Forced Oscillation Grid Vulnerability Analysis: Texas Grid Case Study

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Outline

- A forced oscillation grid vulnerability analysis method is proposed to identify areas/zones in the system critical to forced oscillation

- Effective actuator location is identified through two-dimension scanning method.

- Active power modulation control through IBRs is proposed to reduce the forced oscillation impact .

- Simulation results on the 2000-bus synthetic Texas grid.

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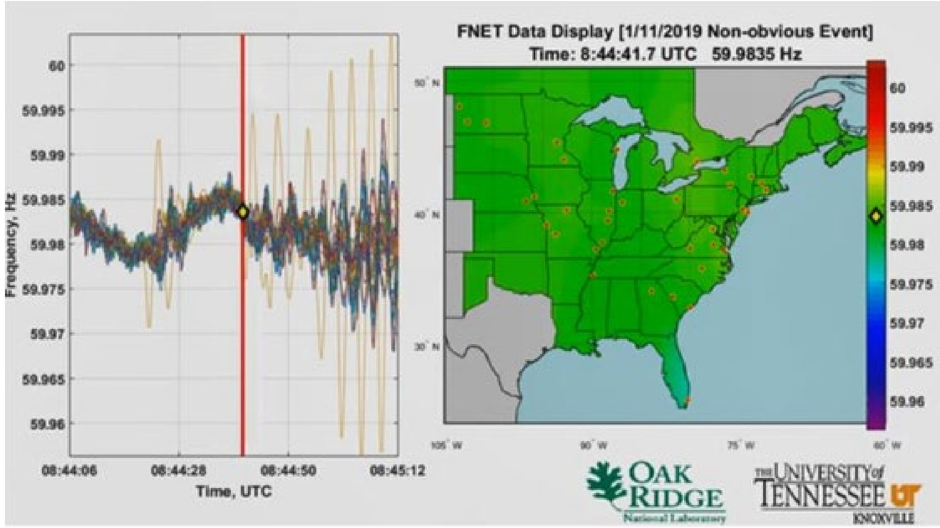
Background-Forced Oscillation

- Cause of forced oscillation
  - is usually caused by an external periodic disturbance from control malfunction or equipment failure.
- Impact:
  - can deteriorate power system stability, damage equipment and reduce power quality.
  - When coincide with dominant natural mode, the oscillation amplitude can be significantly amplified
- The recent 2019 EI forced oscillation event lasted 18 minutes before the forced source was located and removed.

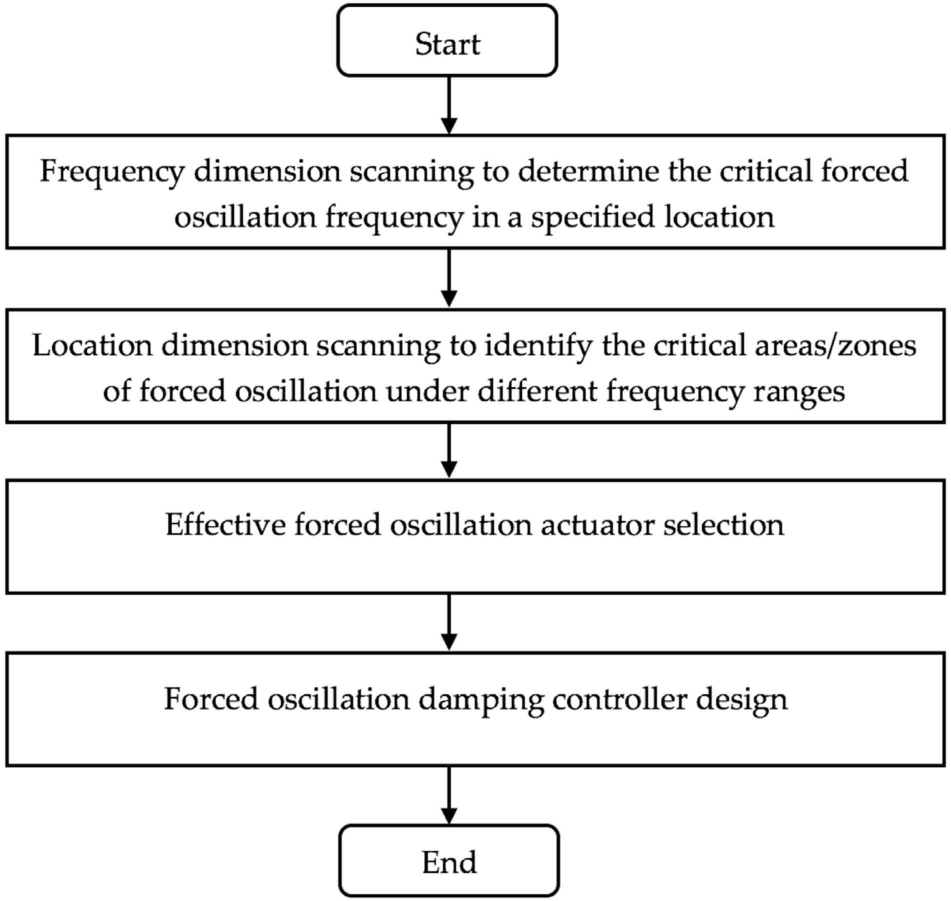


January 11, 2019, EI forced oscillation event [1]

[1]. Eastern Interconnection Oscillation Disturbance January 11, 2019 Forced Oscillation Event, North Amer. Electr. Rel. Corp., Atlanta, GA, USA, Dec. 2019

Grid Vulnerability Analysis Method

Flowchart



- Changing oscillation frequency from 0.1Hz to 1.5 Hz with a 0.05Hz step size
- Implement forced source at large generators in different zones
- Identify the effective actuator as locations with maximum peak-to-peak bus frequency deviation
- Oscillation damping controller design through IBRs

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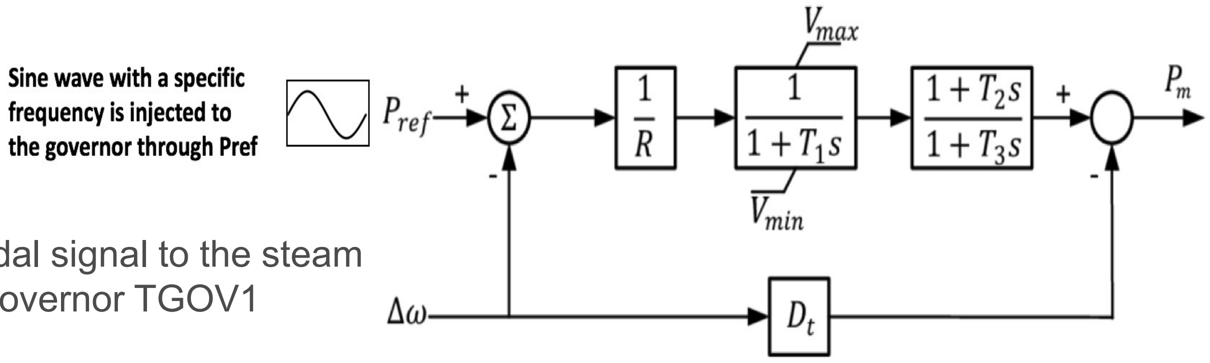
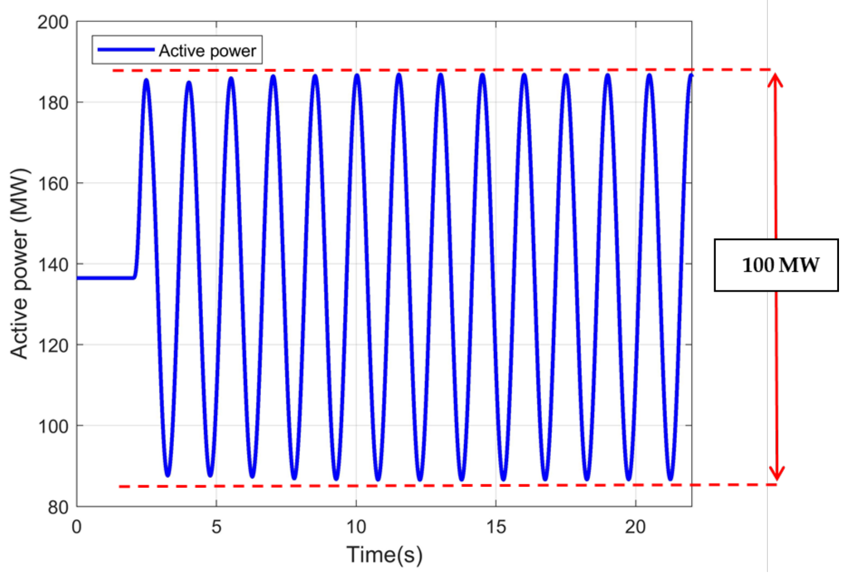
Grid Vulnerability Analysis Method

- Forced oscillation is excited by changing the active power set point of a generator governor model.
- The amplitude of the disturbance was adjusted to generate same peak-to-peak oscillation energy for all the sources.
- The peak-to-peak force oscillation energy is set to be 100MW

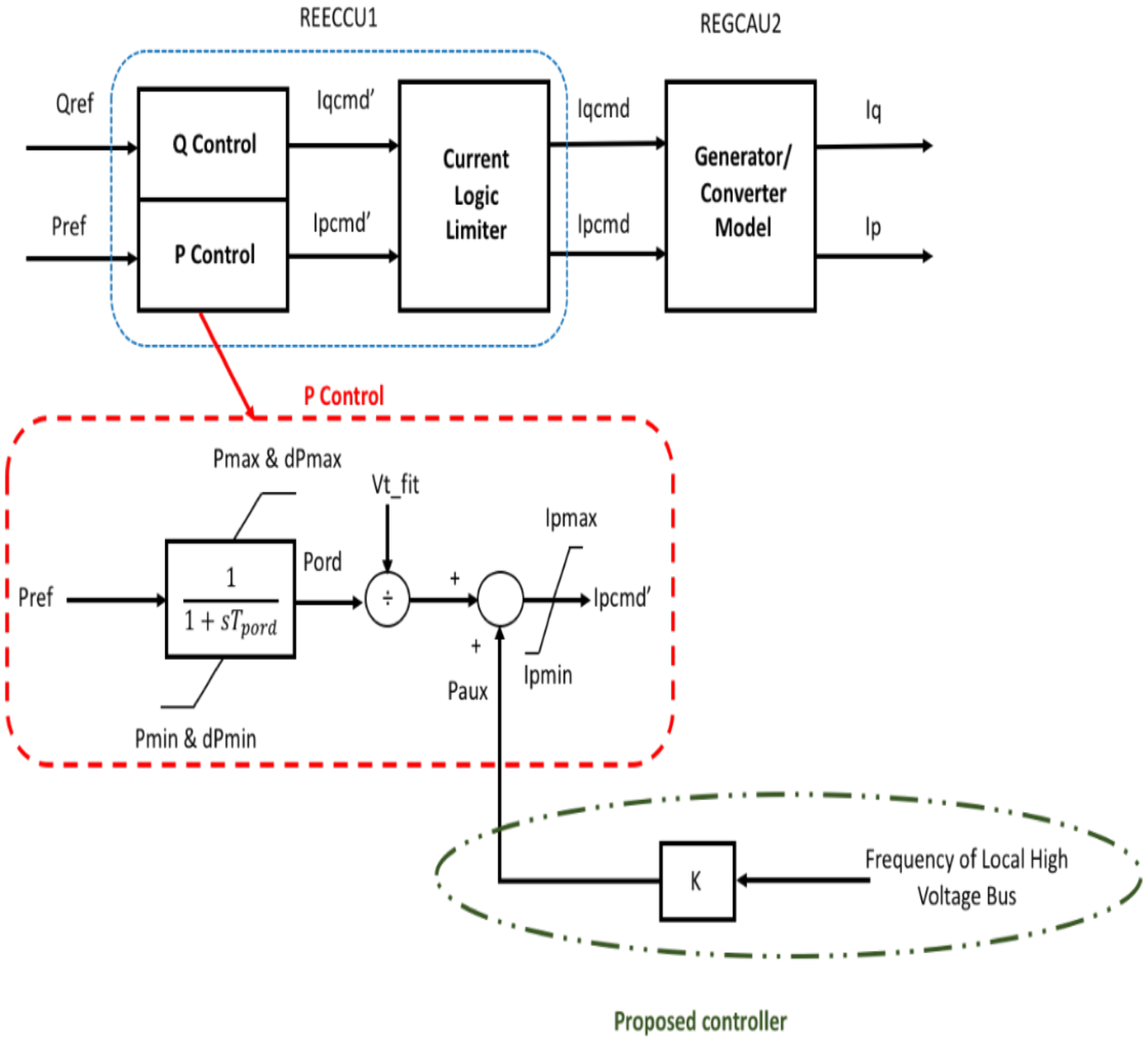


Adding sinusoidal signal to the steam turbine-governor TGOV1



Force oscillation mitigation through IBR

- The IBRs are modeled using the generic model developed by WECC.
- The force oscillation damping controller
  - a droop controller through active power modulation of IBR.
  - bus frequency of a local high voltage bus as input



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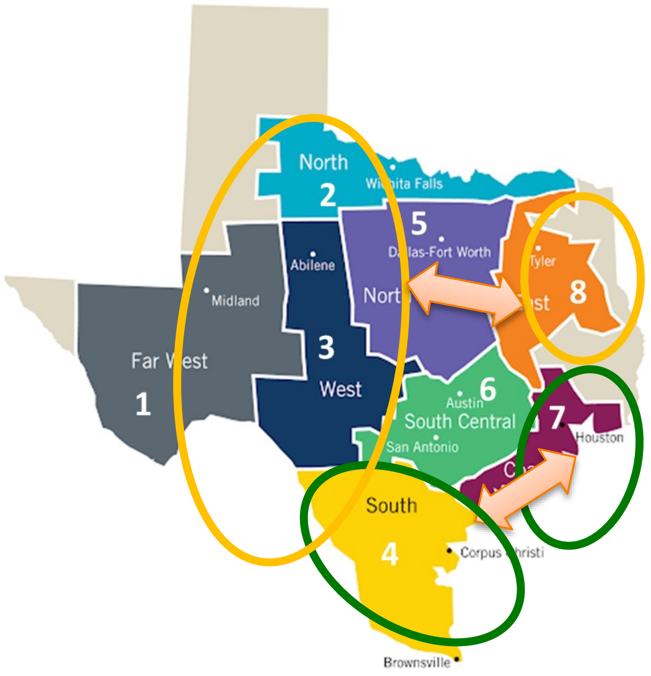
Synthetic Texas Power System Case Study

- The 2000-bus synthetic Texas power grid model developed by Texas A&M was used for the forced oscillation study.
- The model consist of 8 areas and 28 zones.
- The actual total generation is 68.7GW including 8.87GW of renewable generation (12.9%).
- The dominant oscillation mode is 0.67Hz with a damping ratio of 5.1%.
- The other is a 0.60 Hz oscillation mode between Areas 1, 2, 3, 4, 5, and parts of Area 8 and Area 7, with a damping ratio of 6.31%.

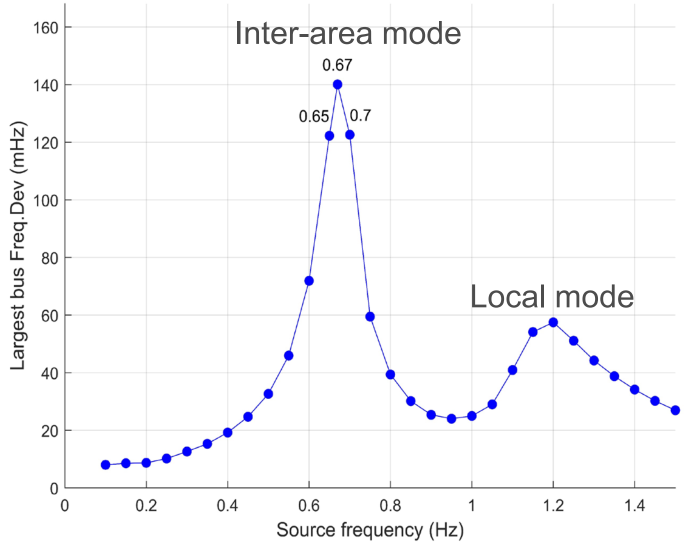


2000-bus synthetic Texas power grid diagram.[2]

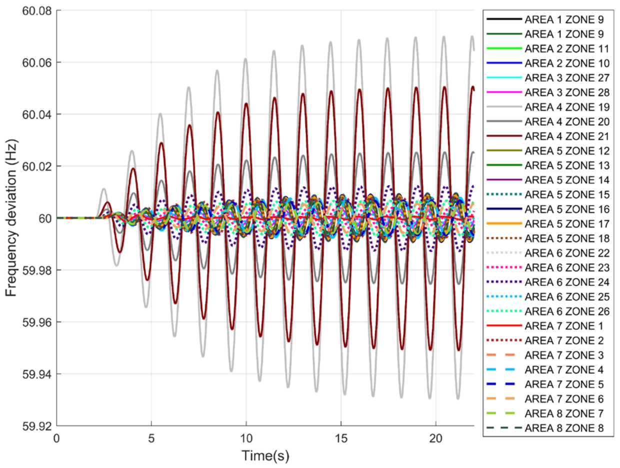
[2]. ERCOT weather zone map. Available online: https://www.ercot.com/news/mediakit/maps

Texas Case Study: Frequency Dimension Scanning

- The largest synchronous generator at each zone is selected as a force source.
- Frequency dimension scanning involves changing the forced oscillation frequency at a fixed source location.
- The force oscillation frequency ranges from 0.1 Hz to 1.5 Hz with a step size of 0.05 Hz. 0.67Hz was also included.



Frequency dimension scanning results when the forced source at Area 4 Zone 19



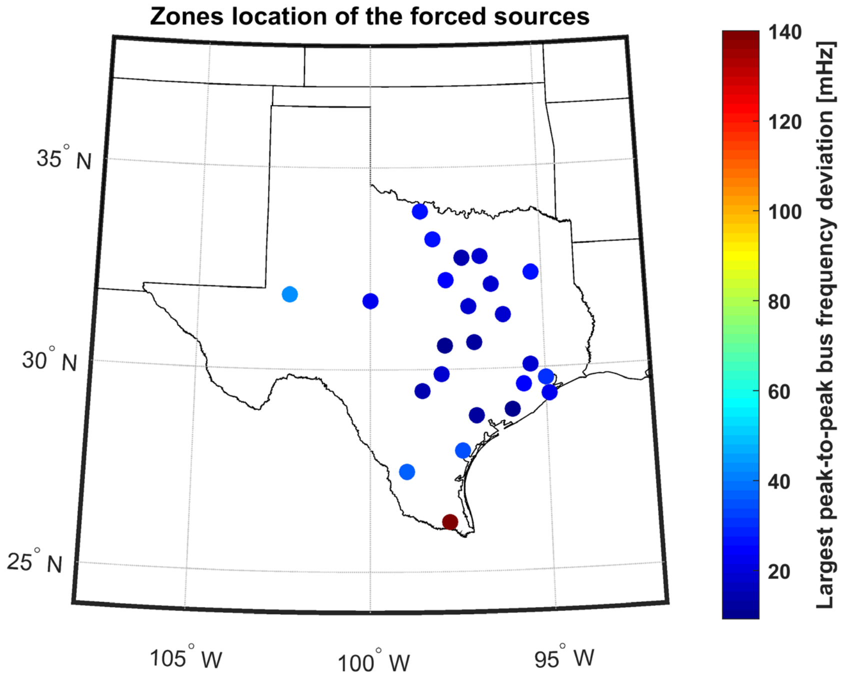
Frequency response at different zones when the 0.67 Hz force oscillation source is located at Area 4 Zone 19

Texas Case Study: Location Dimension Scanning

- Example when force oscillation frequency is 0.67Hz

Result of location scanning at frequency 0.67Hz

Source location	Area – zone with largest bus frequency deviation	Peak-to-peak bus frequency deviation (mHz)
Area 4 Zone 19	Area 4 Zone 19	140.090
Area 1 Zone 9	Area 4 Zone 19	43.622
Area 4 Zone 20	Area 4 Zone 19	37.798
Area 4 Zone 21	Area 4 Zone 19	34.996
Area 7 Zone 4	Area 4 Zone 19	30.780
Area 5 Zone 12	Area 4 Zone 19	27.221
Area 8 Zone 8	Area 4 Zone 19	27.125
Area 2 Zone 11	Area 4 Zone 19	26.910
Area 7 Zone 3	Area 4 Zone 19	25.536
Area 5 Zone 18	Area 4 Zone 19	24.451
Area 7 Zone 2	Area 4 Zone 19	23.359
Area 3 Zone 28	Area 3 Zone 28	23.172
Area 8 Zone 7	Area 4 Zone 19	19.345
Area 7 Zone 5	Area 4 Zone 19	18.532
Area 5 Zone 14	Area 4 Zone 19	18.099
Area 5 Zone 16	Area 4 Zone 19	17.938
Area 6 Zone 22	Area 4 Zone 19	17.764
Area 5 Zone 13	Area 4 Zone 19	17.663
Area 5 Zone 17	Area 4 Zone 19	15.185
Area 6 Zone 26	Area 4 Zone 19	13.886
Area 7 Zone 6	Area 4 Zone 19	12.948
Area 6 Zone 25	Area 4 Zone 19	11.598
Area 6 Zone 23	Area 4 Zone 19	9.652
Area 7 Zone 1	Area 7 Zone 4	9.191



Generator location	Generator	Participation factor (0.67Hz)
Area 4 Zone 19	4192	1.00
Area 4 Zone 21	4058	0.72
Area 4 Zone 20	4115	0.40
Area 8 Zone 8	8080	0.19
Area 1 Zone 9	1051	0.18
Area 5 Zone 12	5063	0.18
Area 2 Zone 11	2023	0.18
Area 5 Zone 18	5319	0.17

Participation factor of 0.67Hz oscillation mode

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Texas Case Study: Actuator Selection of Forced Oscillation Control via IBRs

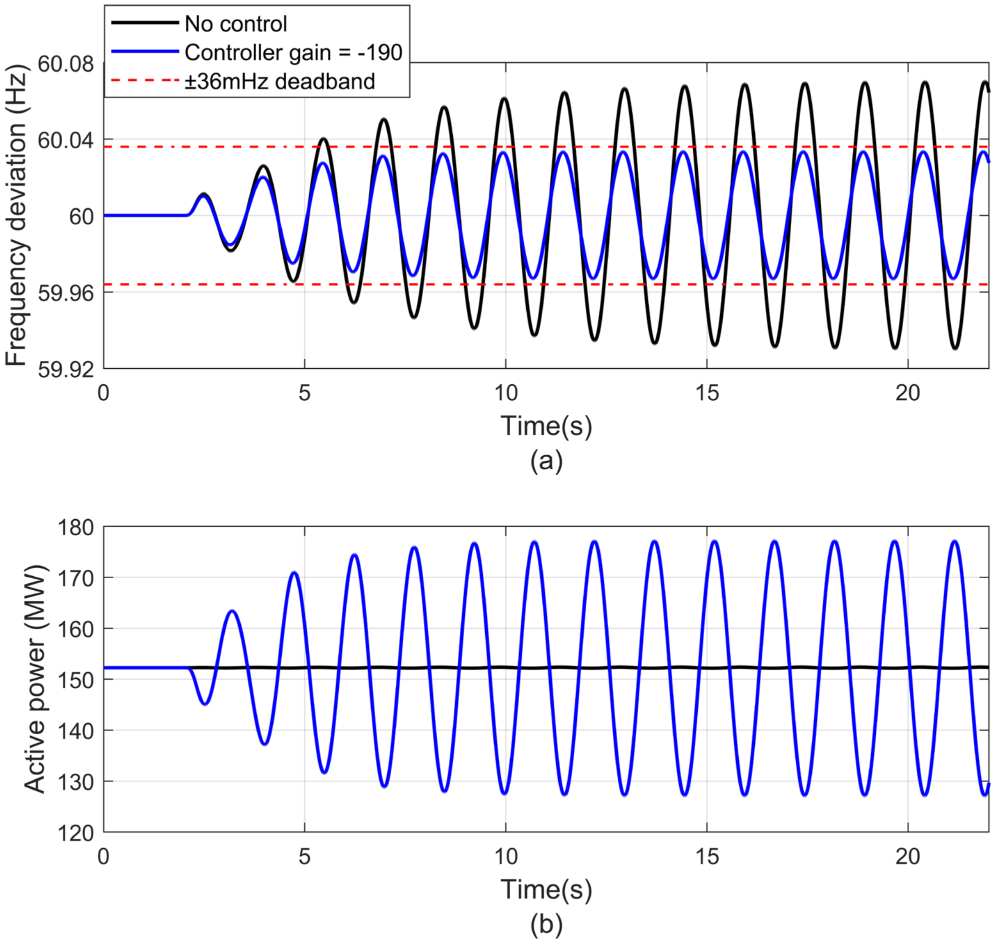
- The actuator with local measurement is effective when it is close to the force source.
- The critical locations under different range of frequencies can be considered as the effective actuator location.

Effective actuator selection based on two-dimensional scanning

Source location	Oscillation frequency (Hz)	Area – zone with largest bus frequency deviation	Peak-to-peak bus frequency deviation (mHz)
Area 1 Zone 9	0.1	Area 7 Zone 4	8.00
Area 1 Zone 9	0.15	Area 7 Zone 4	10.53
Area 1 Zone 9	0.2	Area 7 Zone 4	14.67
Area 1 Zone 9	0.25	Area 7 Zone 4	17.33
Area 1 Zone 9	0.3	Area 7 Zone 4	18.35
Area 1 Zone 9	0.35	Area 7 Zone 4	18.00
Area 4 Zone 19	0.4	Area 4 Zone 19	19.19
Area 3 Zone 28	0.45	Area 3 Zone 28	25.22
Area 4 Zone 19	0.5	Area 4 Zone 19	32.63
Area 4 Zone 19	0.55	Area 4 Zone 19	45.95
Area 4 Zone 19	0.6	Area 4 Zone 19	71.88
Area 4 Zone 19	0.65	Area 4 Zone 19	122.30
Area 4 Zone 19	0.67	Area 4 Zone 19	140.09
Area 4 Zone 19	0.7	Area 4 Zone 19	122.58
Area 4 Zone 19	0.75	Area 4 Zone 19	59.45
Area 4 Zone 19	0.8	Area 4 Zone 21	39.37
Area 4 Zone 19	0.85	Area 4 Zone 21	30.16
Area 3 Zone 28	0.9	Area 3 Zone 28	30.35
Area 3 Zone 28	0.95	Area 3 Zone 28	31.79
Area 3 Zone 28	1	Area 3 Zone 28	31.78
Area 3 Zone 28	1.05	Area 3 Zone 28	33.20
Area 4 Zone 19	1.1	Area 4 Zone 19	40.93
Area 4 Zone 19	1.15	Area 4 Zone 19	54.10
Area 4 Zone 19	1.2	Area 4 Zone 19	57.49
Area 4 Zone 19	1.25	Area 4 Zone 19	51.09
Area 4 Zone 19	1.3	Area 4 Zone 19	44.23
Area 3 Zone 28	1.35	Area 3 Zone 28	46.49
Area 3 Zone 28	1.4	Area 3 Zone 28	48.79
Area 3 Zone 28	1.45	Area 3 Zone 28	51.21
Area 3 Zone 28	1.5	Area 3 Zone 28	53.53

Texas Case Study: Forced Oscillation Control via IBR

- Forced source: Area 4 Zone 19
  Effective actuator: Area 4 Zone 19
- The feedback signal is a local high voltage bus.
- The droop controller is set to be -190.
- When the actuator at the same zone of the force source, the peak-to-peak bus frequency deviation is reduced at all zones in the system within governor dead band ±36mHz.

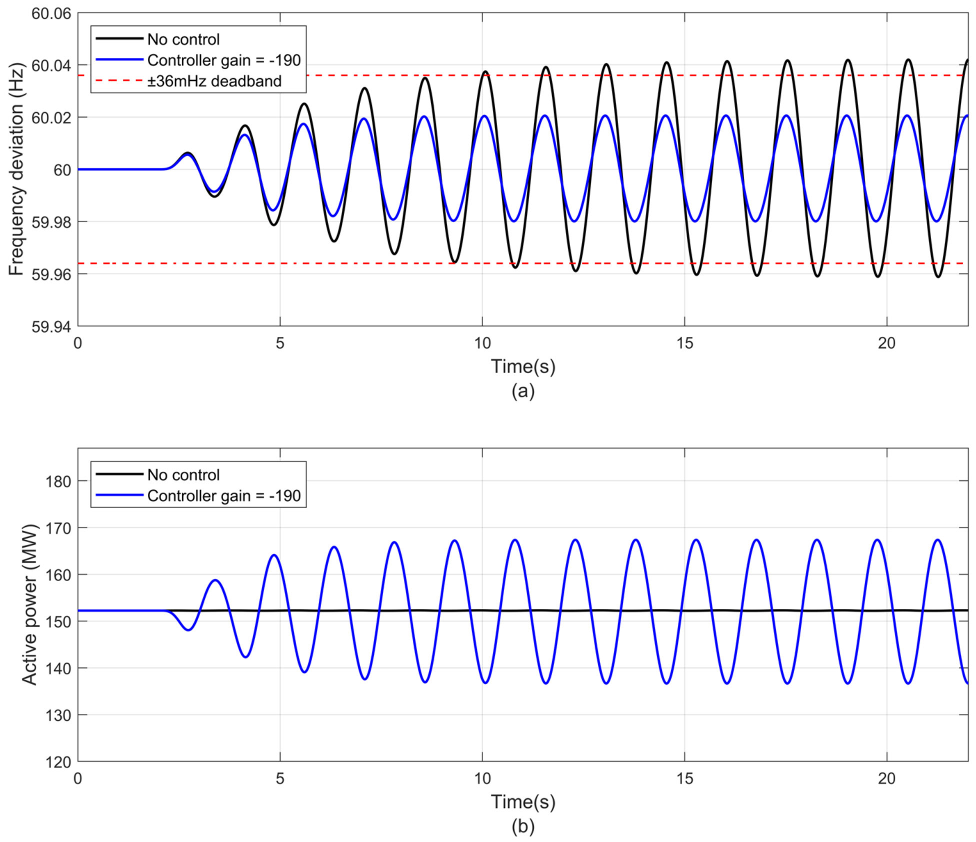


(a) Area 4 Zone 19 Frequency deviation improvement and (b) active power output of the actuator at Area4 Zone 19 when the forced source at Area 4 Zone 19.

Texas Case Study: Forced Oscillation Control via IBR

- Forced source: Area 4 Zone 19
  Effective actuator: Area 4 Zone 19

- When the actuator close to the same zone of the force source, the peak-to-peak bus frequency deviation is reduced at all zones in the system within governor dead band ±36mHz.



(a) Area 4 Zone 19 Frequency deviation improvement and (b) active power output of the actuator at Area4 Zone 19 when the forced source at Area 4 Zone 20.

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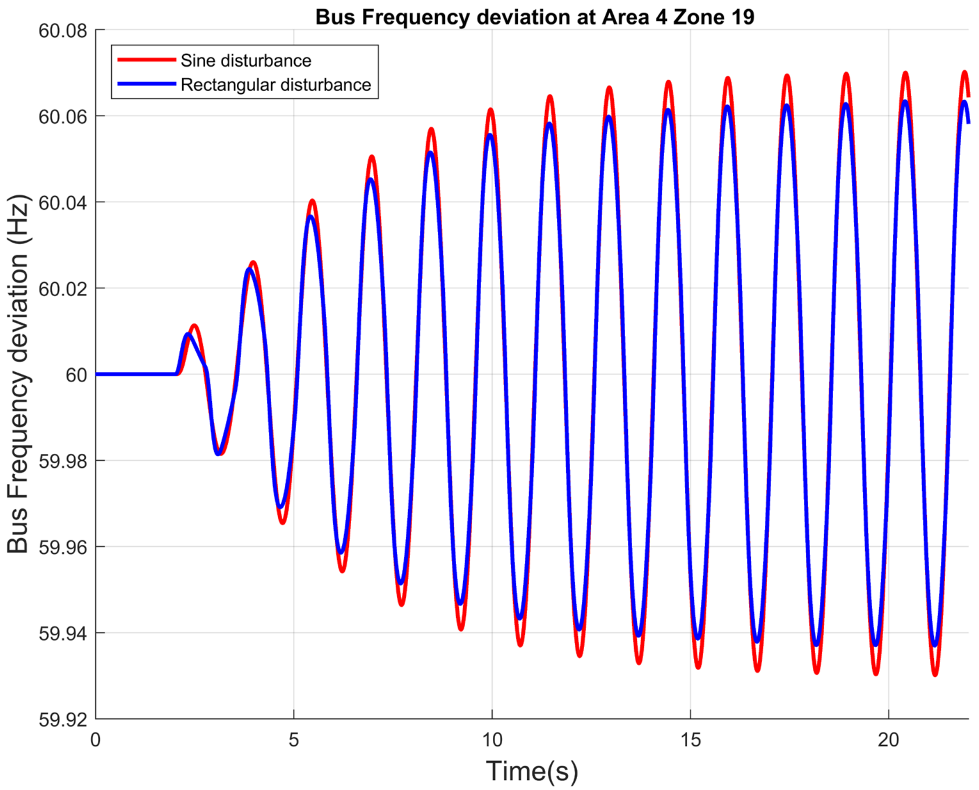
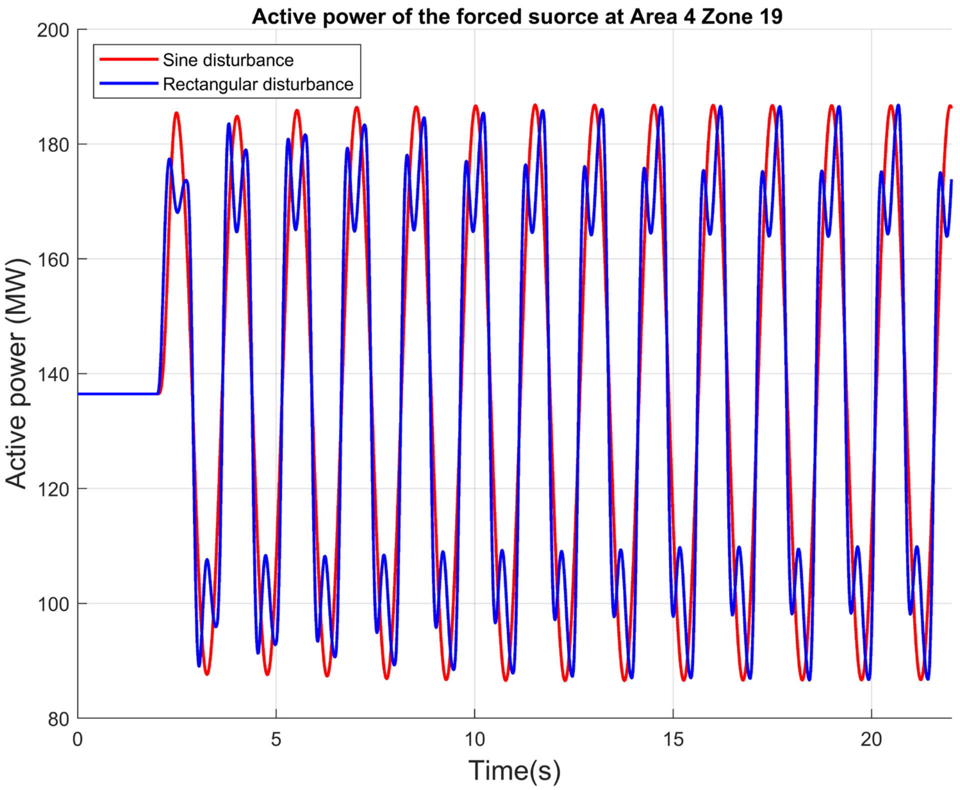
Texas Case Study: Comparison between Sine and Rectangular Wave Disturbance

Bus frequency deviation at Area 4 Zone 19



Active power of the forced source at Area 4 Zone 19



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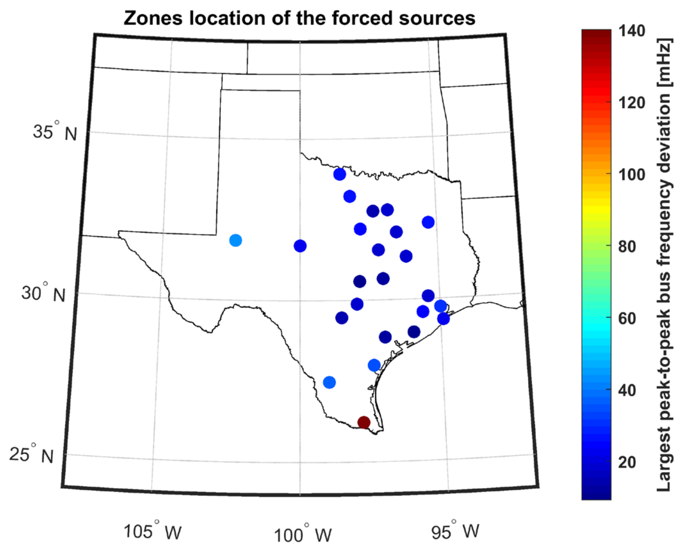
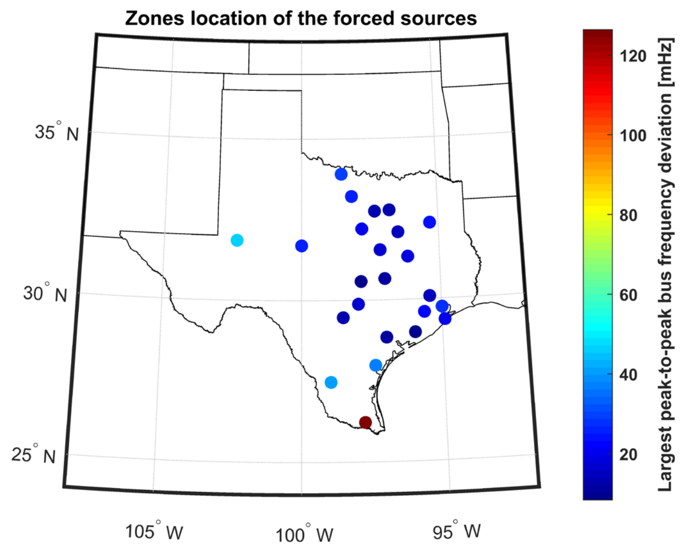
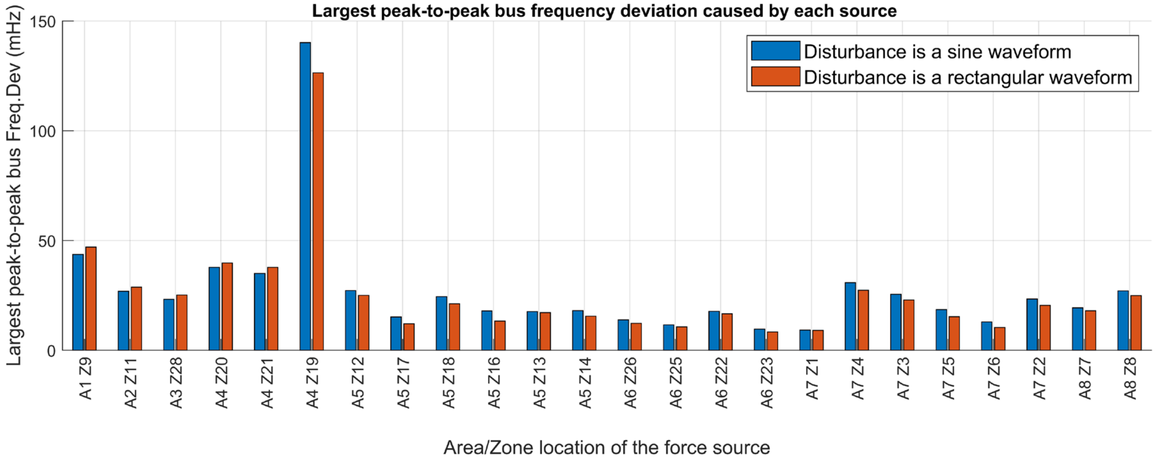
Texas Case Study: Comparison between Sine and Rectangular Wave Disturbance

Disturbance in the form of a sine wave



Disturbance in the form of a rectangular wave





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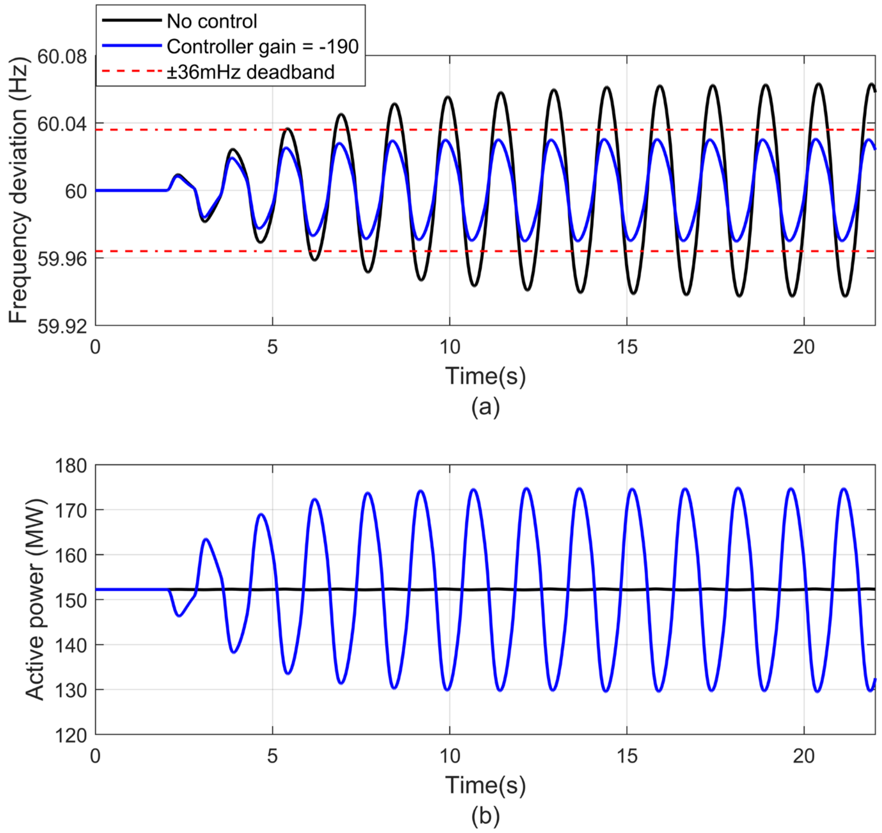
Texas Case Study: Forced Oscillation Control via IBR

- Disturbance is a rectangular waveform with forced oscillation frequency of 0.67Hz

- The actuator is at Area 4 Zone 19 and the force source is at Area 4 Zone 19.



(a) Area 4 Zone 19 Frequency deviation improvement and (b) active power output of the actuator at Area4 Zone 19 when the forced source at Area 4 Zone 19.

Summary and Future Work

- Forced oscillation amplitude amplified at the resonance especially when the source is located at a zone with high participation factor.

- Power oscillation damping controller through IBR was effective in reducing the impact of force oscillation.

- When the actuator is closed to the forced source, the frequency deviation of all the zones in the Texas synthetic system can be reduced.

- Future work:
  - Study the impact of force oscillation through reactive power perturbation.
  - Determine a methodology to set the controller droop gain.

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Thank You!

Q&A