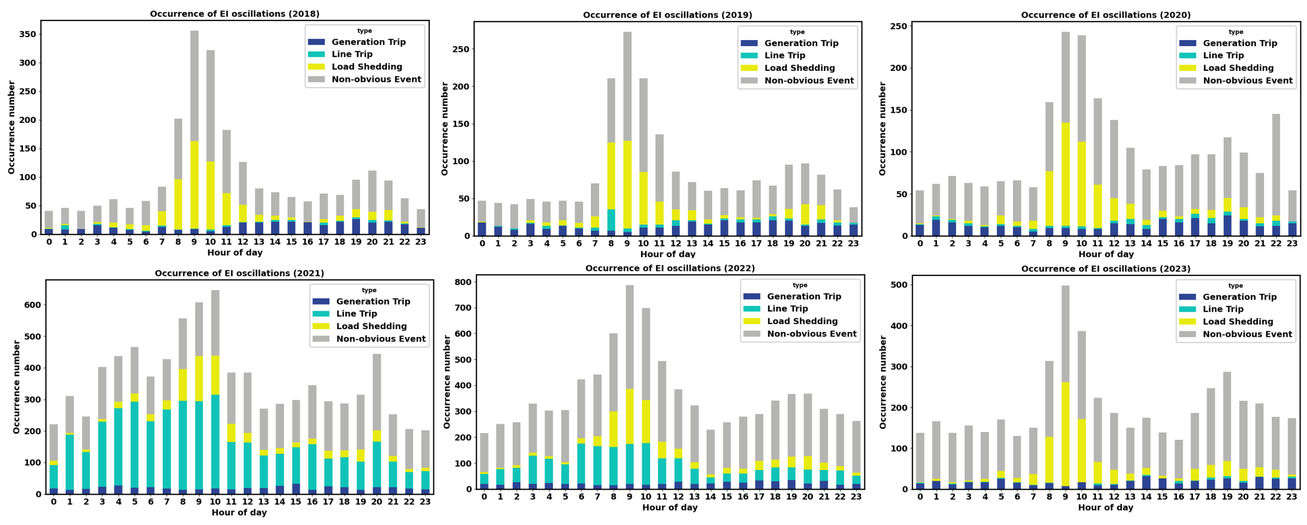

Figure 4. Frequency of EI Oscillations Categorized by Event Type from Year 2017 to Year 2023

Oscillation Modes and Stability Impact (Case: Dominant Frequency)

- **Steady Frequency:** Central oscillation frequency consistently around 0.2 Hz, with little variation throughout the day.
- **Morning Outliers:** Increased outliers between 8 am and 11 am.
- **Frequency Distribution:** Dominant frequency generally aligns closely with the normal distribution at 0.2 Hz; frequencies above 0.5 Hz show significant deviations.
- **Yearly Consistency:** There were no major year-to-year shifts in the persistent oscillation mode despite a broader range of higher frequencies observed.
- **2020 Shift:** Notable increase in frequency centroids in 2020, followed by a decrease and stabilization around 0.6 Hz from 2021 to 2023.

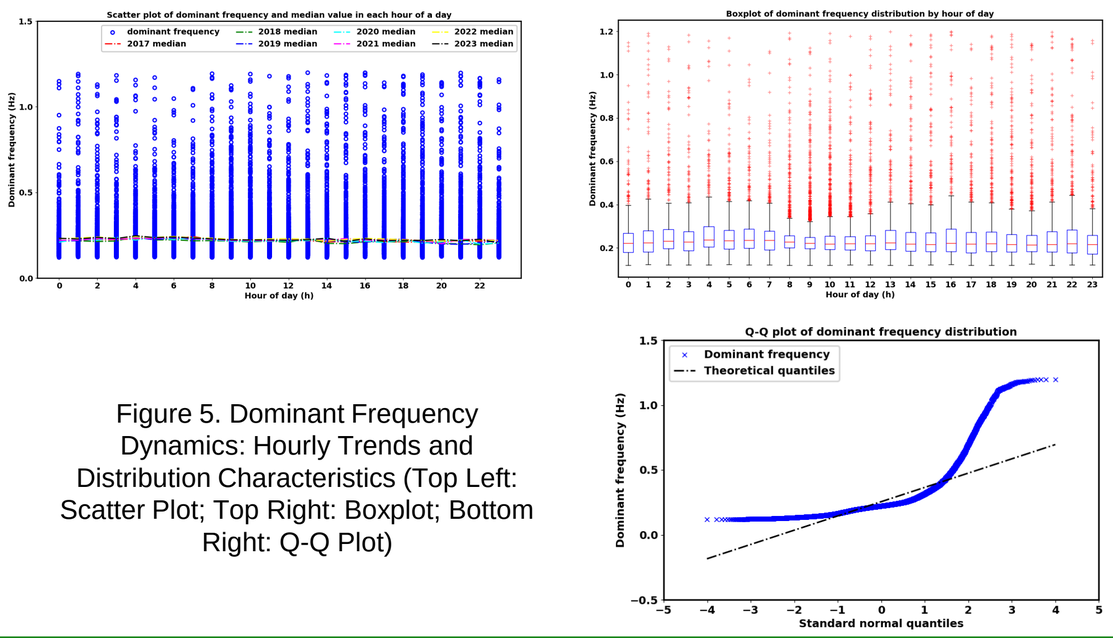

Figure 5. Dominant Frequency Dynamics: Hourly Trends and Distribution Characteristics (Top Left: Scatter Plot; Top Right: Boxplot; Bottom Right: Q-Q Plot)

Conclusion

- **Study Overview:** Analyzed inter-area oscillations in the U.S. Eastern Interconnection, identifying patterns and dominant oscillation types influenced by increasing grid complexity and renewable integration.
- **Key Findings:** Significant deviations in non-obvious oscillation types were identified despite overall stability, highlighting a need for enhanced operational resilience.
- **Future Research:** Further investigation into non-obvious excitations, advanced analytics, and machine learning are recommended to improve oscillation predictions and grid management.

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