Datasets for Power System Forced Oscillation Responses (DPSYFOR)

(Pronounced as Decipher)

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ESIC

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Background

Forced Oscillations

Presence of external input or malfunctioning apparatus, cyclical or periodic external inputs, control interactions

- FO is modeled as a sinusoidal input disturbance:

$$u(t) = A_0 \sin(2\pi f_0 t + \phi_0)$$

So, $\dot{x}$= f(x, u)

- A_0, f_0, and ϕ_0 are amplitude, frequency and phase of the FO input

Existing FO datasets

2021 IEEE-NASPI Oscillation Source Location Contest [1]

#	Oscillation source information	Source monitored by PMU?	Frequency, Hz	Resonance?	Source location, bus/generator	Other key features
1	Generator – Governor	Yes	0.82	No	1431 N	• Easy case of monitored source without resonance
2	Generator – Governor	Yes	1.19	Yes	2634 C	• FO resonates with a local mode at 1.19 Hz • 1.19-Hz natural mode is excited by a fault
3	Generator – Exciter	No	0.379	Yes	1131 G	• The source is in the exciter; FO resonates with the lowest-frequency inter-area mode
4	Generator – Governor	No	0.379	Yes	3831 NN	• The source is in the governor; FO resonates with the lowest-frequency inter-area mode
5	Generator – Governor	No	0.68, 0.76	Almost	4231 C	• Changed the frequency of forced signal from 0.68 Hz before t=58 s to 0.76 Hz after t=61 s without creating resonance. System has modes at: 0.614 Hz, 0.708 Hz, 0.741 Hz and 0.78 Hz
6	Generator – Governor	Yes	1.27	Yes	7031 C	• FO resonates with a local mode in the North area • Line 2604-6404_1 is tripped at t=70 s, slightly changing FO shape
7	Generator – Exciter	Yes	0.379	Yes	2634 C	• FO resonates with the lowest-frequency inter-area mode at 0.379 Hz • Strong FO interaction with controls potentially misleading energy-based methods
8	Generator – Governor	Yes	0.614	Yes	6333 C	• FO resonates with a regional inter-area mode at 0.614 Hz • PMU is available only from the North area, where the source is located
9	Generator – Governor Generator – Exciter	Yes Yes	0.762	Yes Yes	6533 C 4131 H	• FO resonates with a natural mode whose damping is reduced by adjusting PSS gain (KS=–2) in the generator 4131_H, creating negative damping contribution from that generator
10	Generator – Governor Generator – Governor	No Yes	1.218 0.614	Yes Yes	3931 NB 6335 C	• There are two FOs, and each resonates with a natural mode
11	Load	Yes	0.614	Yes	4009	• FO resonates with a regional inter-area mode at 0.614 Hz • The source is the load at Bus 4009. This bus has also connection to HVDC and a generator (neither is a source)
12	Generator – Governor	Yes	0.377, 0.744, 1.11, 1.48	Almost	6335 C	• Rectangular forcing signal (fundamental frequency=0.377 Hz) • The second harmonic resonates with a natural mode
13	HVDC	Yes	0.614	Yes	4010 and 2619	• FO resonates with a regional inter-area mode at 0.614 Hz • Source is in the HVDC controls at California side, while both terminal buses 4010 and 2619 may look like the sources in the AC network

[1] S. Maslennikov and B. Wang, “Creation of simulated test cases for the oscillation source location contest,” in 2022 IEEE Power Energy Society General Meeting (PESGM), pp. 1–1, 2022.

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Proposed FO datasets

Power Grid Models: to design and simulate FO datasets

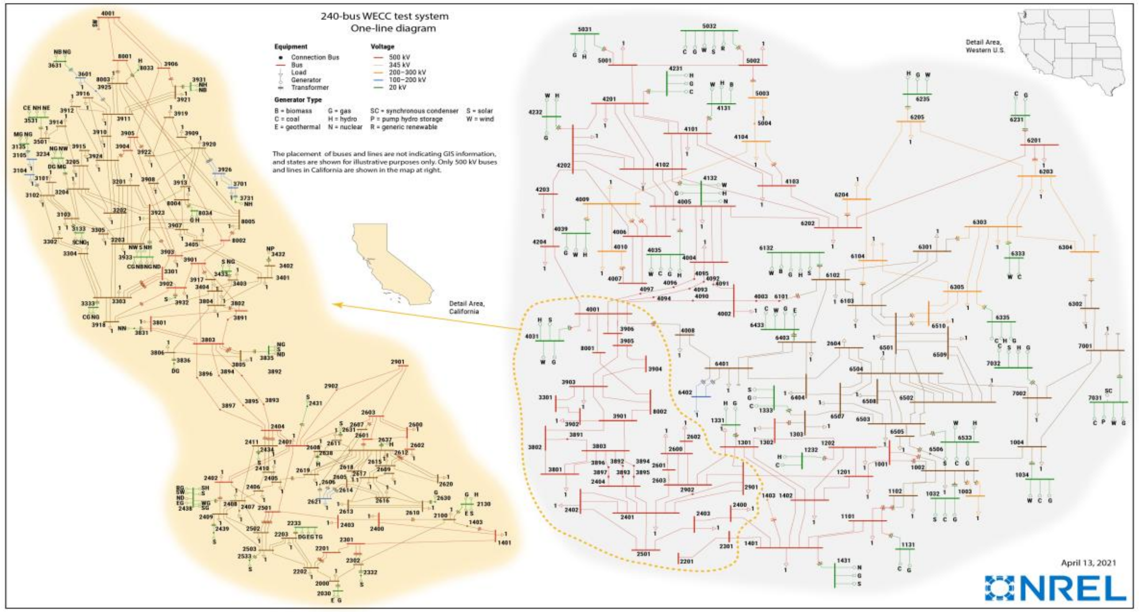

Fig 1: One-line diagram of the 240-bus system developed by NREL[1]

- Number of buses: 243
- Generator units: 146 units
  - Synchronous machine: 109
  - Renewable: 37
- Transmission lines: 329
- Transformers: 122
- Loads: 139

Fig 2: One-line diagram of the Western Interconnection (Validated model of the August 10, 1996 blackout[2])

- Number of buses: 15000
- Generator units: 1000 units

[1] H. Yuan, R. S. Biswas, J. Tan, and Y. Zhang, “Developing a reduced 240-bus WECC dynamic model for frequency response study of high renewable integration,” 2020.
[2] V. Venkatasubramanian and Y. Li, “Analysis of 1996 western American electric blackouts,” in *Proc. Bulk Power System Dyn. Control Conf.*, Venice, Italy, 2004, pp. 685–721.

Responses of FO

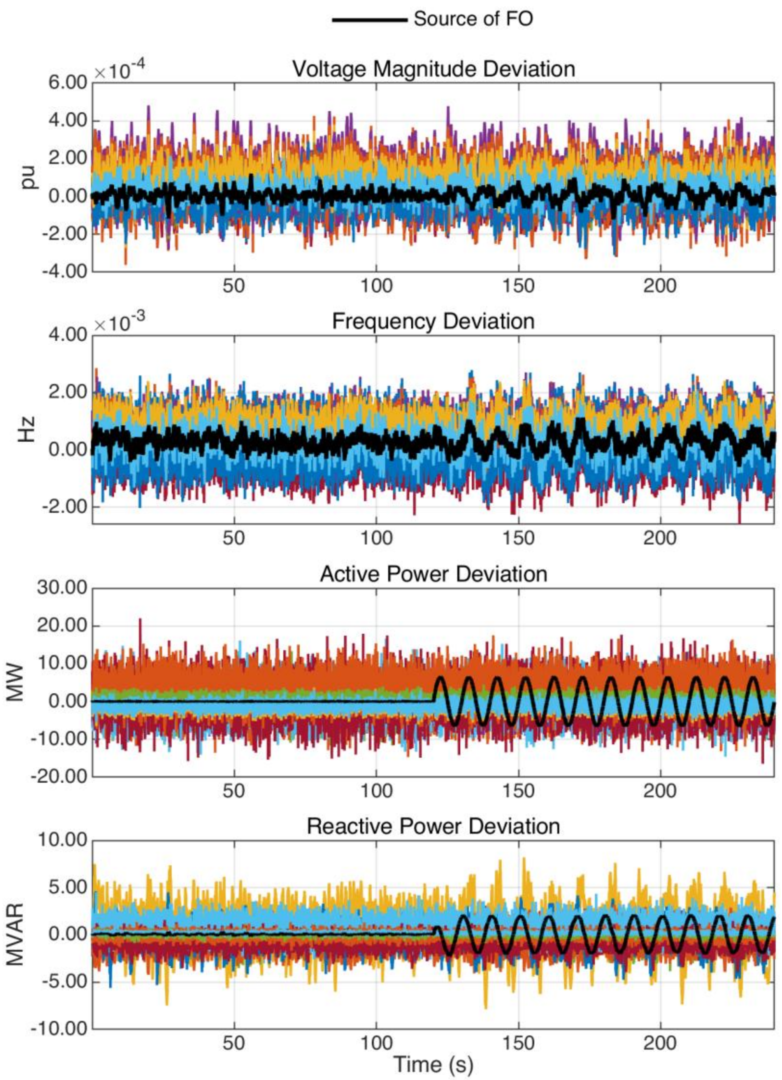

Fig 1: Responses when the FO of frequency 0.1 Hz is injected at the TGOV1 governor of the 4035 C generator

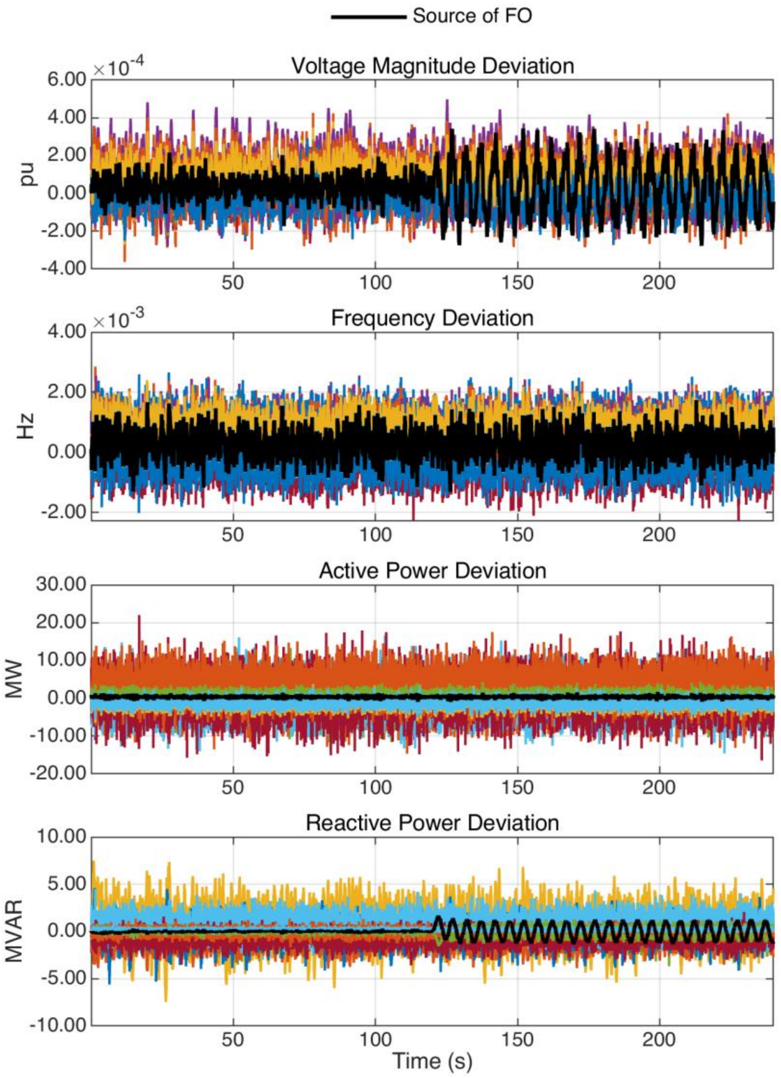

Fig 2: Responses when the FO of frequency 0.2 Hz is injected at the SEXS exciter of the 2030 E generator

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FO datasets

Dataset insight

Data length: 240 seconds, FO injected at 120 seconds

Reporting rate: 30 frames per second

Oscillation source: governor (TGOV1, HYGOV), exciter (SEXS, IEEEX1)

Oscillation frequency: 0.1 Hz, 0.2 Hz, …, 1.5 Hz

Oscillation amplitude: 1%, 5%, and 10%

Measured quantity: time, bus voltage magnitude, bus voltage phase angle, active and reactive power outputs at generator buses

File name: FO_<source>_<magnitude>_<frequency>_<bus number>_<generator type>

example: FO Gov 0.02pu 0.10Hz 1032 C

Each data file: Mini-WECC model: 7201 rows and 1117 columns

Large WECC model: 7201 rows and 4201 columns

Total cases: 27000 FO scenarios

FO datasets

Table 1: Summary of FO datasets for 240 Mini-WECC System

System	Case	System Information	Mag. (pu)	Freq. (Hz)	Oscillation Sources	No. of Cases
240 Mini-WECC System	Case-1	System damping is lower than 2%	0.01	0.1, 0.2, 0.3,...,1.5	TGOV1, HYGOV, SEXS	2565
			0.05			2565
			0.10			2565
	Case-2	System damping is higher than 4%	0.01			2565
			0.05			2565
			0.10			2565
	Case-3	Case-2 with varying PSS numbers	0.01			2800
	Case-4	0.73 negatively damped mode	0.01			2565
			0.05			2565
			0.10			2565
Total						**25885**

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FO datasets

Table 1: Summary of FO datasets for the Large WECC system

System	Case	System Information	Magnitude (pu)	Frequency (Hz)	Oscillation Sources	No. of Cases
Large WECC System	Case-1	System damping is higher than 4%	0.1, 0.01, and 0.05	Randomly selected between 0.1–1.5	TGOV1, IEEEX1	3000

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Existing FO Source Location Approaches:

Amplitude based method:

This method assumes that the resonance effect with natural modes is not strong.

The method identifies the source by analyzing the oscillation amplitudes in the generator's real and reactive power outputs.

The generator exhibiting **the largest oscillation amplitude** in either channel is considered the potential FO source.

Specifically, real power measurements are effective for detecting governor-based FOs, whereas reactive power measurements are more sensitive to exciter-based FOs.

The oscillation type can be inferred by comparing the magnitudes of the dominant signals in both real and reactive power.

Existing FO Source Location Approach:

Dissipating energy flow (DEF) method:

It performs a decentralized calculation of oscillation energy at the machine level using PMU data

$$W^{D}_{ij,t+1} = W^{D}_{ij,t} + 2\pi\,\Delta P_{ij,t}\,\Delta f_{i,t}\,t_s + \Delta Q_{ij,t}\,\frac{\Delta V_{i,t+1} - \Delta V_{i,t-1}}{2V^{*}_{i,t}}$$

where,

$W^{D}_{ij,t+1}$, ΔP_{ij} and ΔQ_{ij} denotes the flow of dissipated energy, sinusoidal steady state active and reactive power flows in branch ij

Δf_i and V_i denotes denotes deviations from the steady − state value of the frequency and voltage magnitude at bus i

$V_i^* = \overline{V} + \Delta V_i$ is the average voltage in the studied period and t_s is the time Interval between PMU samples

Generator unit with highest dissipating energy is the source of FO.

Mini-WECC Results

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FO at the Governor

Case	FO magnitude (pu)	Amplitude Based (%)	DEF (%)
Case-1	0.01	38.06	99.35
	0.05	67.93	99.68
	0.1	67.24	98.49
Case-2	0.01	41.93	99.78
	0.05	68.04	100
	0.1	75.38	100
Case-3	0.01	32.56	98.29

Note: Case-1: 0.01 and 0.05 were tested on frequency ranging from 0.1 Hz to 1 Hz for both DEF and amplitude method

Mini-WECC Results

FO at the Exciter

Case	FO magnitude (pu)	Amplitude based (%)	DEF (%)
Case-1	0.01	3.59	40.59
	0.05	22.59	58.18
	0.1	38.83	61.78
Case-2	0.01	3.82	38.84
	0.05	22.85	58.77
	0.1	40.75	58.61
Case-3	0.01	2.34	41.27

Results

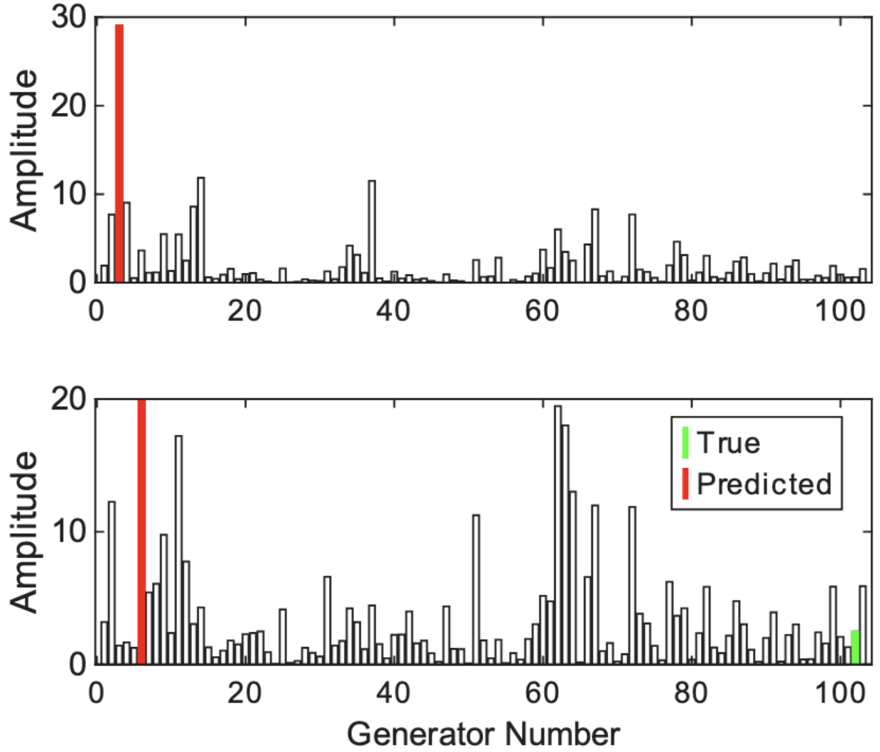

Fig 1: Oscillation amplitudes of active/reactive powers of generators in the mini-WECC system during FO for cases with correct (top) and incorrect (bottom) source locations by the amplitude-based method

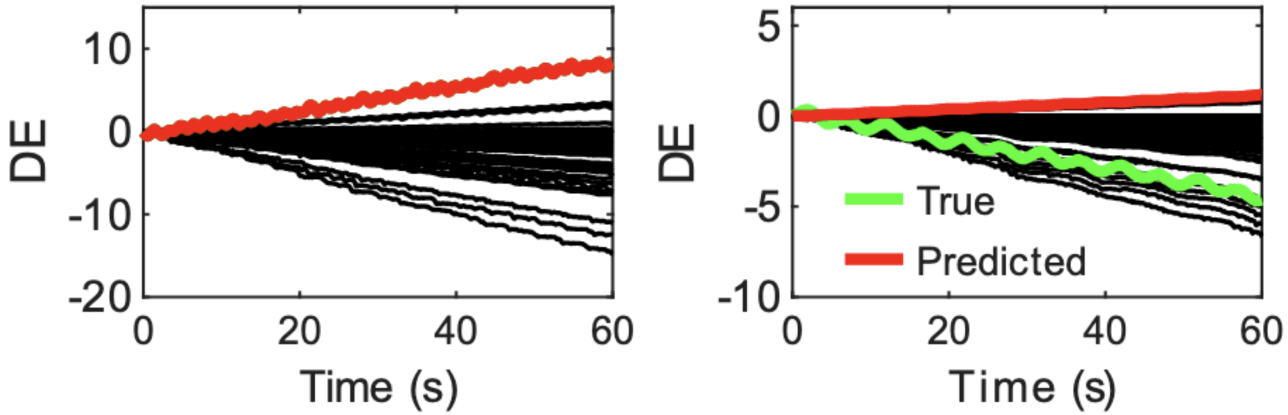

Fig 2: Dissipating energy of generators in the mini-WECC system during FO for cases with correct (left) and incorrect (right) DEF estimations

Conclusion

- ❑ The proposed FO dataset library is an effective resource for studying and analyzing existing FO source location algorithms, as well as developing data-driven machine learning models

- ❑ Existing methods show limitations when tested on extensive test cases.

- ❑ There is still a need to develop a reliable FO source location algorithm that works universally.

W A S H I N G T O N   S T A T E   U N I V E R S I T Y

References

D. Joshi, S. Ghimire, H. Wajid, and V. M. Venkatasubramanian, “Forced oscillation analysis using physics-based and machine learning models on a comprehensive dataset library,” Power Systems Computations Conference, Electric Power Systems Research (EPSR), to appear, 2026.

D. Joshi, M. Kc, H. Wajid and V. Venkatasubramanian, ”Descriptor: Dataset for Power SYstem Forced Oscillation Responses (DPSYFOR),” in IEEE Data Descriptions, vol. 3, pp. 19-24, 2026

DPSYFOR data set available at

https://eecs.wsu.edu/research/esic/sail/

eecs.wsu.edu/research/esic/sail/Forced Oscillation Dataset/

Index of /research/esic/sail/Forced Oscillation Dataset

Name	Last modified	Size	Description
Parent Directory		-	
240 Mini-WECC Model/	2026-01-12 10:46	-	
Model/	2026-01-12 10:51	-	
Validated 1996 WECC Model/	2026-01-12 10:52	-	

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Thank you!

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Motivation

0.25 Hz forced oscillation observed across several areas in the Eastern Inter-connection

Interact with a frequency close to that of a well-known North-South mode of Eastern Interconnection (EI,) having a frequency of 0.22 Hz

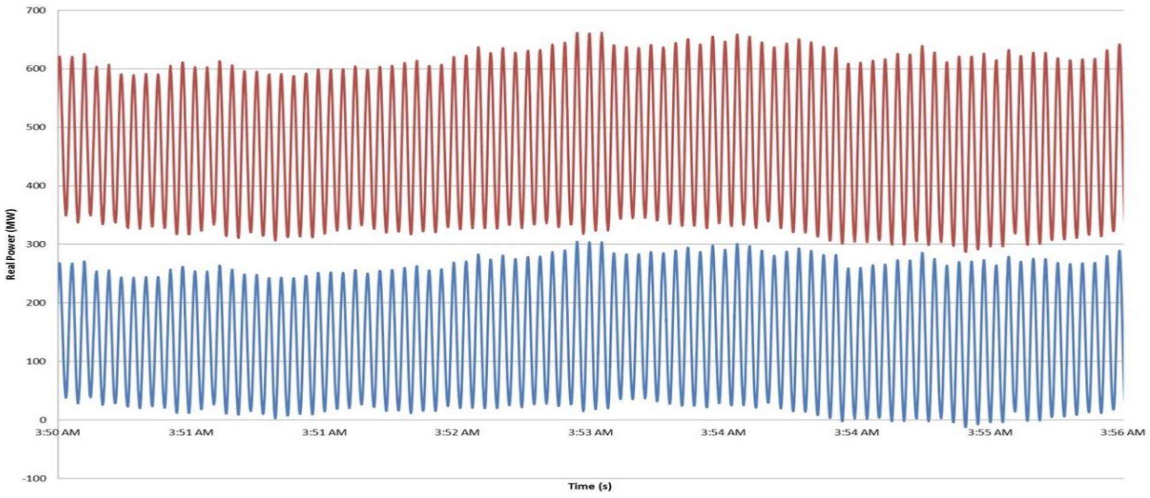


Fig 1: FO Observed in the Real Power of EI[1]

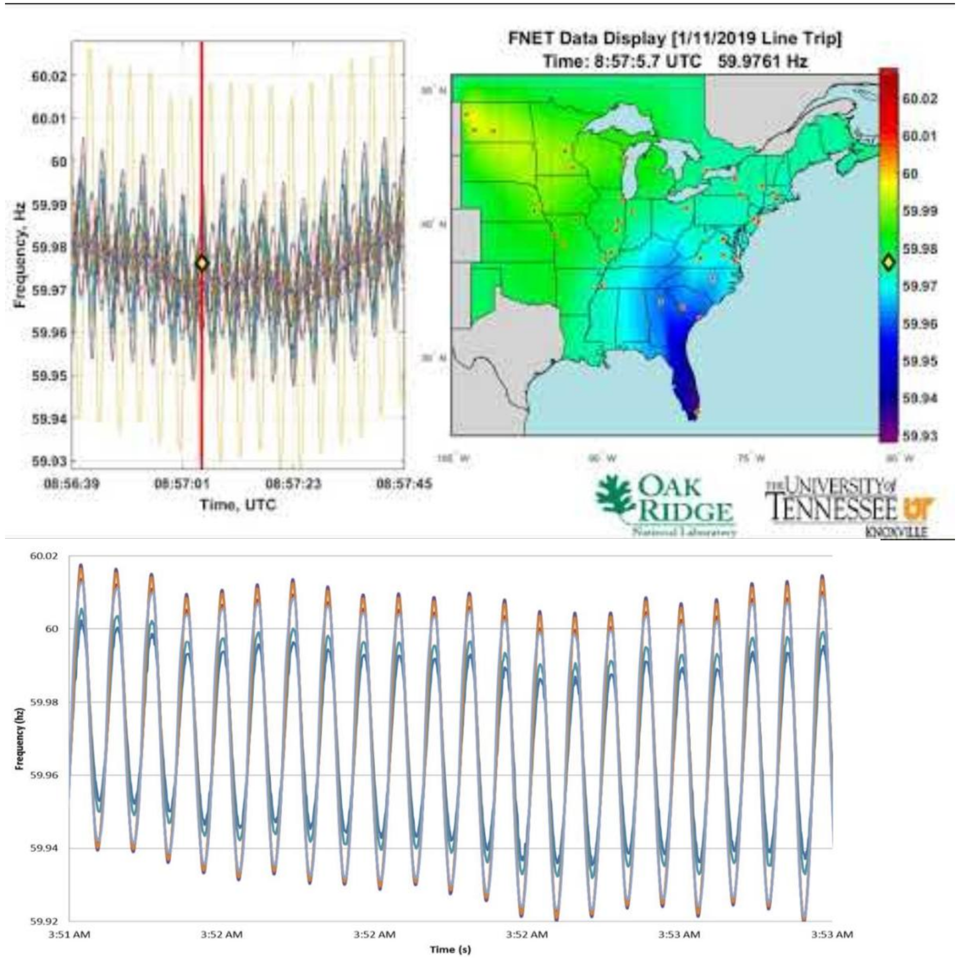
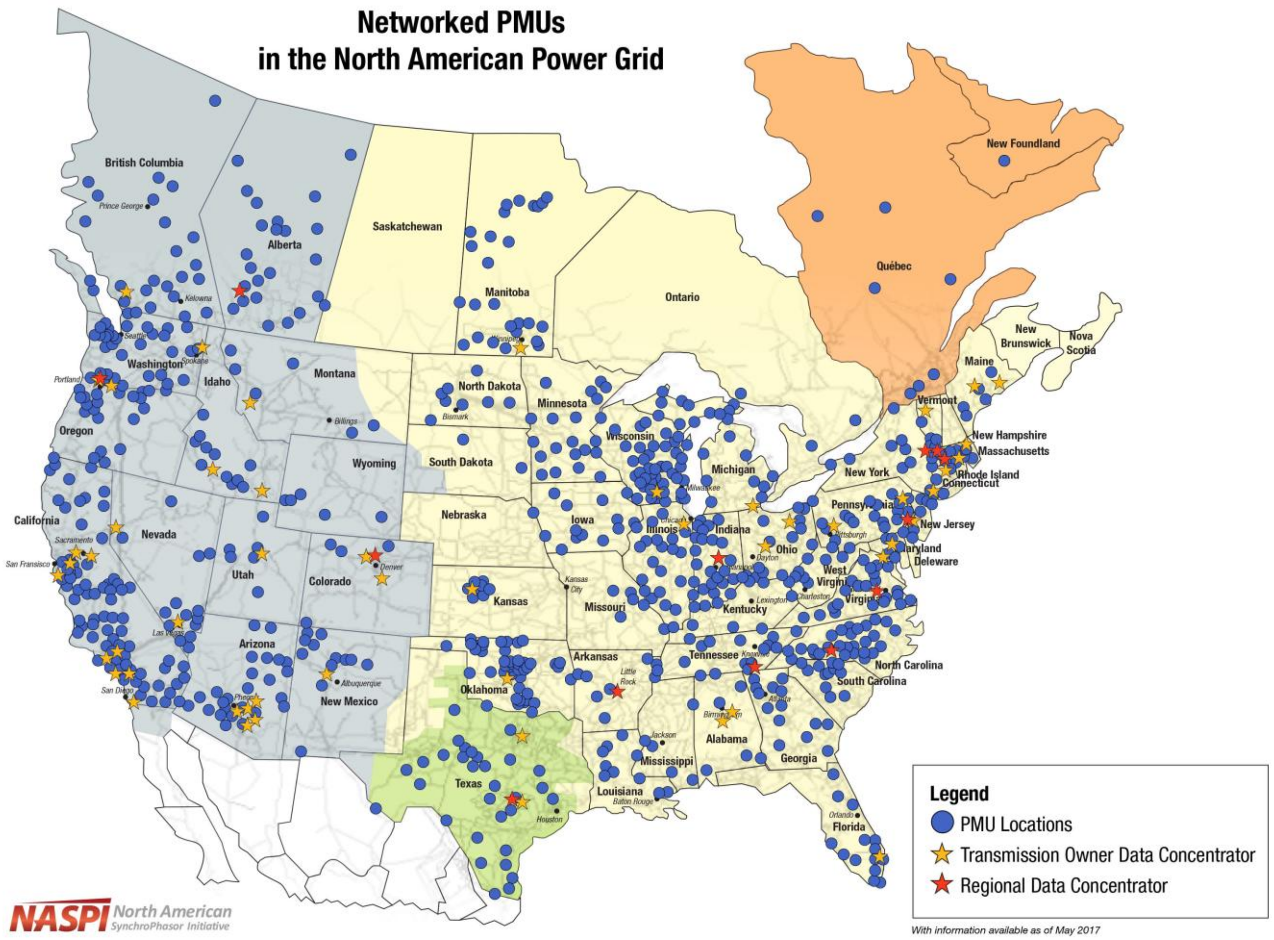


Fig 2: FO Observed in the UTK Fnet Frequency Measurements of the EI

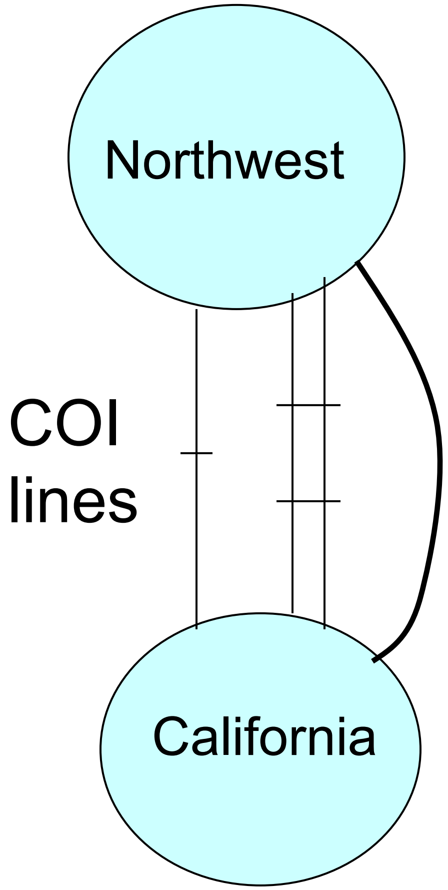
[1] NERC, "Eastern Interconnection Oscillation Disturbance - January 11, 2019 Forced Oscillation Event", December 2019, Available at https://www.nerc.com/pa/rrm/ea/Documents/January_11_Oscillation_Event_Report.pdf.

Motivation

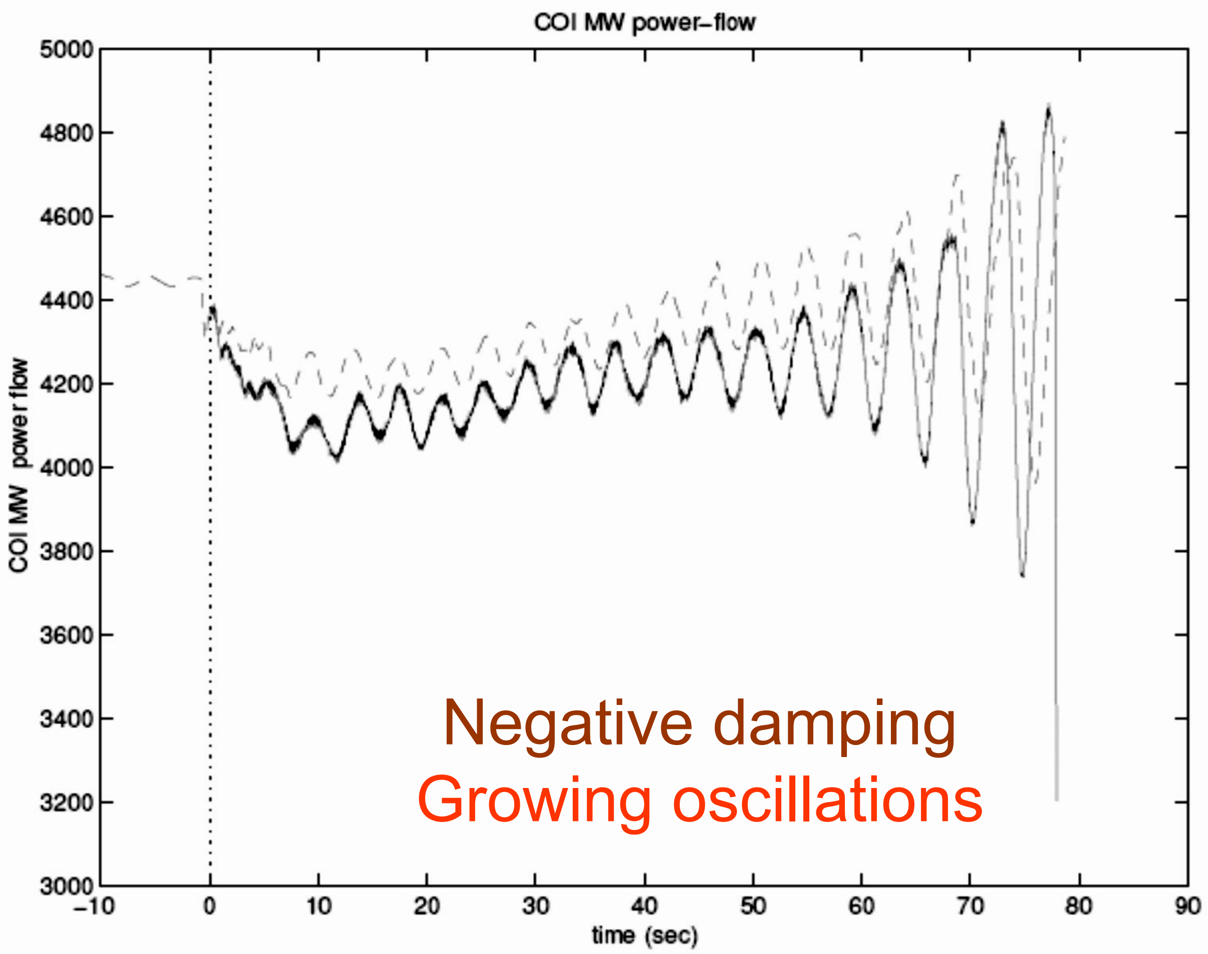
- As of 2019, over 2500 PMUs in the USA
- The widespread deployment of PMUs across the grid has opened pathways for the development of data-driven algorithms.
- PMUs may capture the event; however, recordings and analysis of those events are not available to the public for research.



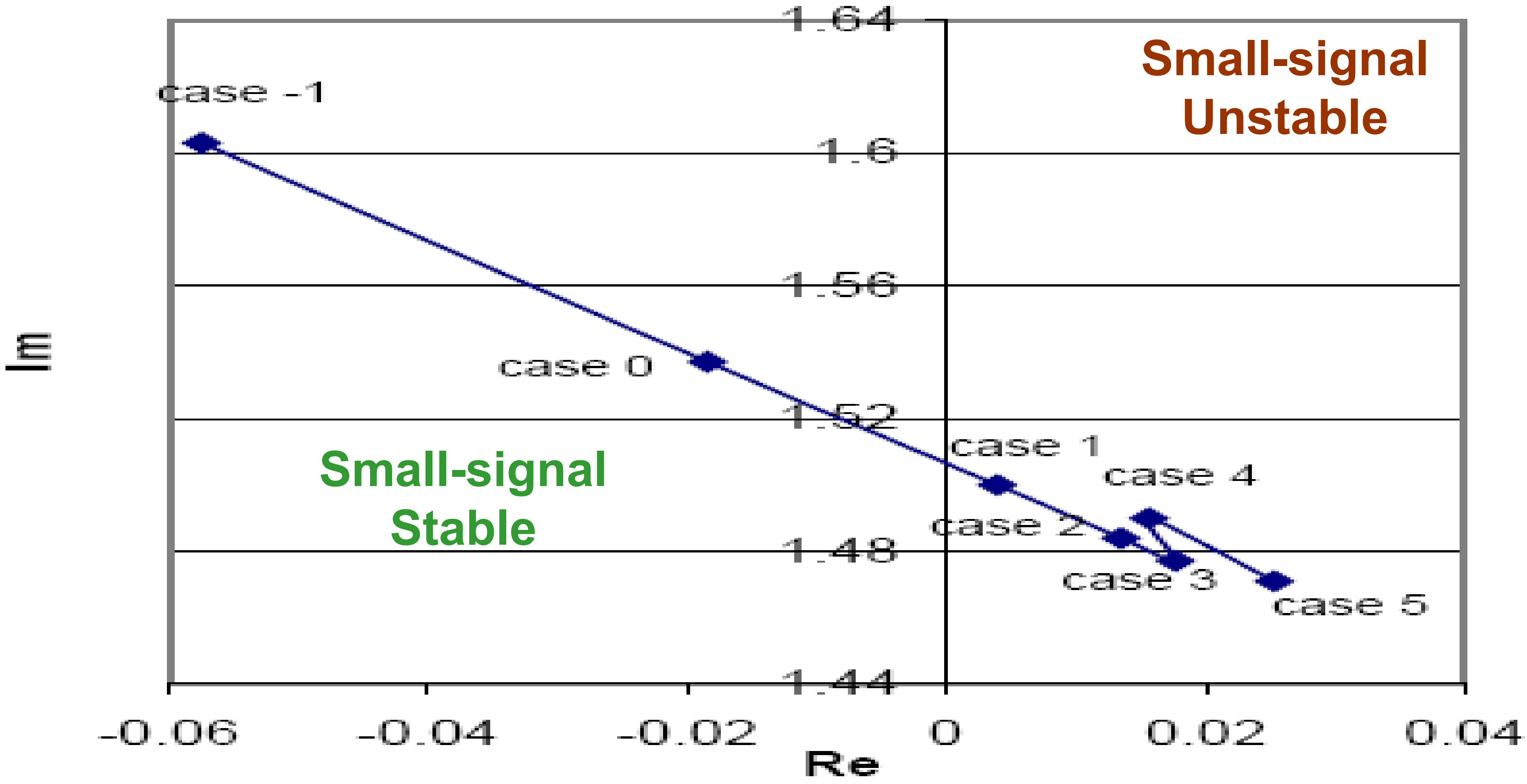
August 10, 1996 Western Interconnection Blackout



Unstable 0.25 Hz
Inter-area mode



August 10, 1996 model analysis



The damping ratio of the 0.25 Hz was about 5% for Case -1

Design of FO

$$\dot{x} = f(x, y, h)$$
$$0 = g(x, y, h)$$
$$h = H\sin(\omega_f t)$$

Where,
f denotes non-linear dynamics f the dynamic state variable x
g represents algebraic network equality constraint to solve variable y
h represents sinusoidal forced disturbance with oscillation amplitude h_f and ω_f

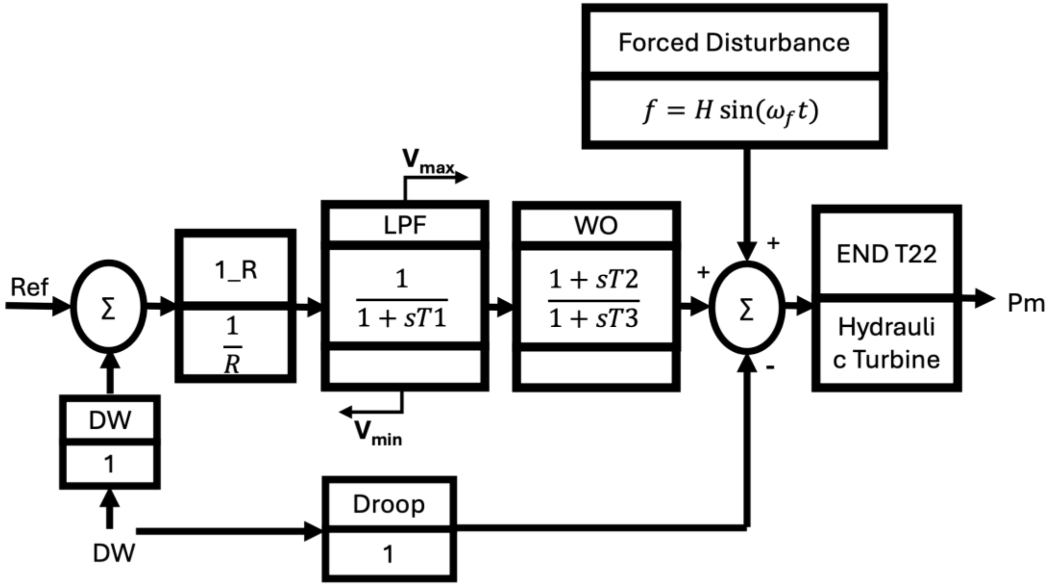


Fig 1: FO injected at the TGOV1 governor model

Parameters of the TGOV1 governor model	
R	Permanent droop, pu
T1	Steam bowl time constant, sec
Vmax	Maximum valve position limit
Vmin	Minimum valve position limit
T2	Numerator time constant, sec
T3	Reheater time constant, sec
D	Turbine damping coefficient, pu

Design of FO at the Exciter

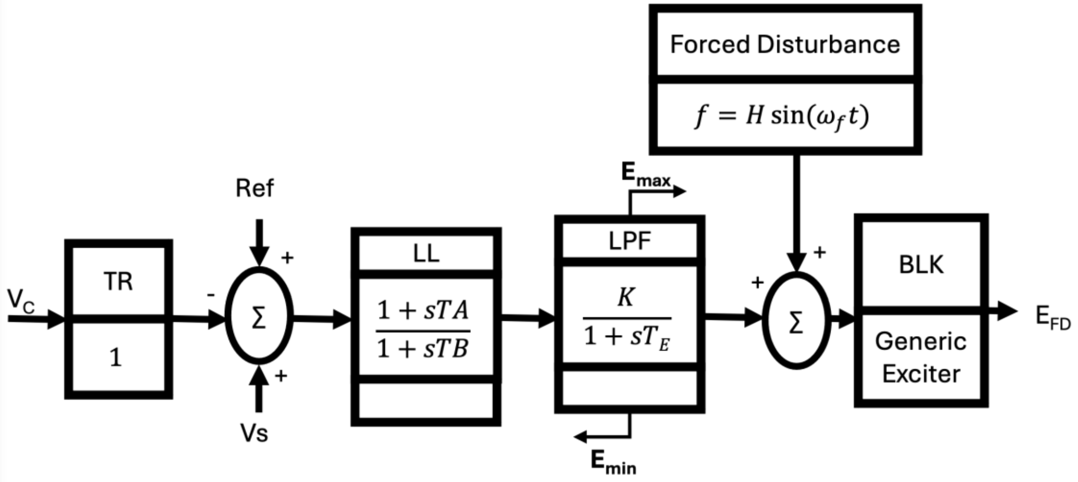


Fig 1: FO injected at the static exciter model

Parameters of the static exciter model	
T_A/T_B	Time constant of lag-lead compensator, sec
K	Voltage regulator gain
T_E	Exciter field time constant, sec
Emin	Minimum excitation output, pu
Emax	Maximum excitation output, pu
K	Rectifier regulation factor, pu
T_R	Transducer time constant, pu

Modelling of Load Fluctuations as Process Noise

Noise profiles were randomly assigned to all loads in each test case (240 bus system)

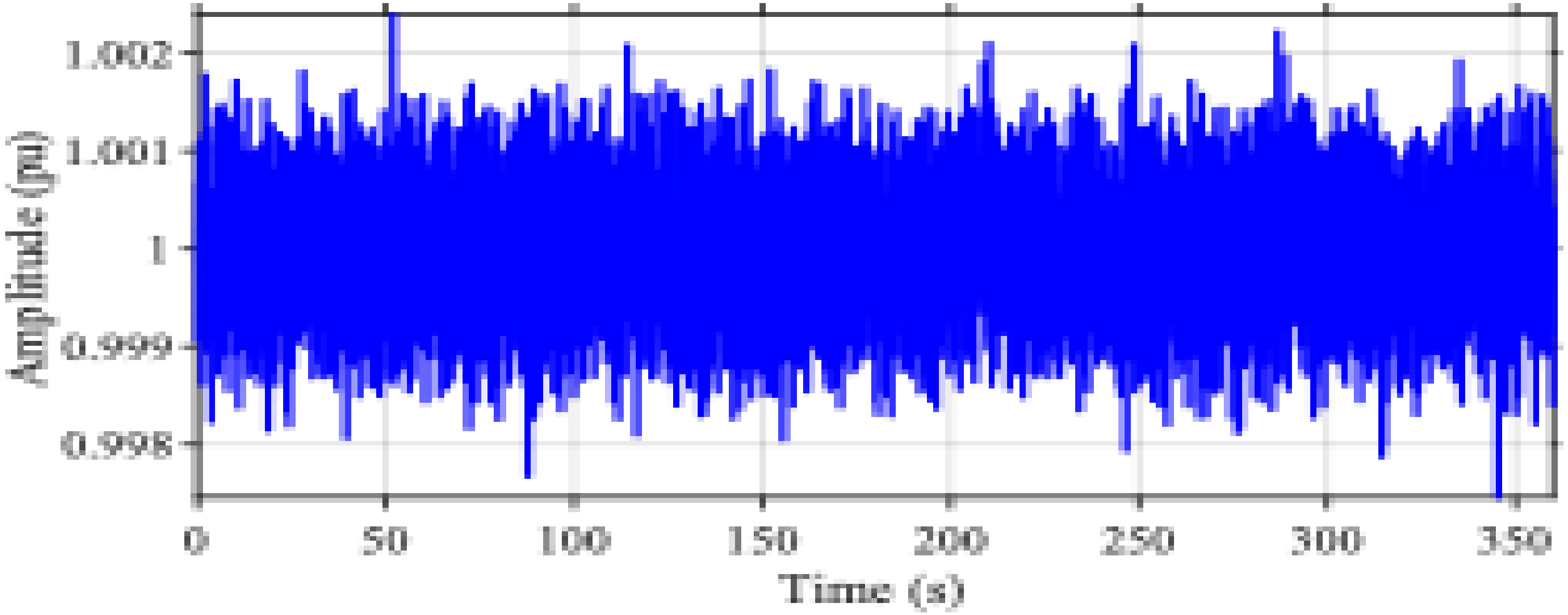


Fig 1: An example of a load noise profile