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Identifying Oscillations Injected by Inverter-Based Solar Energy Sources in Dominion Energy's Service Territory using Synchrophasor Data and Point-on-Wave Data

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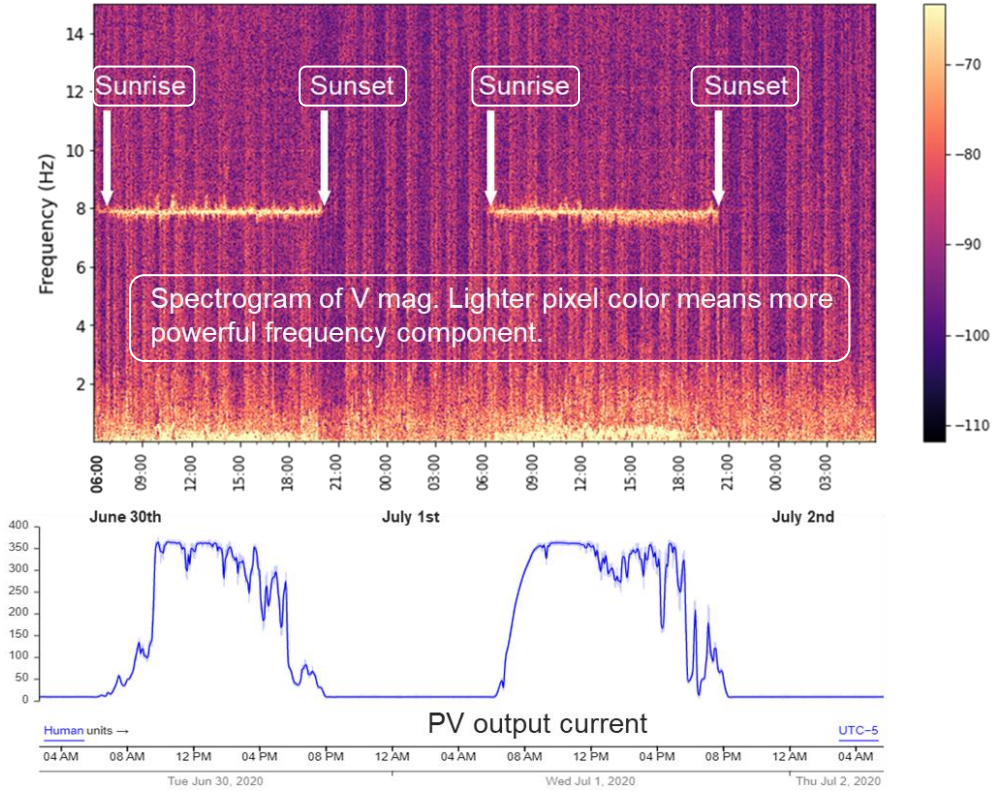
Oscillation Mode Discovery

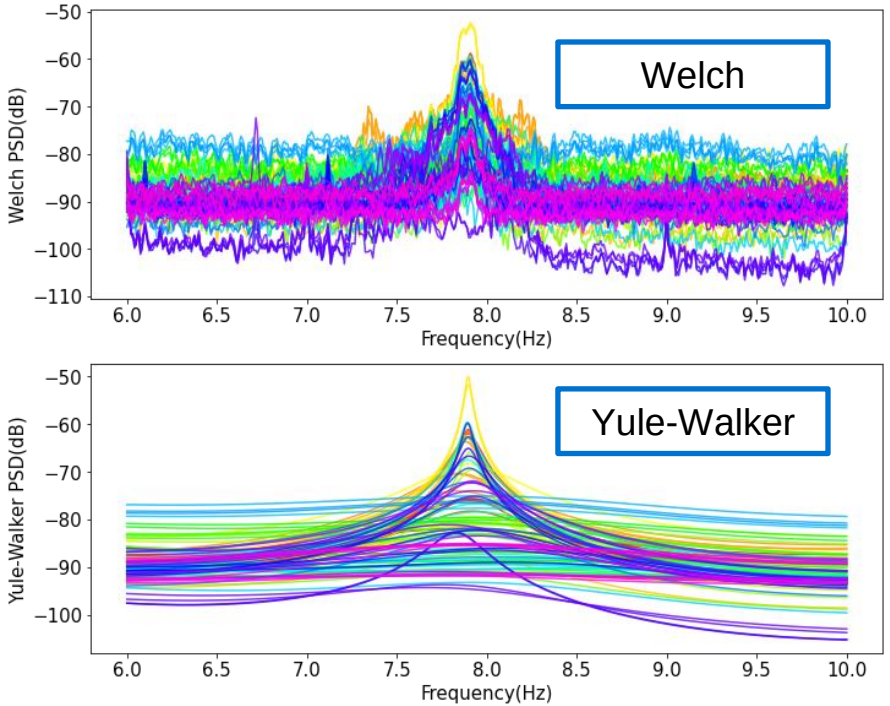
- We first detected the 8 Hz oscillation mode in a voltage magnitude measurement at a substation with inverter-based PV installation.

- The spectrogram clearly shows the 8hz mode correlated with sunrise to sunset. It also correlates with the PV power output at that substation.



System Impact Evaluation

- We found that the mode appears in 115 voltage magnitude measurements from 25 substations.
- We used power spectrum density (PSD) plots to show the identified frequency components.
- This mode affects large areas with various energy levels indicating that the oscillation energy is dissipating and supports the existence of a source(s).



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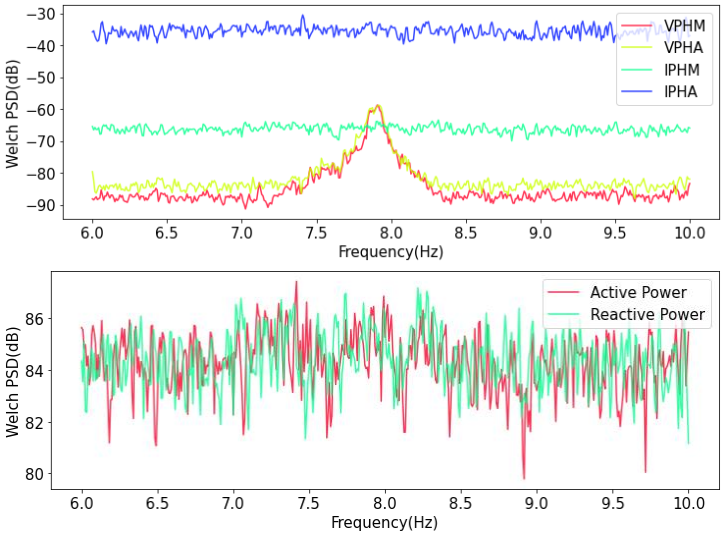
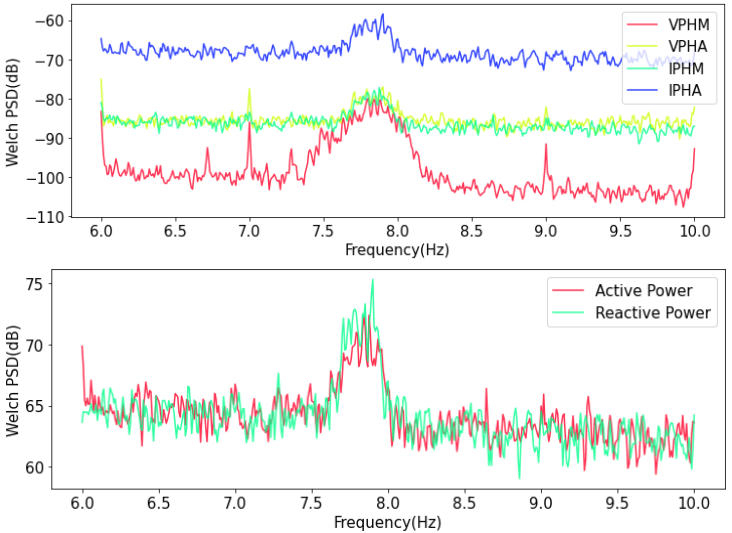
System Impact Evaluation



- **Most cases:** The mode only appears in voltage measurements, not in current or power calculations.



- **Rare cases:** The mode appears in both voltage and current measurements, as well as in active and reactive power calculations.

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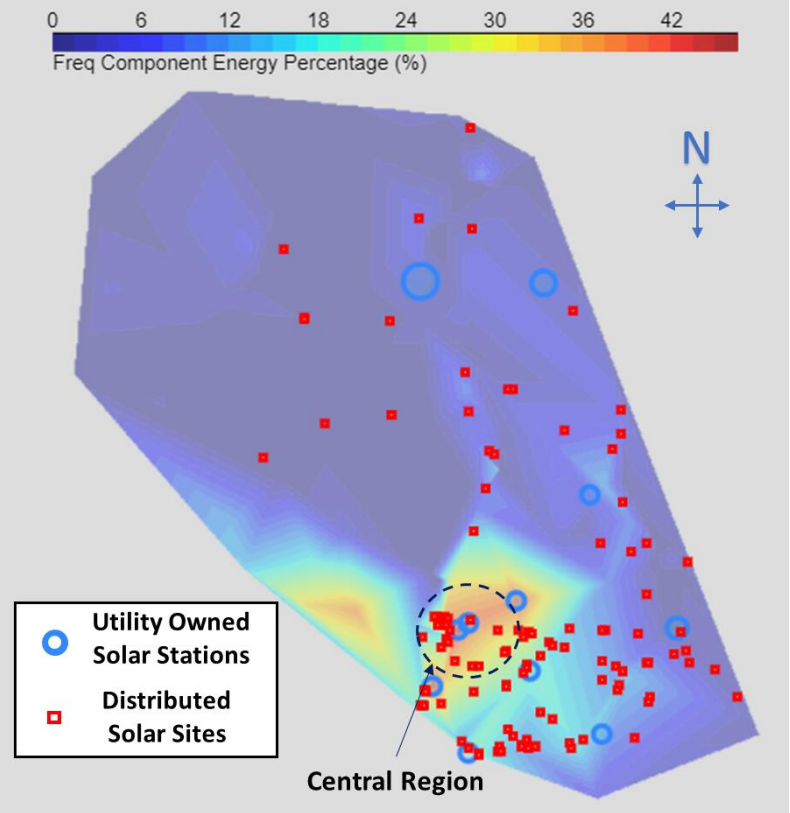
System Impact Evaluation

- To better quantify the geographical spread of this mode, we proposed a metric of the mode energy for voltage measurement.
- The 8 Hz mode appears most powerfully in the central region, coinciding with the PV installed there.
- Even though the eastern region does not have PV, the oscillation propagated there.



* Geographical contextualization omitted due to confidentiality

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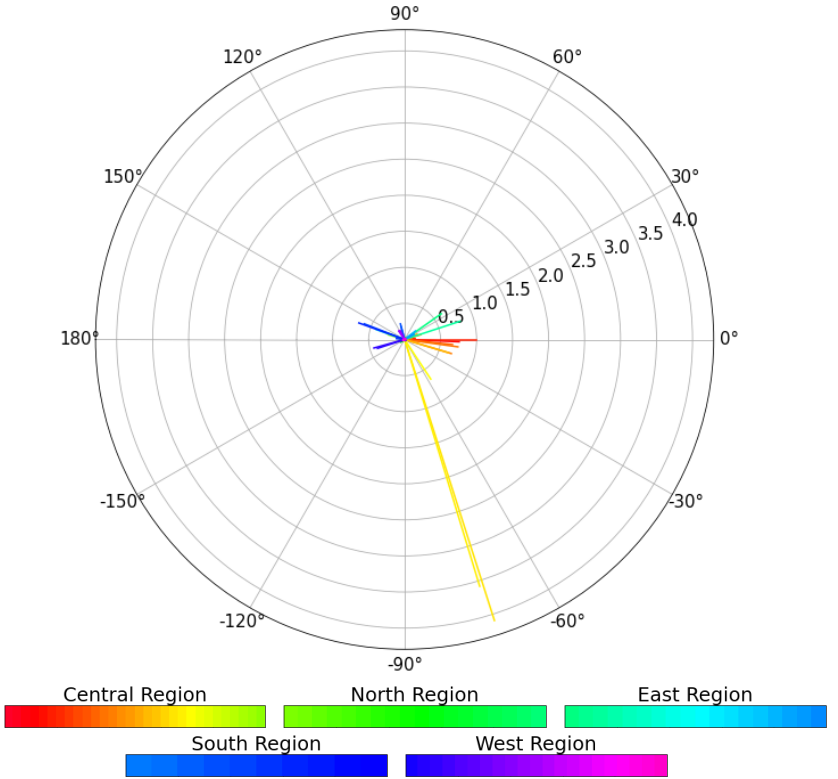
Mode Source Estimation

- Mode shape estimates confirm that the frequency of this mode is 7.8936 Hz.

- This mode shows up most prominently in the measurement streams from the central region.



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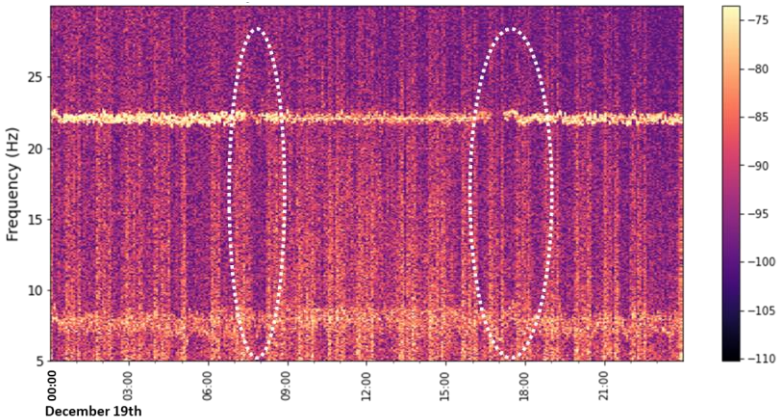
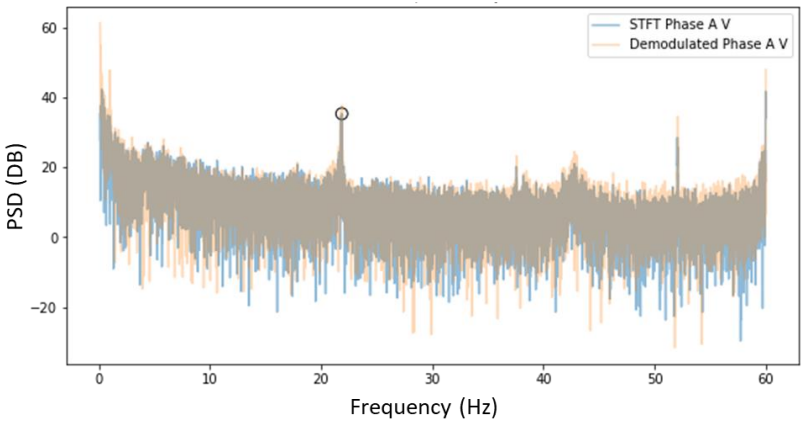
True Oscillation Frequency with Point-on-Wave Data

PMU data with 60 frames/sec reporting rate
(Nyquist frequency is 30 Hz)



Point-on-wave (PoW) data with 960 Hz sampling rate



- The true oscillation frequency is **22 Hz**. The observed 8 Hz mode before is most likely an **aliasing** of the true mode. This demonstrates the importance of verifying the frequency using higher reporting rate PMU data and/or PoW data when analyzing unforeseen oscillation modes.
- Given limited access for higher reporting rate (60 Hz) PMU data and PoW data, this work uses the 8 Hz oscillation to assess the spread and impact of this mode.

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Conclusions

- We found a new oscillation mode at multiple substations with PV installations.
- This mode appears with sunrise and disappears with sunset, strongly suggesting a correlation with PV.
- Voltage magnitude measurements show this mode most clearly. The mode appears less clearly in other types of PMU signals.
- The mode has profound system impact.
- Mode shape estimation suggests that the PVs in the central region are major contributors to this oscillation mode.
- Point-on-Wave data indicates the true frequency of this mode is around 22 Hz.

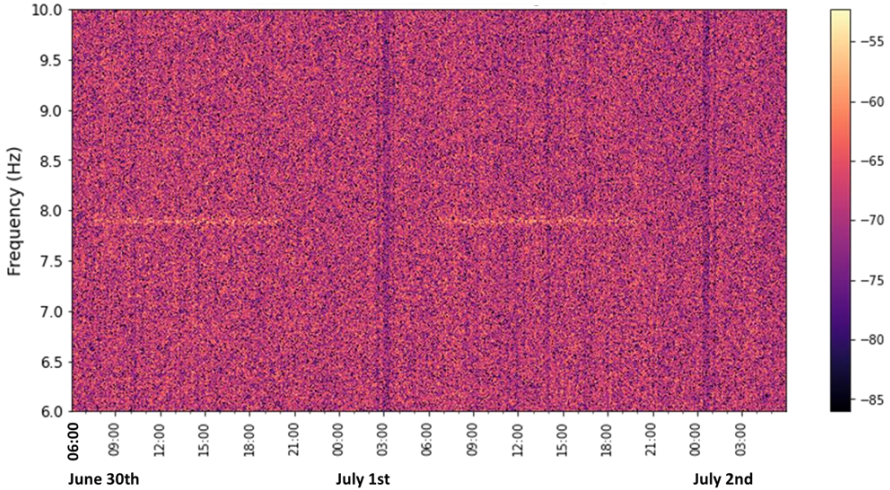
Publication

Chen Wang, Chetan Mishra, Luigi Vanfretti, and Kevin D. Jones, “**Identifying Oscillations Injected by Inverter-Based Solar Energy Sources**”, *IEEE Power Engineering Letters* (submitted)

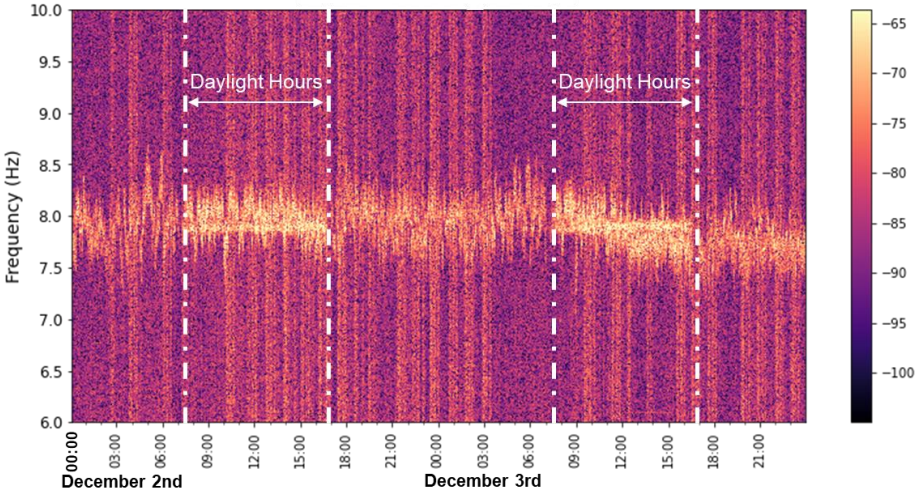
Thank you!

Appendix I

- **Further observations**



❖ This mode does not appear in **current phasors** as clearly as in voltage phasors.



❖ This mode takes on a different pattern on **winter days**.

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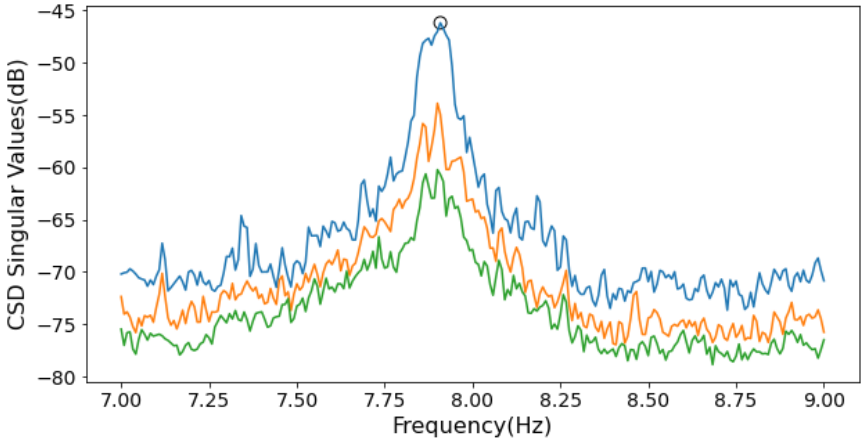
Appendix II

- **Confirming a Single Mode**

- While many streams contain this mode, the close overlap of the peaks in the PSD plot make it difficult to tell if it is a single mode or multiple modes from visual inspection alone.

- Using singular value decomposition to analyze mode multiplicity, we plotted the three most different modes (see graph). Their similar appearance confirms there is one single mode.



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