Inertia Estimation Using Ambient and Probing Based PMU Measurements

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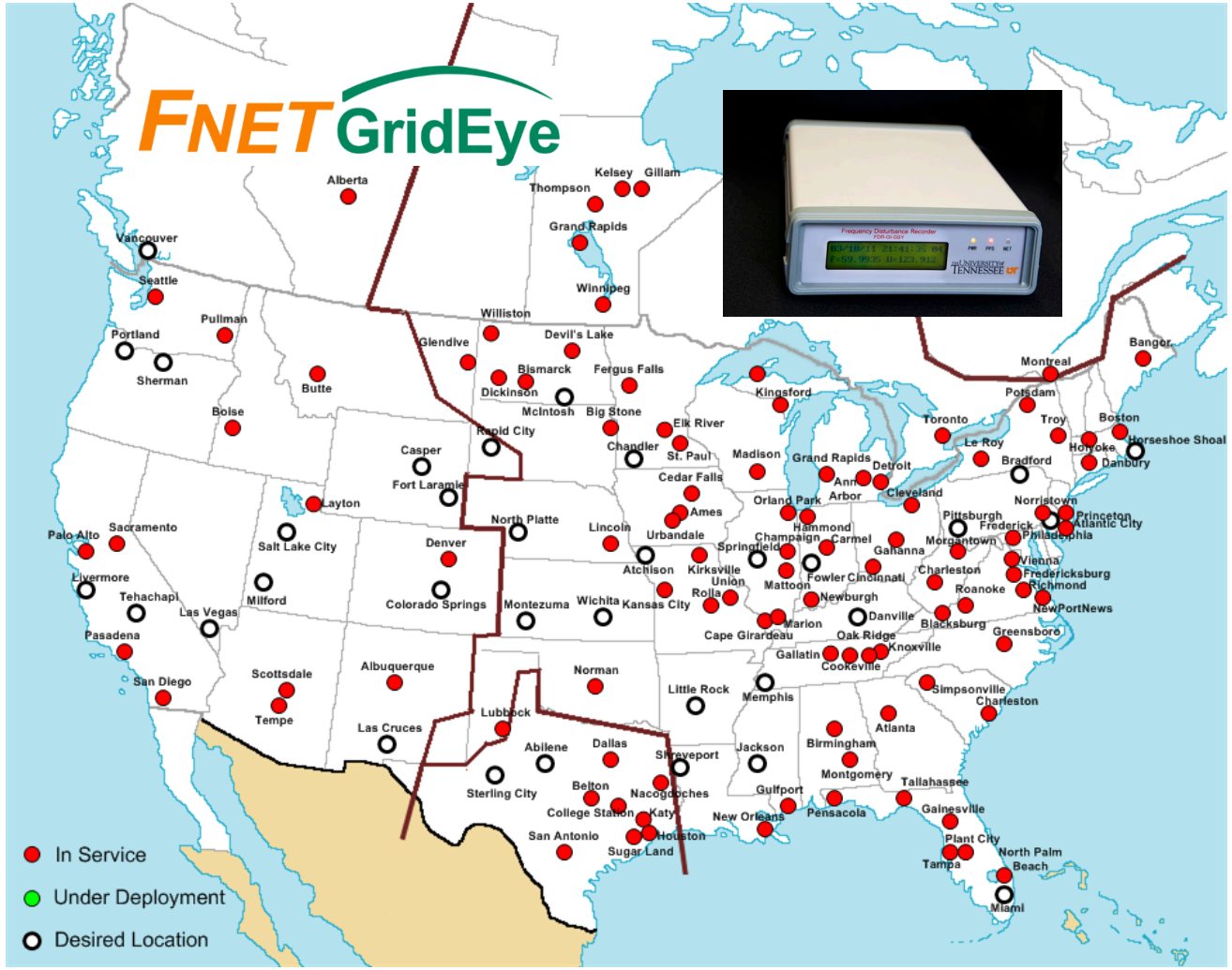
Inertia Estimation Methods Overview

Methods	Pros	Cons
Dispatch-based	Simple, Can be implemented based on SCADA/EMS data.	Grid forming IBR inertia not considered. Load inertia not included
Event-based	Most accurate. Could factor in other contributions	Needs to wait for the occurrence of an event.
Ambient-based	Real-time continuous inertia estimation.	Accuracy is limited, need calibration with known values
Probing-based	Can pick any desired time by controlled probing injections.	Requires hardware with control to produce the probe signal

Grid PMU Monitors in US and Worldwide

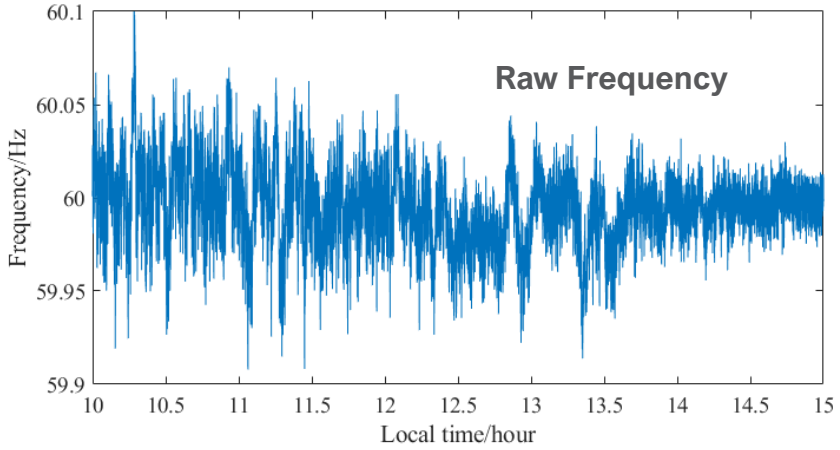


Live data streaming

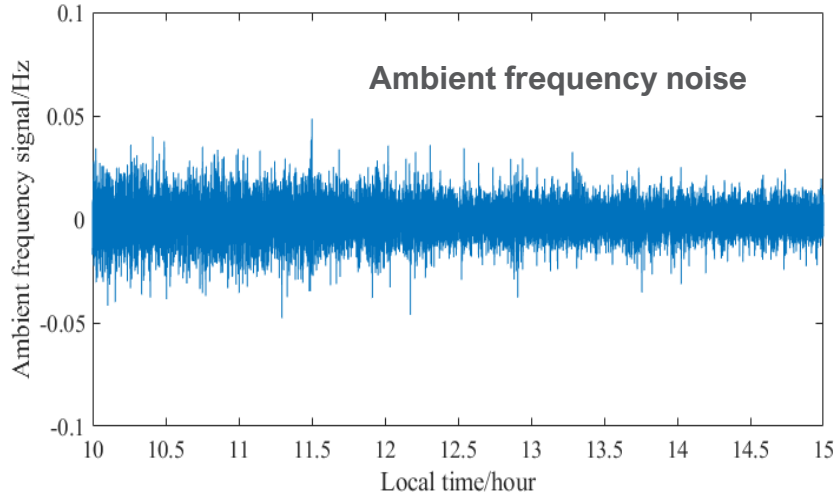
https://fnetpublic.utk.edu/

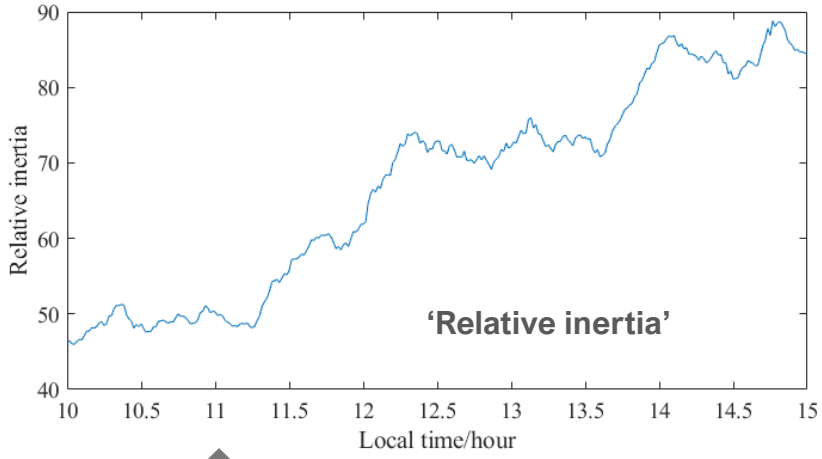
Inertia Estimation Using Ambient Frequency

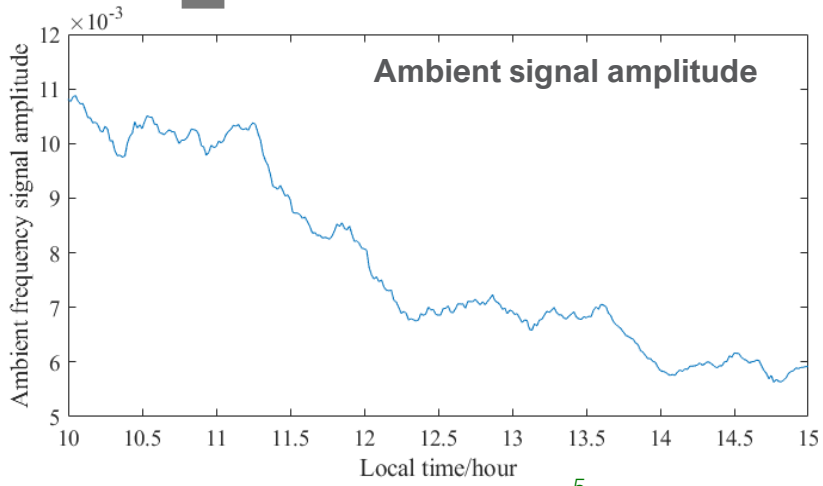
The process of calculating “relative inertia”



Slow trend filter





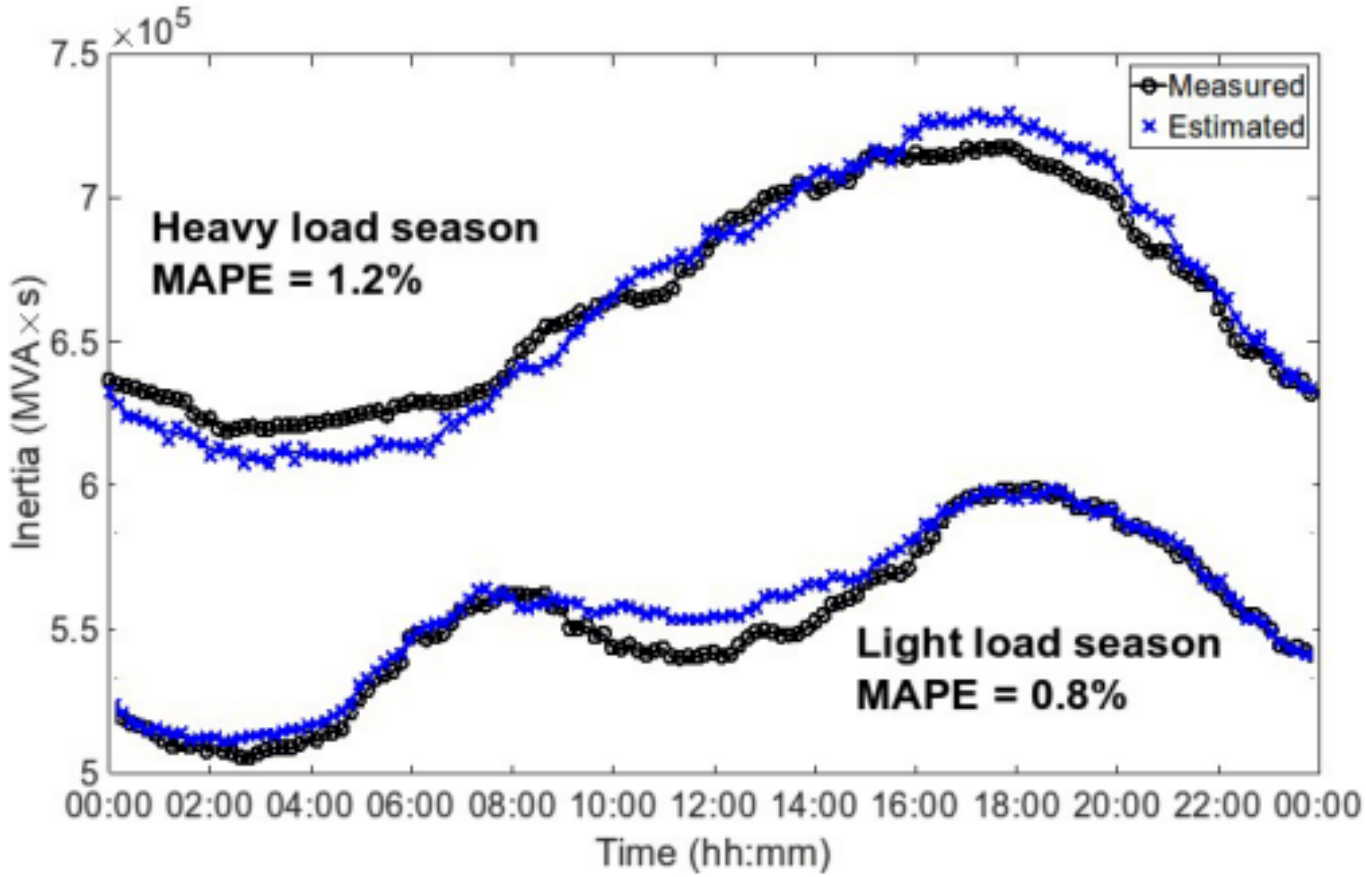


Inertia Estimation Using Ambient Frequency

Machine learning – WECC results vs NERC Data

Inputs to ML:

- Ambient frequency
- Weather
- Typical load profile



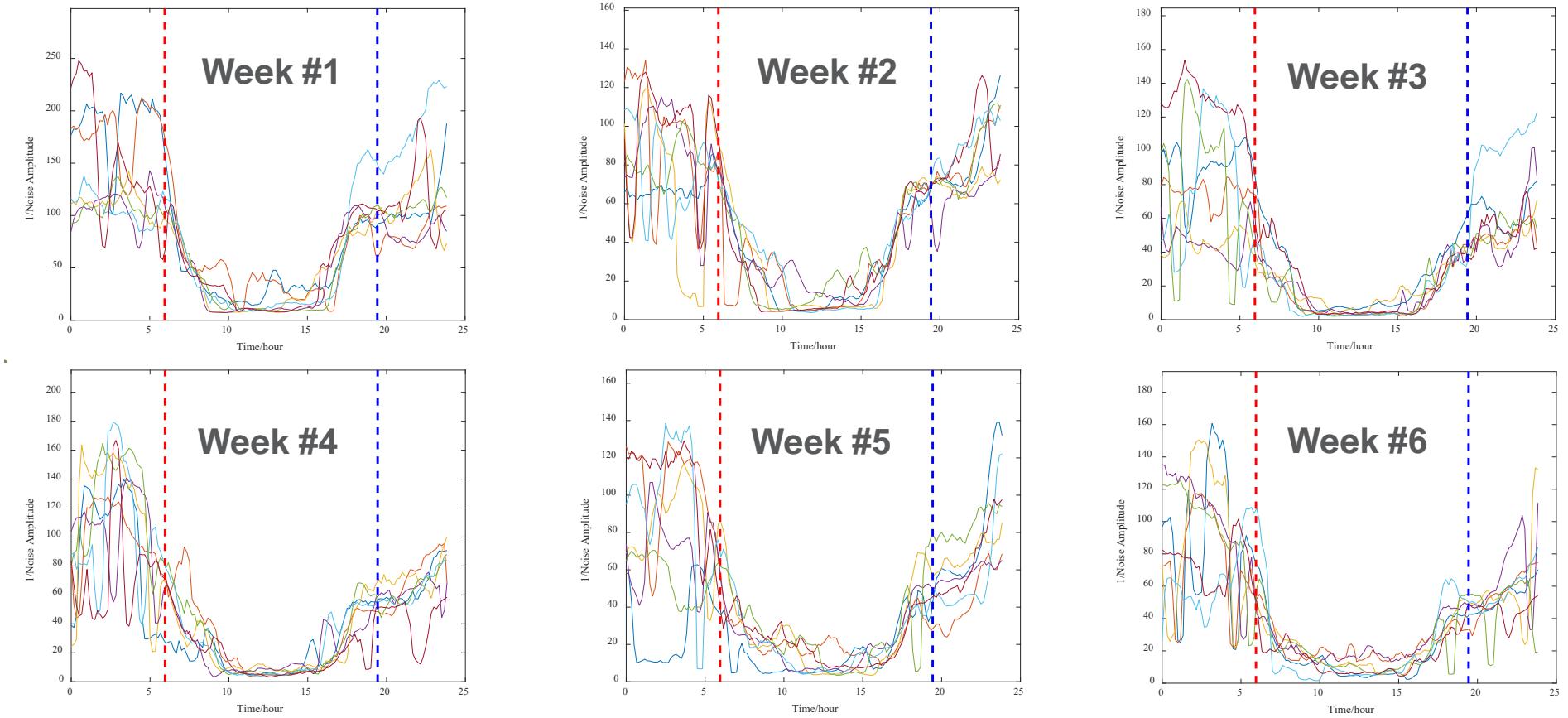
Performance of the machine-learning based inertia estimation using ambient frequency signal

Inertia Estimation Using Ambient Frequency Signal

- ‘relative inertia’ results from one island grid

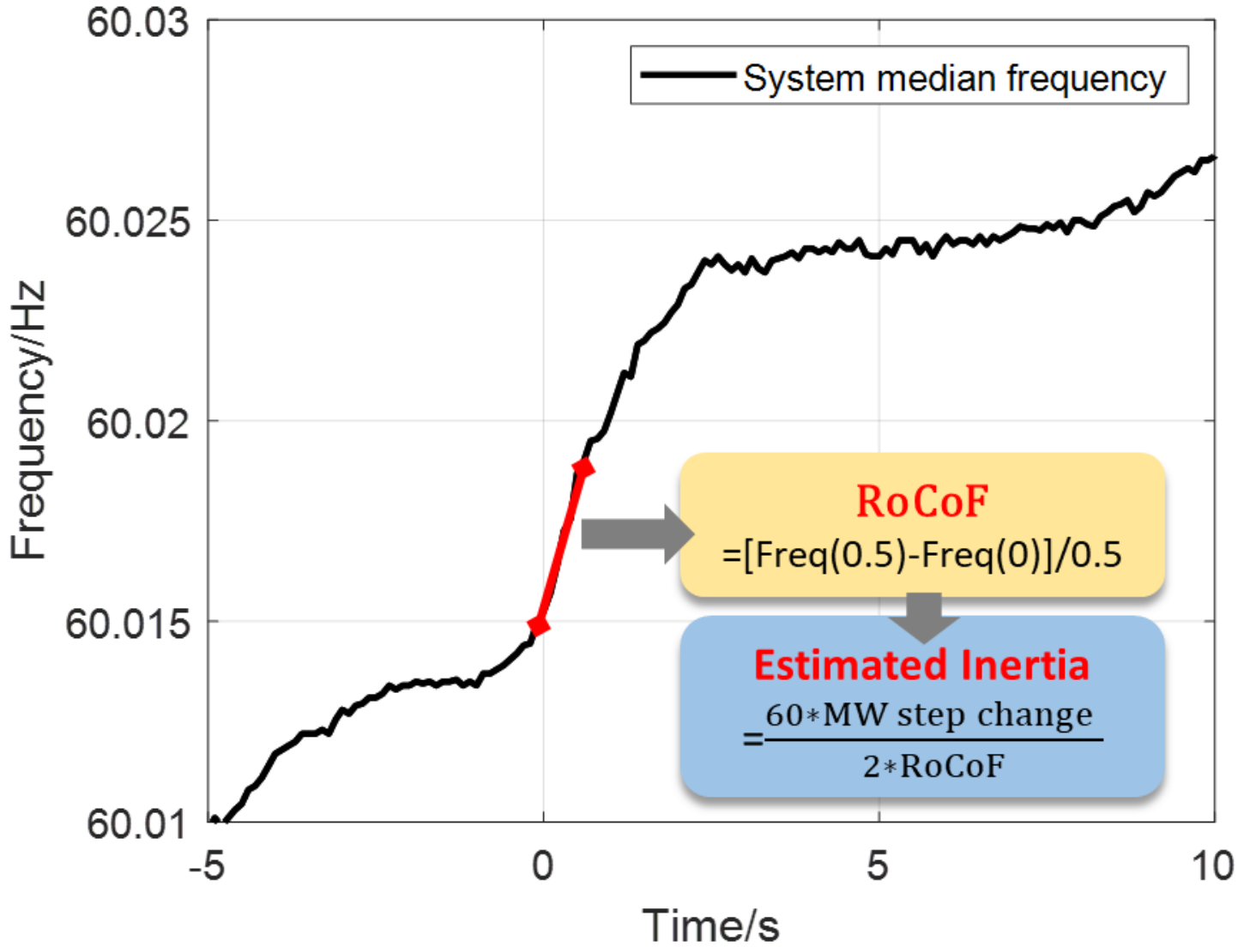
------ Sunrise time

------ Sunset time



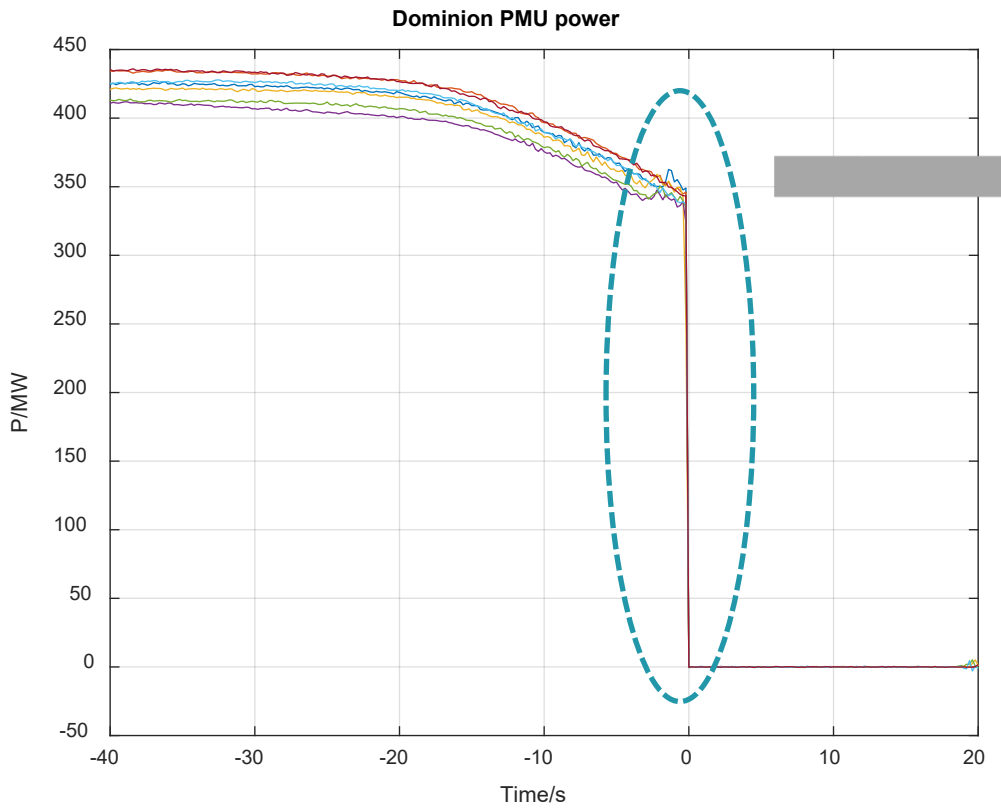
Event based Method from Pump Hydro Operations

The rate of change of frequency **(RoCoF)** after a step change in MW is proportional to the **MW change** and the inverse of system **inertia**



Pumped Storage Operation Provides Probing Signals

PMU data of Bath County pump switching off events show that the MW change is relatively constant.



PMU power of ten Bath county pump switching off events

Event #	Time EDT	Step change, MW
1	06/30/2021 13:13:30	347.7
5	06/28/2021 11:11:00	342.5
6	06/24/2021 05:52:23	339.2
7	06/18/2021 07:05:26	339.8
8	06/12/2021 08:51:15	339.1
9	05/30/2021 07:27:00	343.5
10	05/17/2021 02:25:00	344.8

MW step change difference

(Max-Min)/Average=(347.7-339.1)/342.4=**2.5%**

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Monitors Deployed Near Helms Pump Storage Plant

Three monitors deployed in Fresno City near Helms pump storage plant:

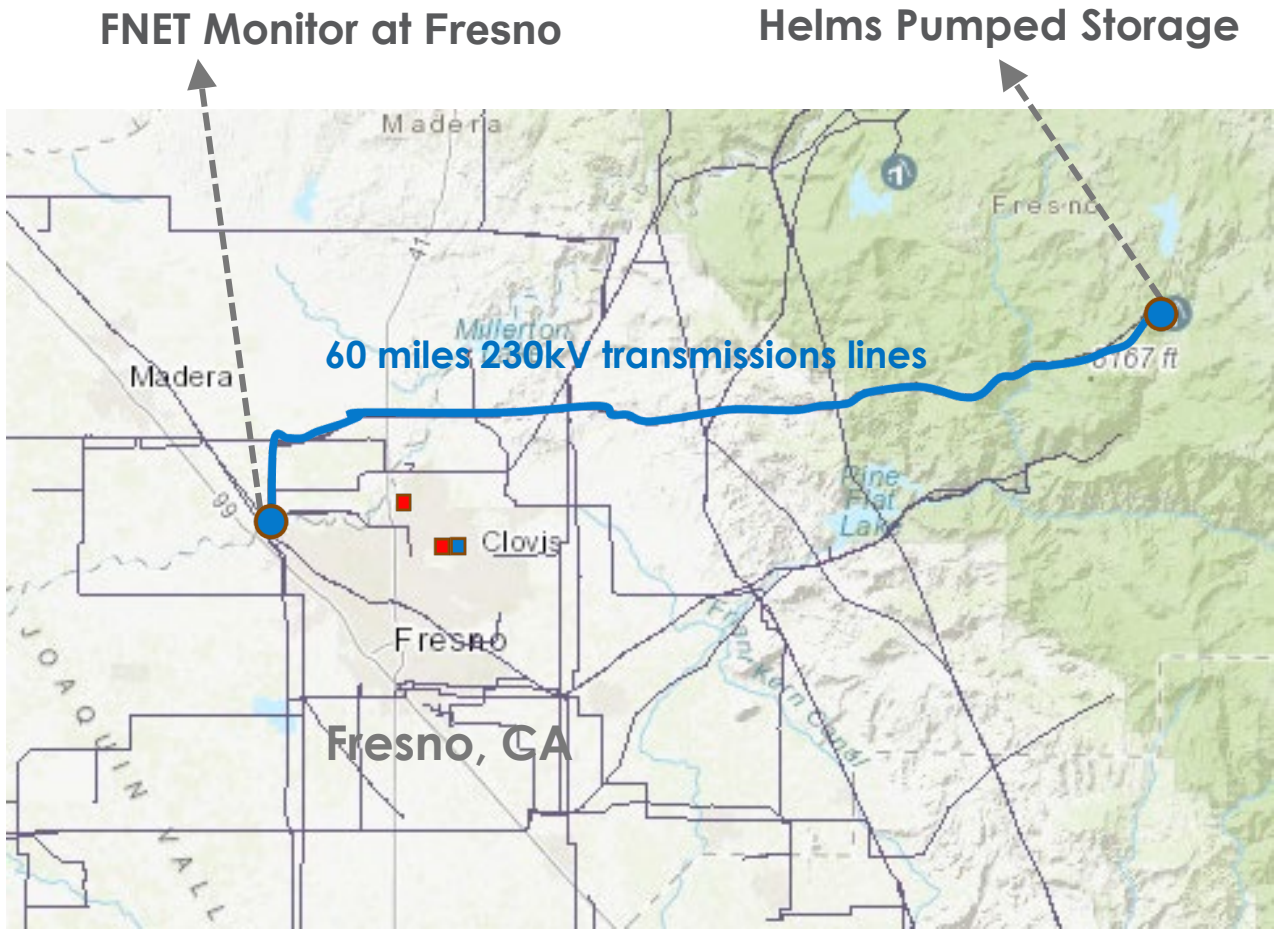
- UGA-POW and FDR: Prof. Carlos Perez, faculty from Fresno City College.
- UGA-POW: Dr. Ram Adapa, Technical Executive, EPRI

FDR

Measured Signal	Resolution (points/s)
Frequency	10
Voltage	10
Angle	10

UGA-POW

Measured Signal	Resolution (points/s)
POW voltage	**1440**
Frequency	**120**
Phasor Voltage	10
Angle	10



Available from EIA U.S. Energy Mapping System: https://www.eia.gov/state/maps.php

UGA-POW FDR

Inertia Estimation Visualization at WECC

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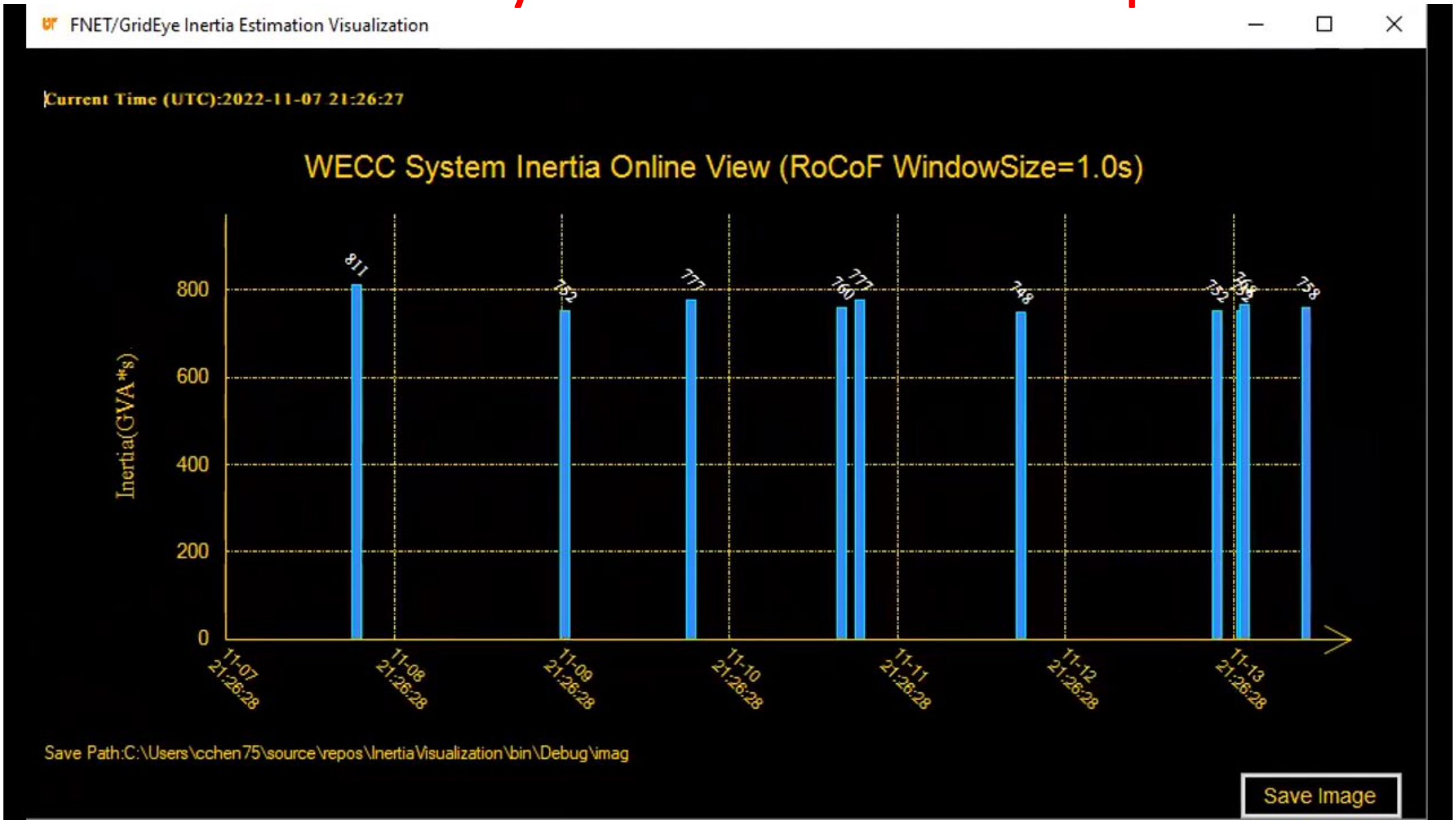
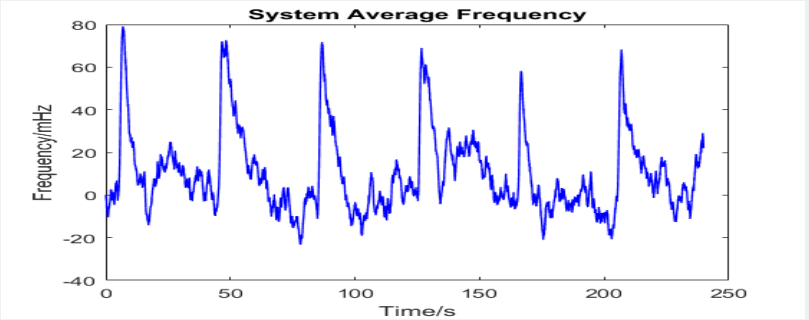
Bath County and Raccoon Mt. Units are Operational



Probing based Inertia Estimation

Funded by SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy



Number of signals, interval

Shape, Duration, Ramping

Magnitude

Enable/disable option of probing injection

Probing test frequency

Inverter

Probing signal

grid

Power injection measurements

Probing injection time stamp

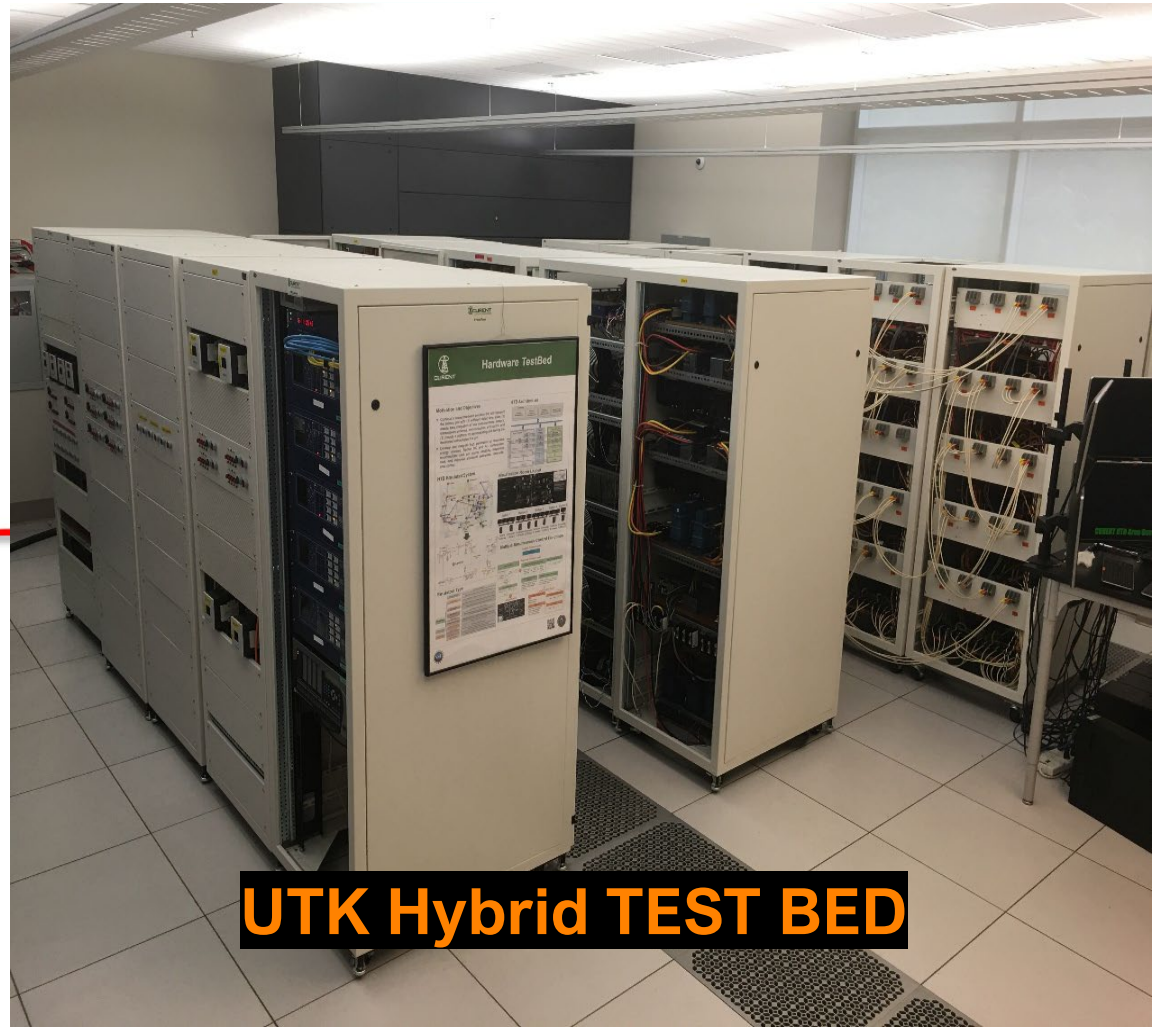
UGA

Inertia estimation computer

Probing parameter adjustment

Frequency measurements

Power-HIL System Setup at NREL and UTK



PHIL Test Results – Case 1

- only different SGs online +77db noise, average error is 2.85%.

	Case 1 - A	Case 1 - B	Case 1 - C	Case 1 - D
Ground truth inertia	102.046	97.5	86.347	90.847
PHIL test data results	105.28	99.30	90.07	88.97
Error	**3.17%**	**1.85%**	**4.31%**	**2.07%**

PHIL Test Results– Add GFL,GFM + 77db noise

- average inertia estimation error is 7.03%, droop error is 3.50%.

	Case 2 - A	Case 2 - B	Case 2 - C	Case 3	Case 4
Inertia ground truth	102.046	102.046	102.046	187.233	187.233
Estimated inertia	92.511	94.273	105.372	191.184	211.319
Error	**9.34%**	**7.62%**	**3.26%**	**2.11%**	**12.86%**
Droop ground truth	8.486	6.422	4.009	8.775	16.553
Estimated droop	8.208	6.095	3.848	9.046	16.886
Error	**3.28%**	**5.09%**	**4.02%**	**3.09%**	**2.01%**

Probing Field Tests at KIUC Completed in 2024

Report out soon…

Field demonstration utilizes the Lawai 28.2 MW DC solar power plant to inject probing pulses to the KIUC grid. Injection power from BESS unit up to 1.5 MW.