# A Comprehensive Method to Mitigate Forced Oscillations in Large Interconnected Power Grids: EI Case Study

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**Presented by Andrew Arana and Lin Zhu**


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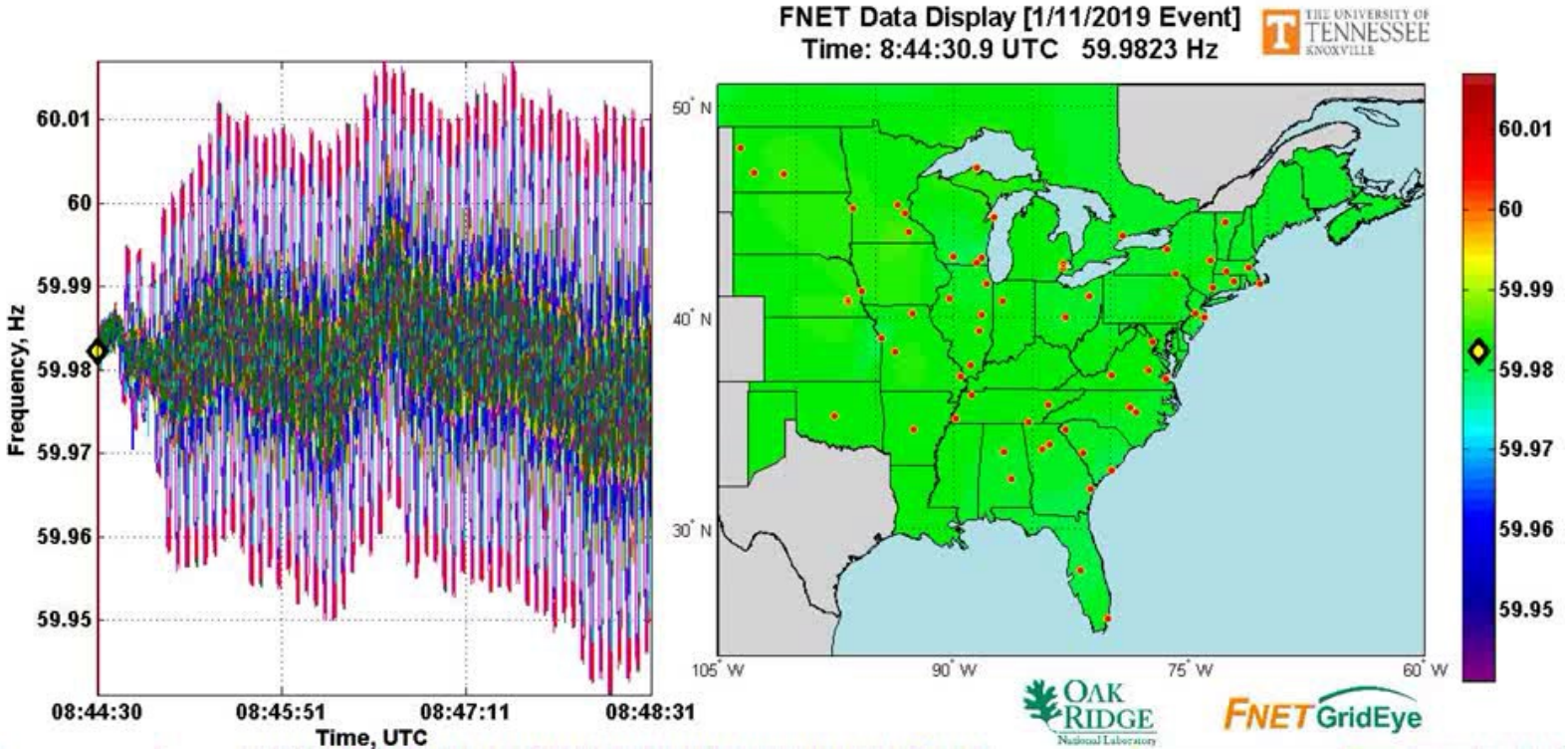
# Jan. 11, 2019 Forced Oscillation Event in EI

- 0.25 Hz forced oscillations propagated through entire EI, interacted with the natural system mode near that frequency.
- The generating unit experienced oscillations of around 200 MW peak-to-peak; however, power swings were observed as far as the New England area of about 50 MW




Source generator: Florida



Source: Eastern Interconnection Oscillation Disturbance January 11, 2019 Forced Oscillation Event, NERC, December 2019.

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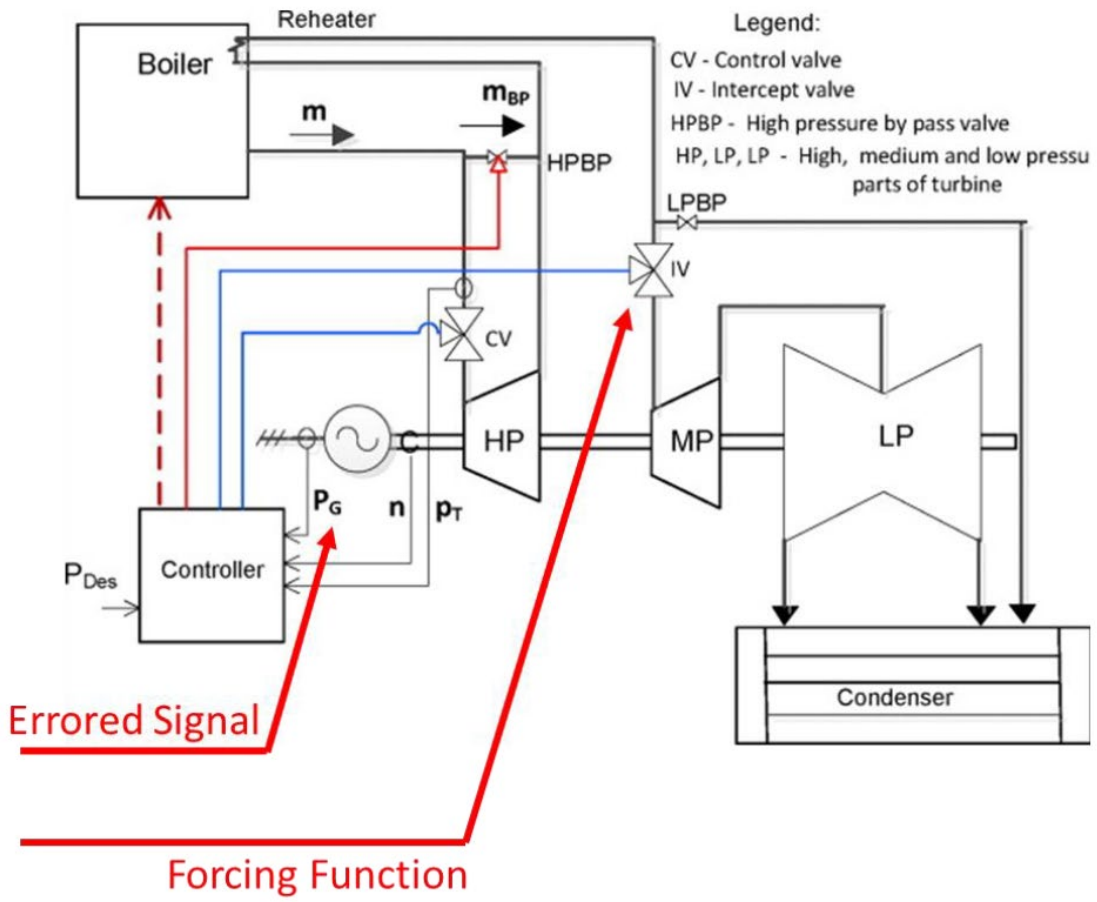
# Jan. 11, 2019 Forced Oscillation Event in EI

- A failed PT connection and errored voltage measurement in the power load imbalance (PLI) turbine controls caused a steam turbine at a combined-cycle power plant to oscillate for around 18 minutes
- While redundancy was built into the plant control and protection system inputs, the turbine controls relied on a single PT measurement.
- PLI operation caused the intercept valves of the steam turbine to shut and reopen periodically with a cyclical period of about four seconds.



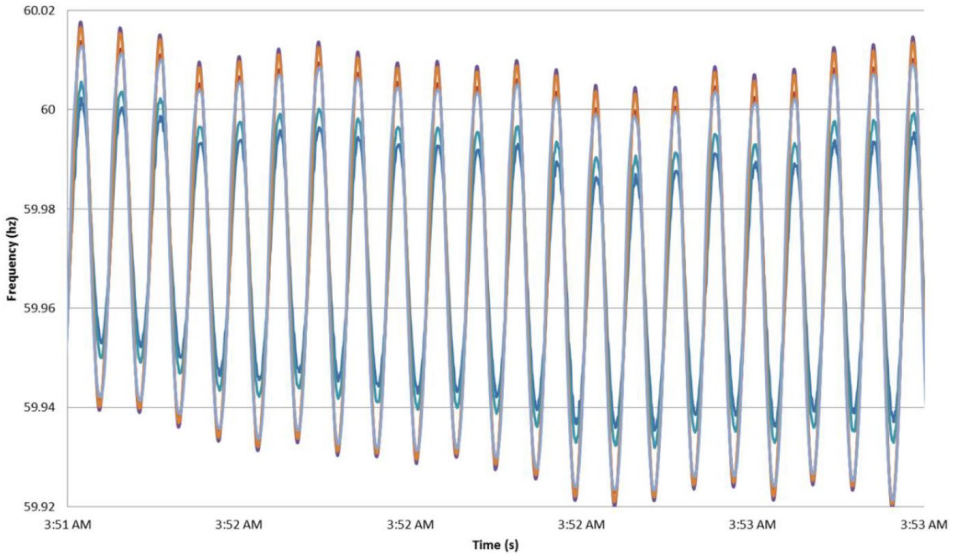

**Basic Illustration of PLI Failure Mode**



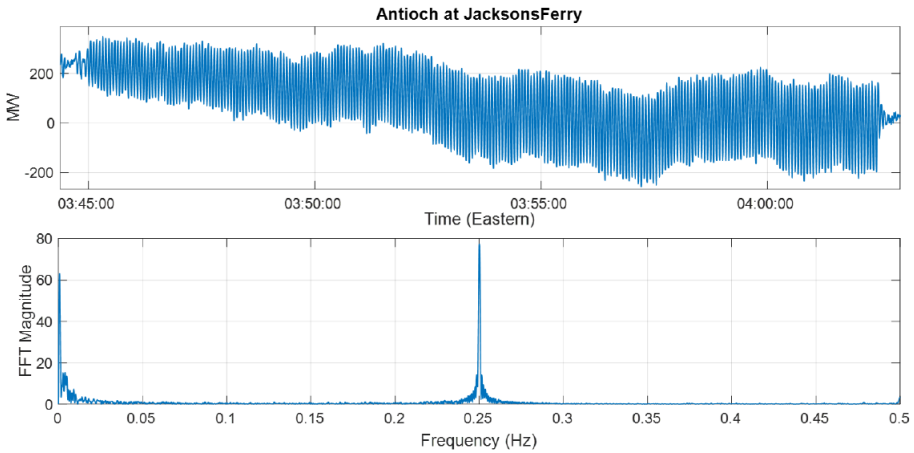
Source: Eastern Interconnection Oscillation Disturbance January 11, 2019 Forced Oscillation Event, NERC, December 2019.

# Jan. 11, 2019 Forced Oscillation Event in EI

- RCs were forced to call neighboring RCs individually that led to misinformation and mischaracterization of the event initially.
- Wide-area operator action did not contribute to mitigating the oscillation event, and most tools were ineffective at identifying a source location for the oscillation.
  - Source location tools deployed in a few utilities/ISOs.
  - Source location takes a quite long time due to limited PMU coverage and lack of coordination among utilities/ISOs.
  - Forced oscillations could last for tens of minutes to hours until the driving source is removed.




**Frequencies in FPL Footprint**




**Line Active Power Flow in AEP Footprint**

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Source: Eastern Interconnection Oscillation Disturbance January 11, 2019 Forced Oscillation Event, NERC, December 2019.

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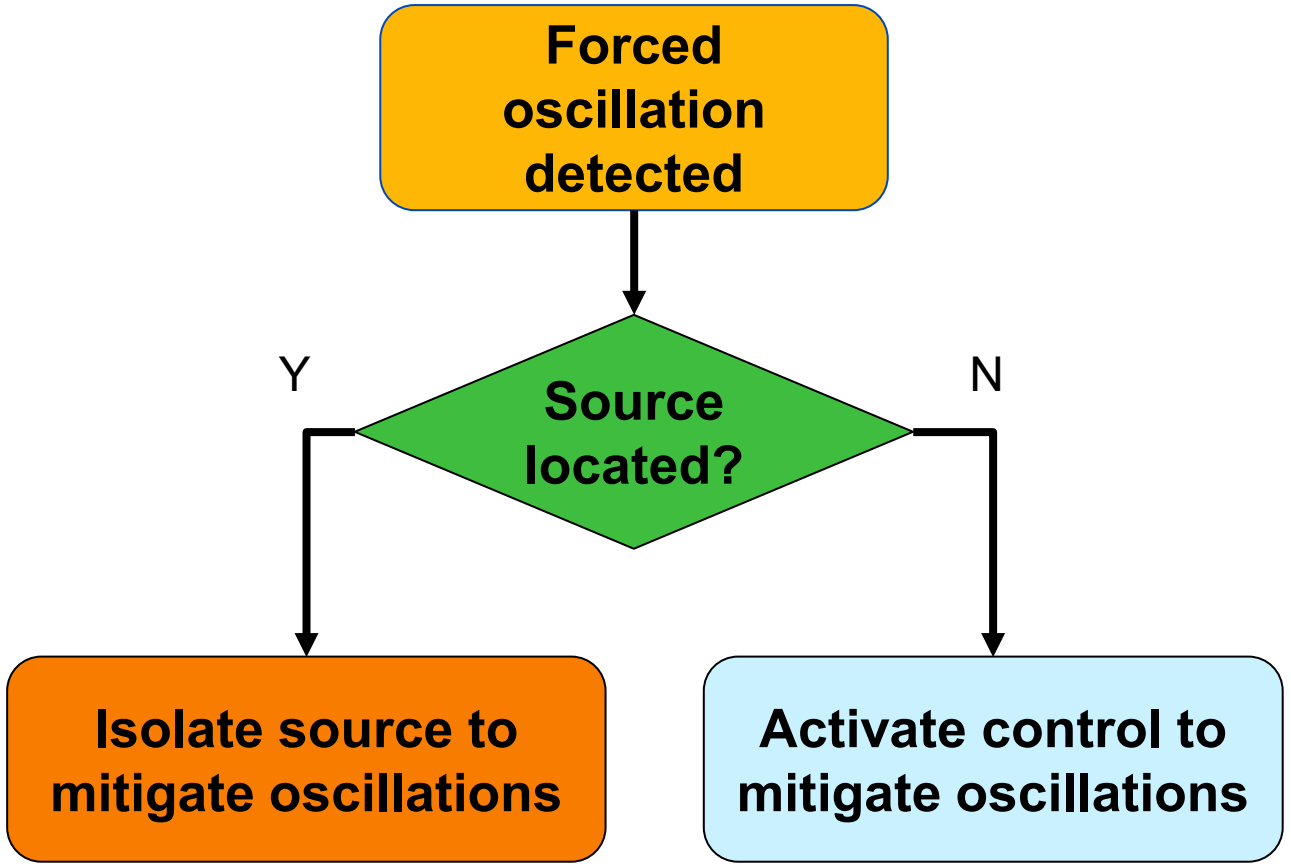
# A Comprehensive Method to Mitigate Forced Oscillation

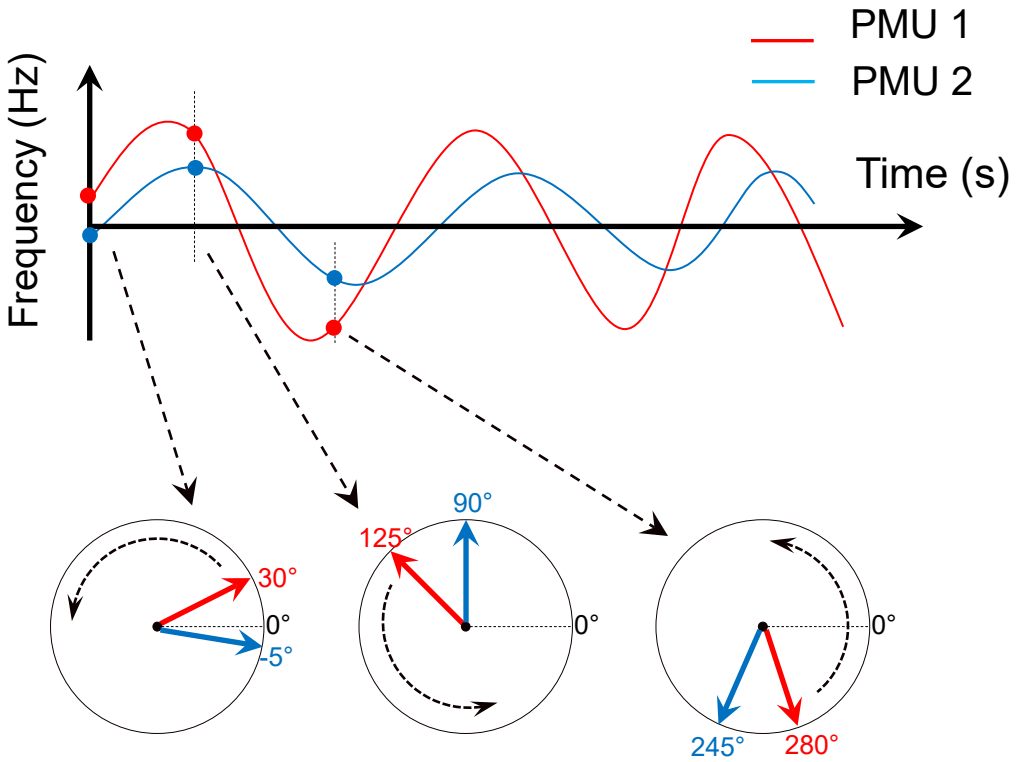
- Forced oscillation source location
- Use of Battery Energy Storage Systems (BESS) and/or Inverter Based Renewables (IBR) to suppress magnitude of forced oscillations
  - If source cannot be located quickly, activate control to reduce forced oscillation energy
  - Allow sufficient time to locate source




**Comprehensive Method to Mitigate Forced Oscillation**

# Source Location Based on Oscillation Mode Angle

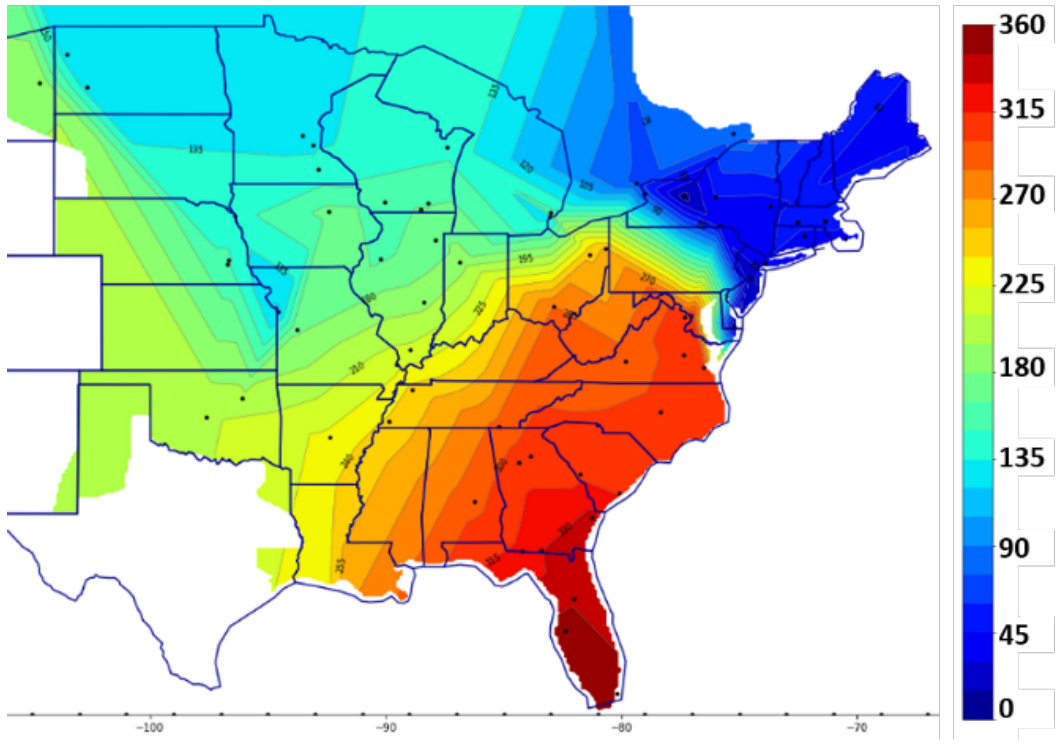
- Observations
  - Source area has the most leading mode angle.
  - Mode angle gradually decrease from source area to other areas.
  - The dissipating energy generated by the source flows from the oscillation mode angle leading area to the oscillation mode angle lagging area.
- Requires no topology information and power measurements, easier for implementation and field application.
  - Oscillation mode angle can be calculated from different types of measurements, e.g., frequency, voltage mag.



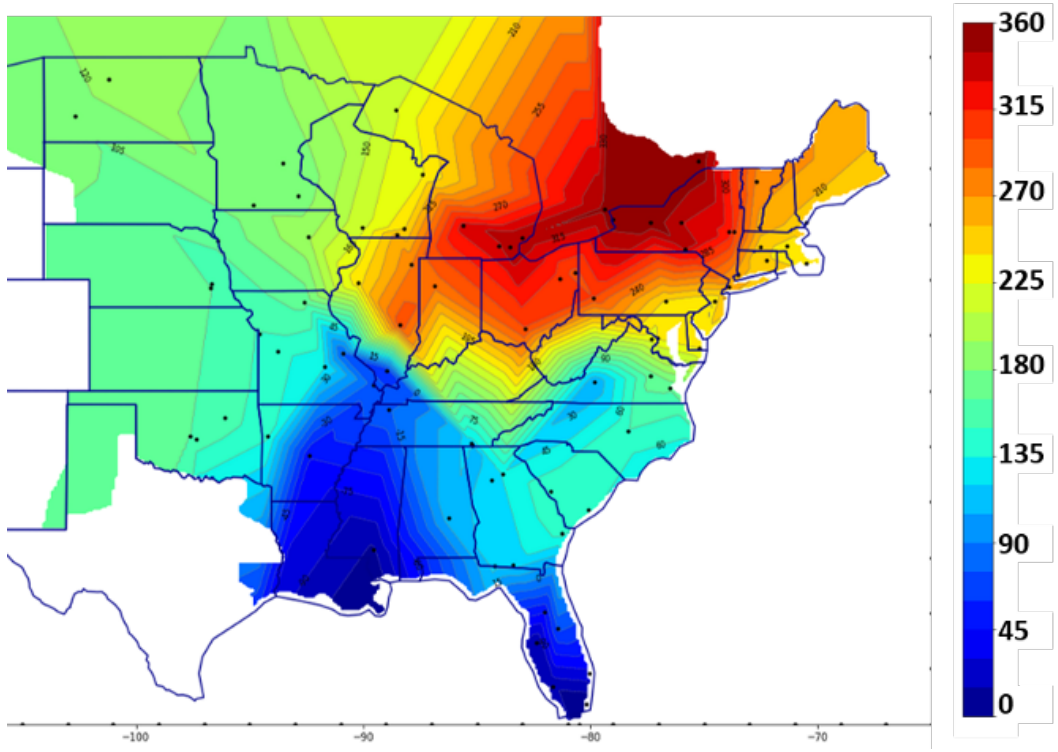

**Oscillation Mode Angle**
**(PMU1 is leading PMU2 by 35°)**

# Source Location Based on Oscillation Mode Angle

- Validation with actual forced oscillation event data
  - Dark red area has the most leading oscillation mode angle



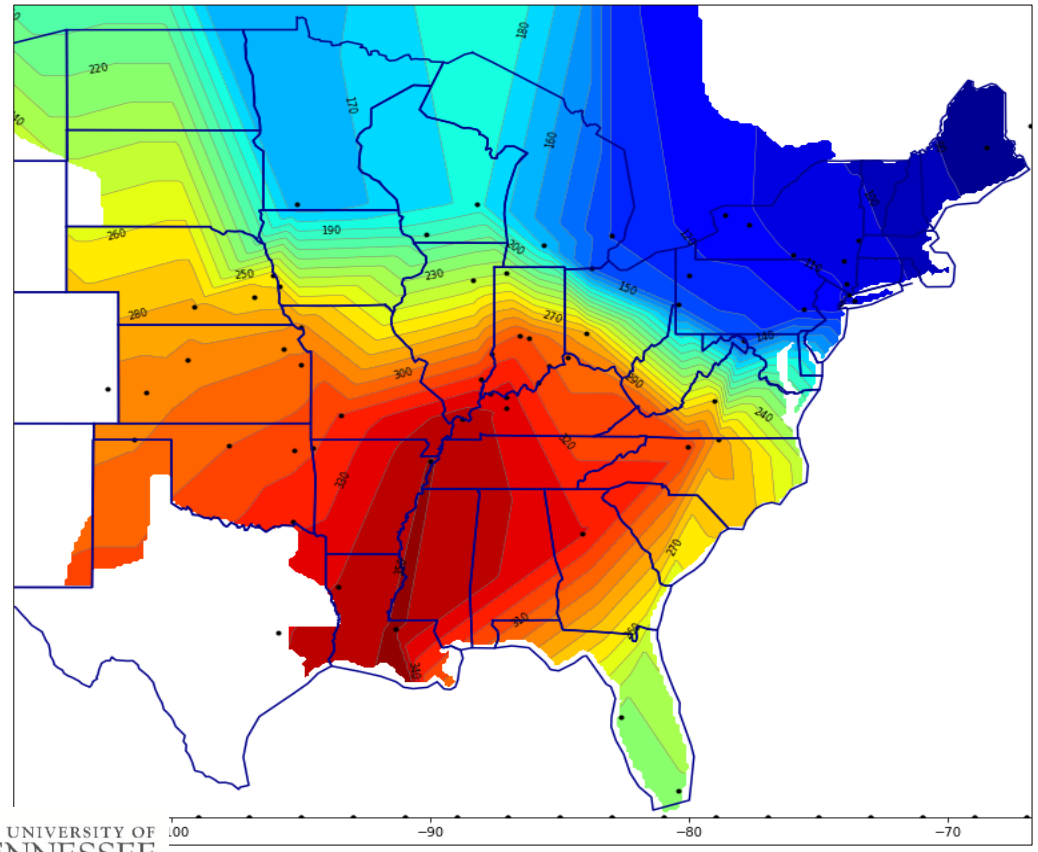

Jan. 11, 2019 event (source: Florida)



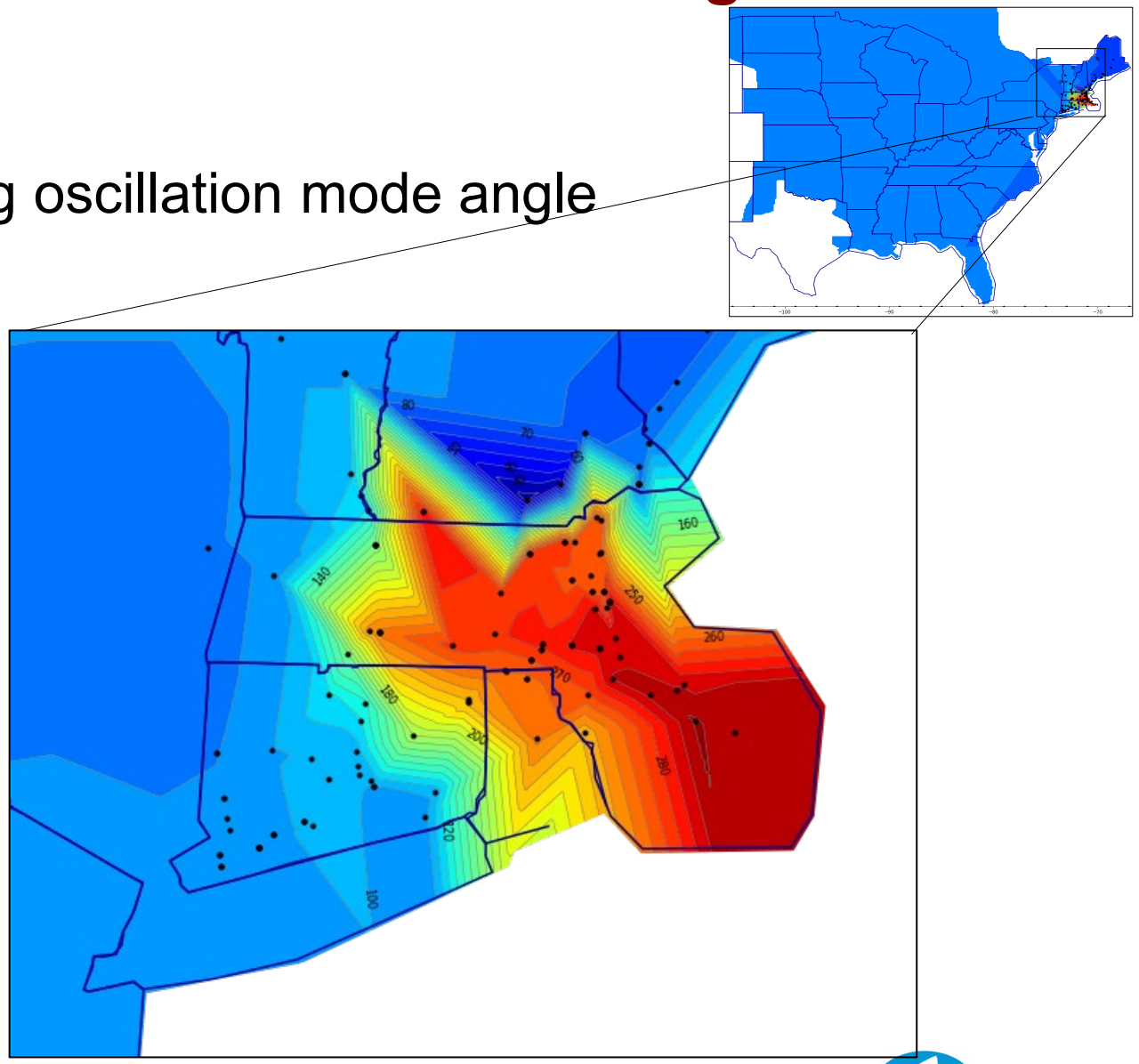

April 7, 2020 event (source: near Northwest NY)

# Source Location Based on Oscillation Mode Angle

- Validation with simulated events
  - Dark red area has the most leading oscillation mode angle



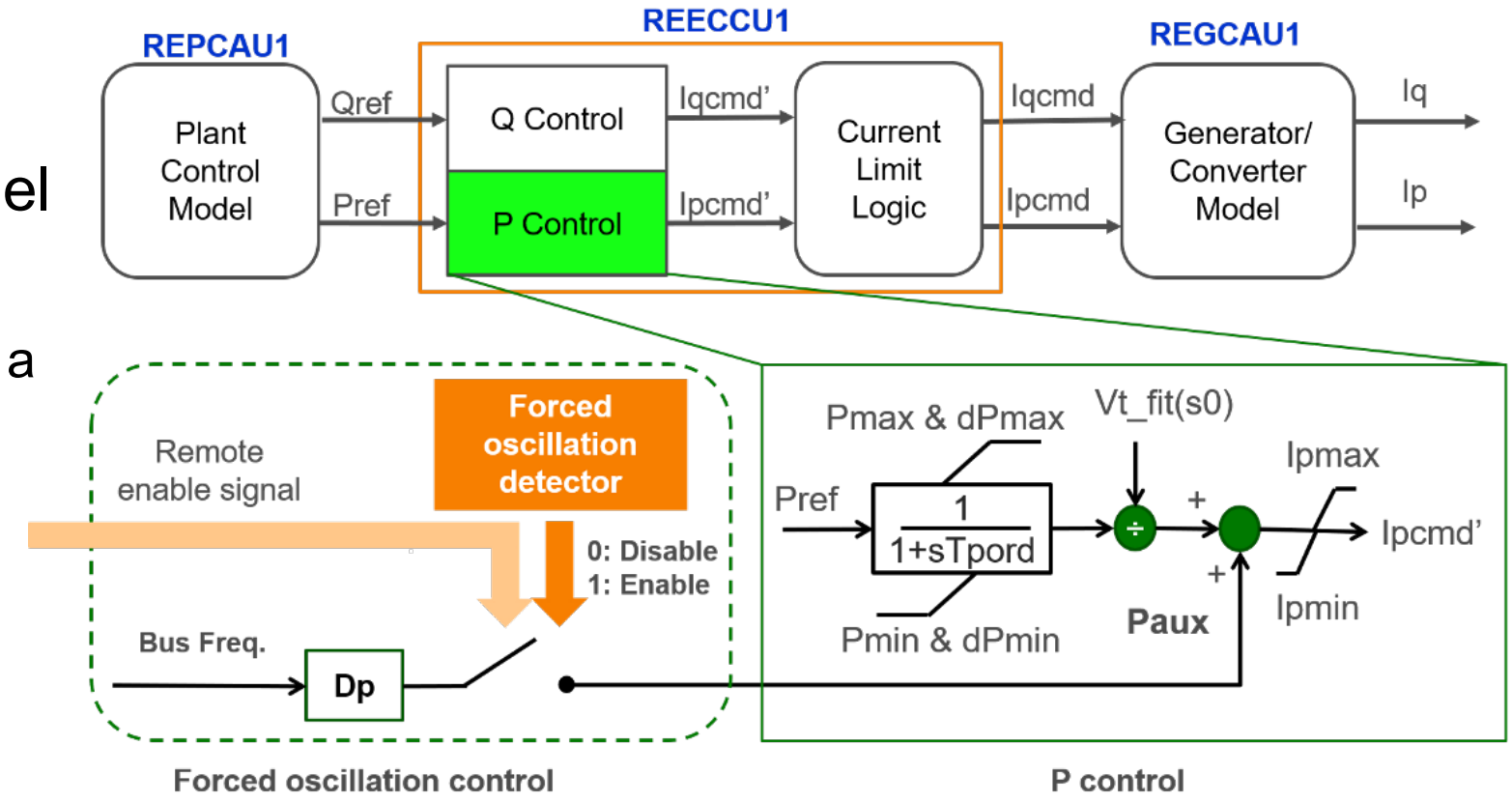

Source: TVA area



Source: ISO-NE (local oscillation)

# Forced Oscillation Mitigation Using BESS

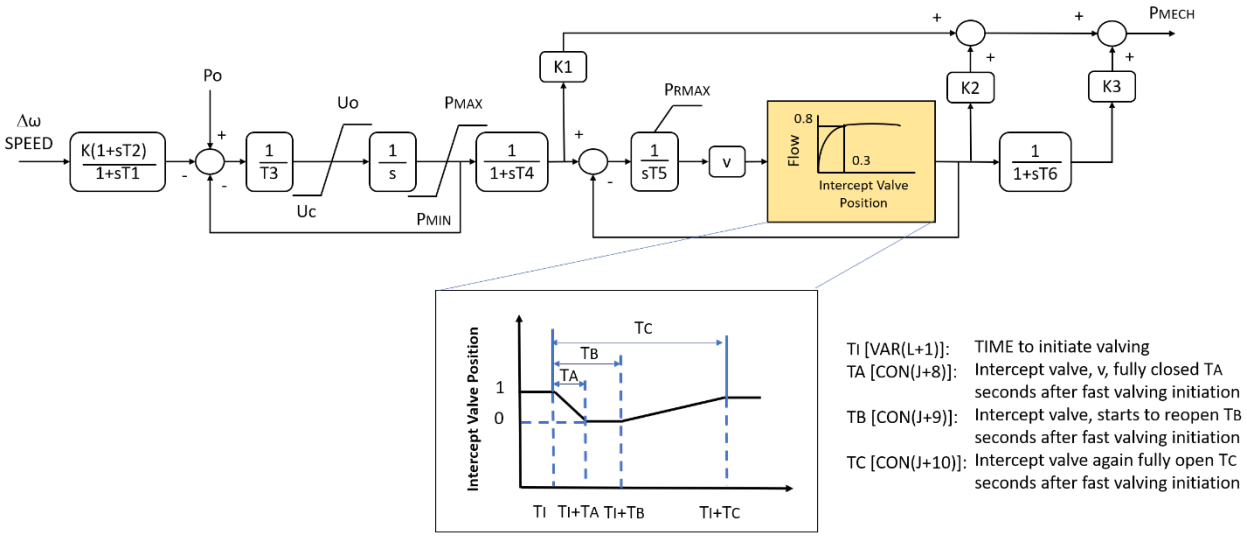
- WECC BESS model used
- Active power control of the BESS electrical control model
- Controller
  - Input: Frequency deviation of a HV bus close to the BESS
  - Output: Added to $P$aux to modulate the active current command
  - Forced oscillation detector
  - Droop control




**BESS model with forced oscillation control**

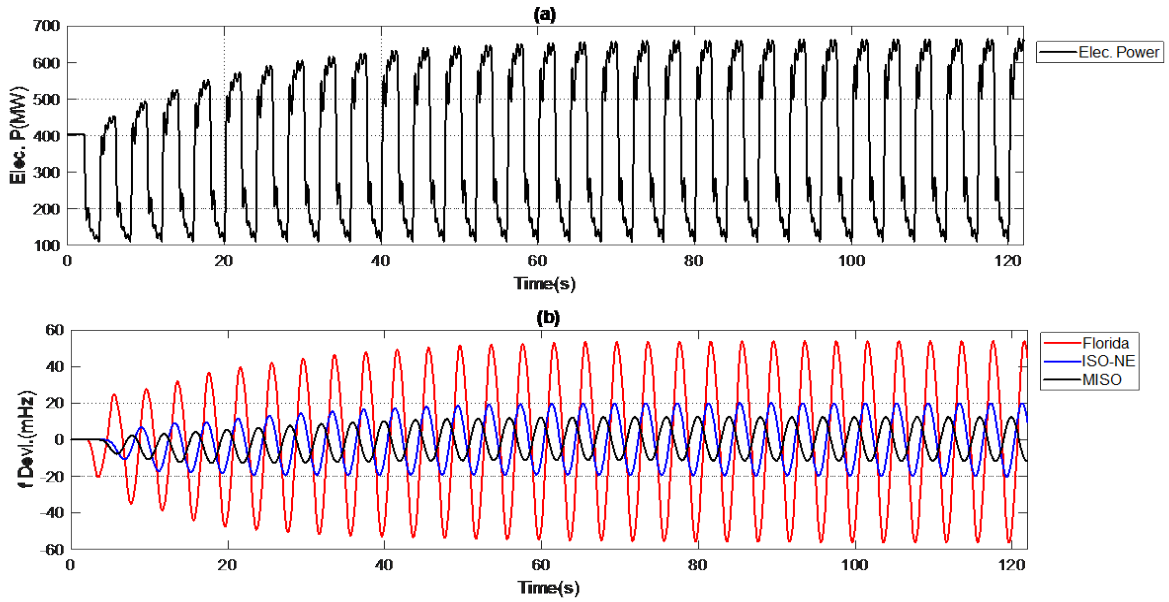
# Replication of EI Jan. 11 Forced Oscillation Event

- Fast valving feature of the TGOV3 model used to replicate the event
- Initiate fast valve every 4 seconds




**TGOV3 governor model with fast valving feature**

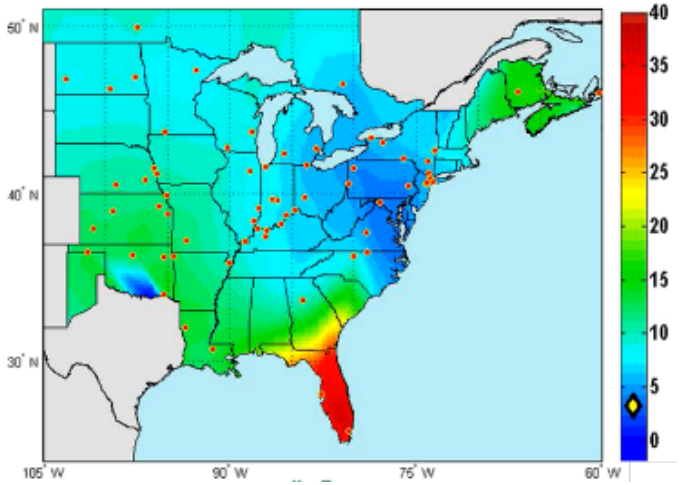
**Generator Electrical Power**



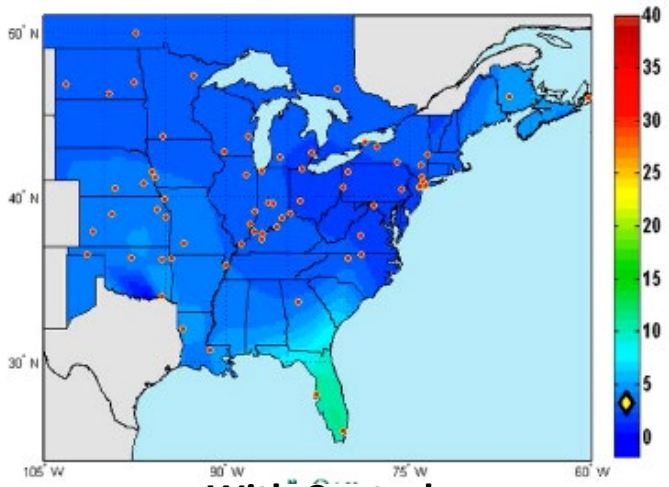

**Bus frequency deviation in Florida (red), ISO-NE (blue) and MISO (black)**

# Simulation Results in EI 70k-bus Model

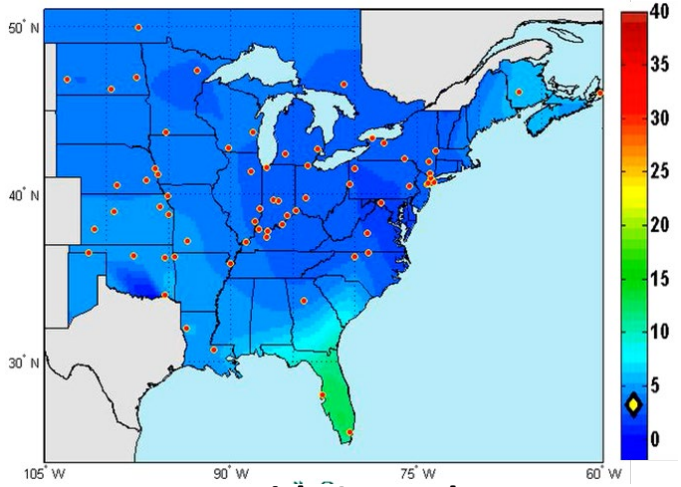
- Source in Florida, BESS in Florida
  - Case 1: No Control (Jan. 11 2019 event)
  - Case 2: With Control, one aggregated 409 MW BESS
  - Case 3: With Control, 12 distributed 35 MW BESSs




**No Control**




**With Control**
**(1×409 MW BESS in Florida)**




**With Control**
**(12 ×35 MW BESS in Florida)**

**Source: Florida**

**Battery: Florida**

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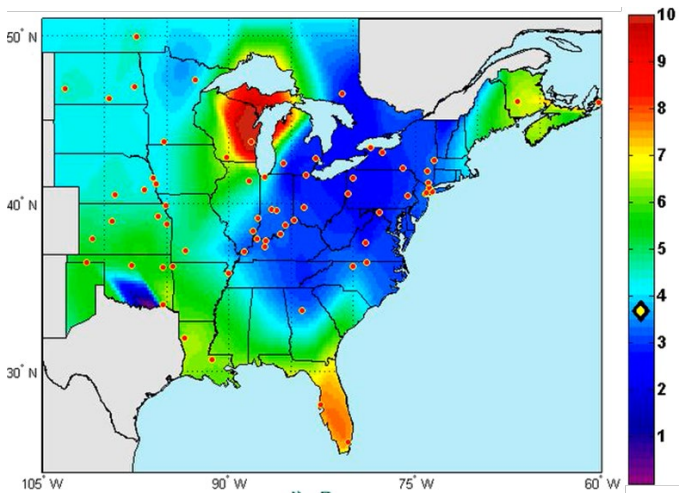
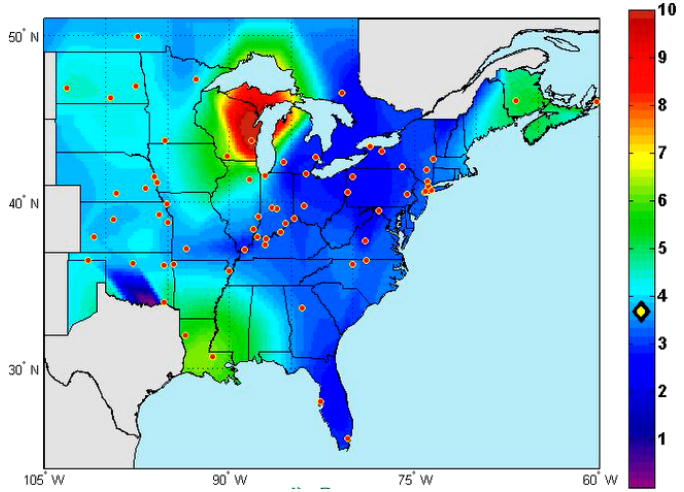
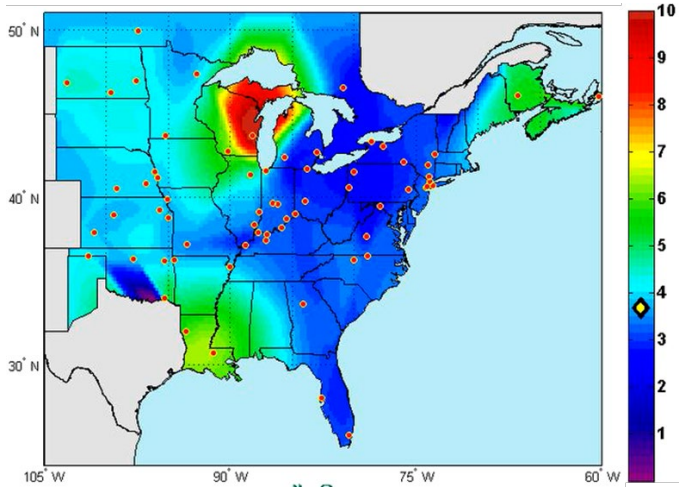
# Simulation Results in EI 70k-bus Model




No Control



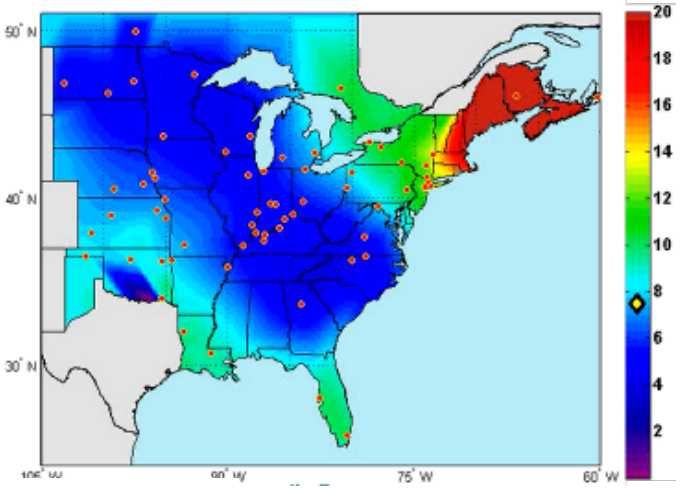

With Control
(1×409 MW BESS in Florida)



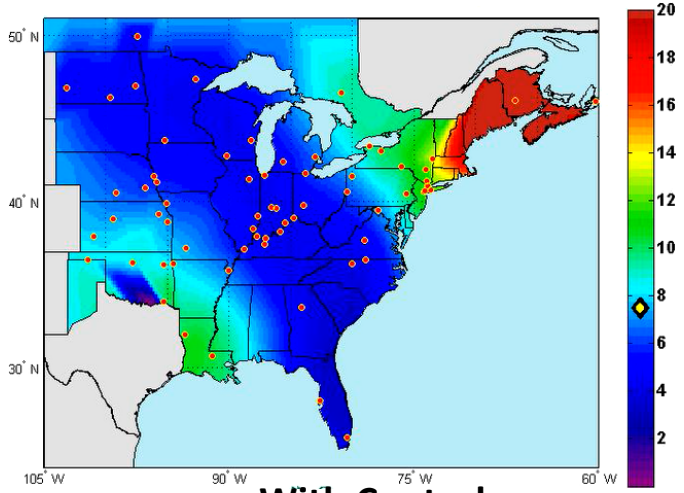

With Control
(12 ×35 MW BESS in Florida)

**Source: MISO**

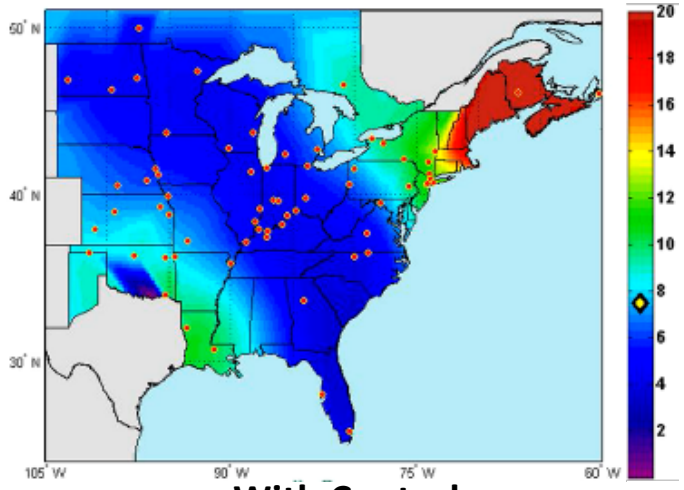
**Battery: Florida**




No Control




With Control
(1×409 MW BESS in Florida)




With Control
(12 ×35 MW BESS in Florida)

**Source: ISO-NE**

**Battery: Florida**

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