Inertia Estimation Using Ambient and Probing Based PMU Measurement

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THE UNIVERSITY OF TENNESSEE KNOXVILLE

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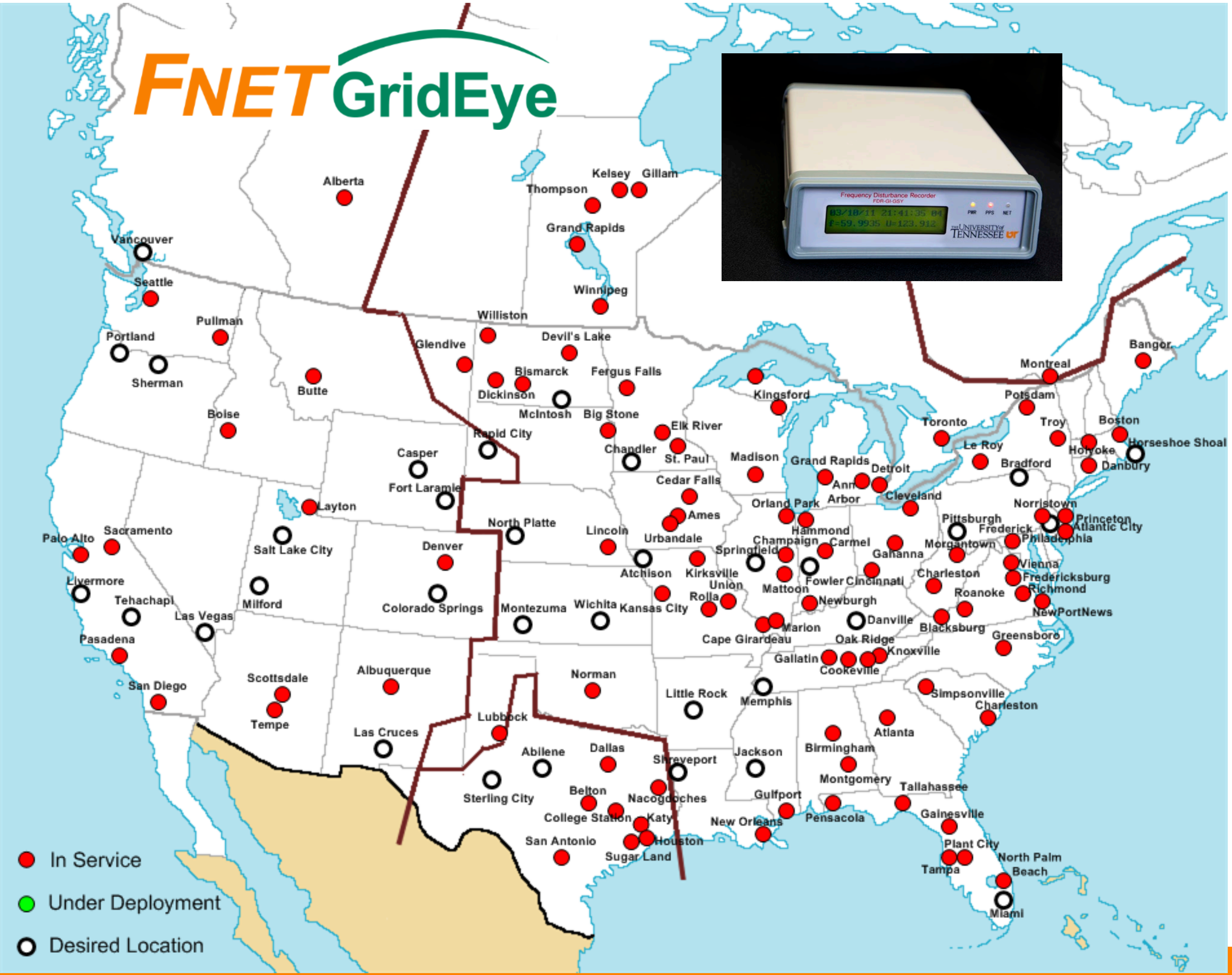
Inertia Estimation Methods Overview

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

Grid PMU Monitors in US and World

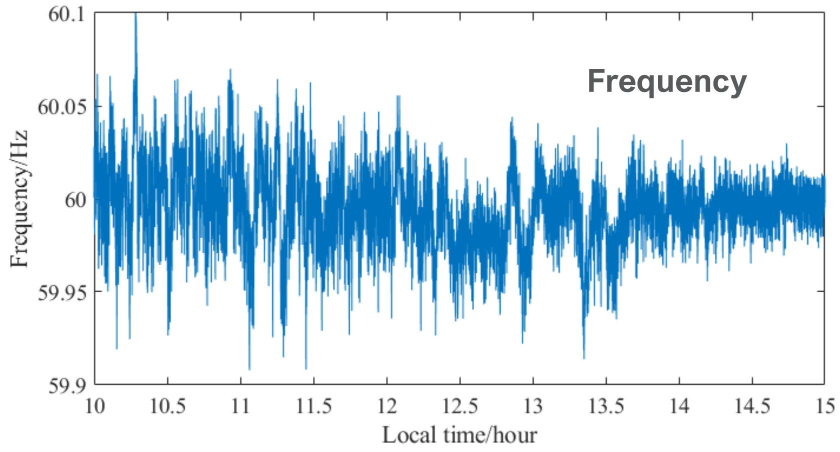


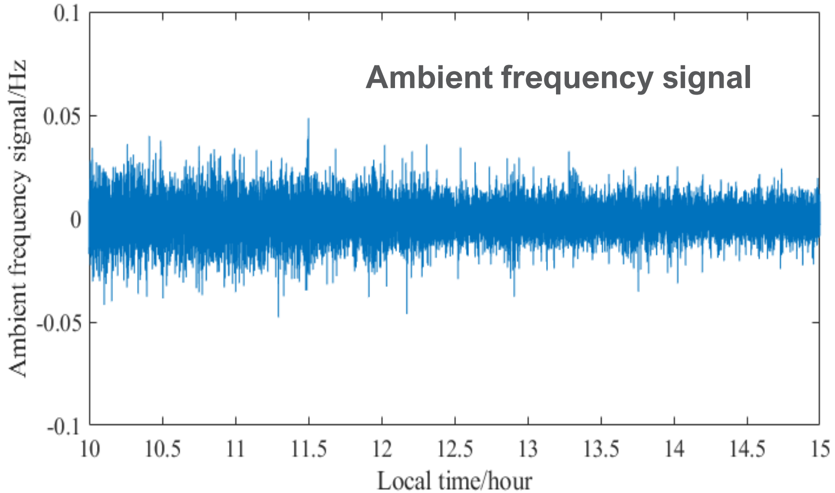
Live data streaming

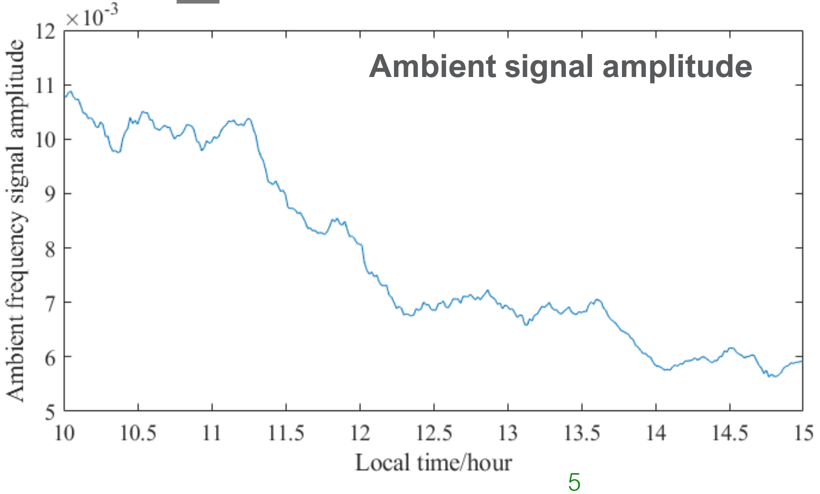
https://fnetpublic.utk.edu/

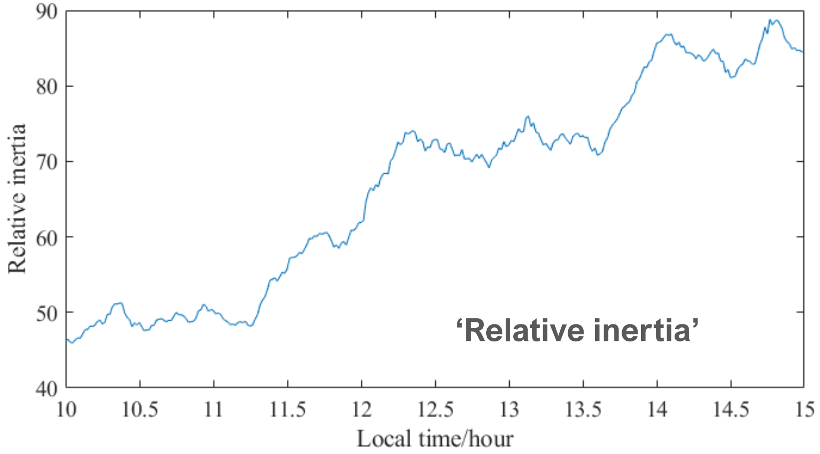
Inertia Estimation Using Ambient Frequency Signal

The process of calculating ambient frequency based 'relative inertia'





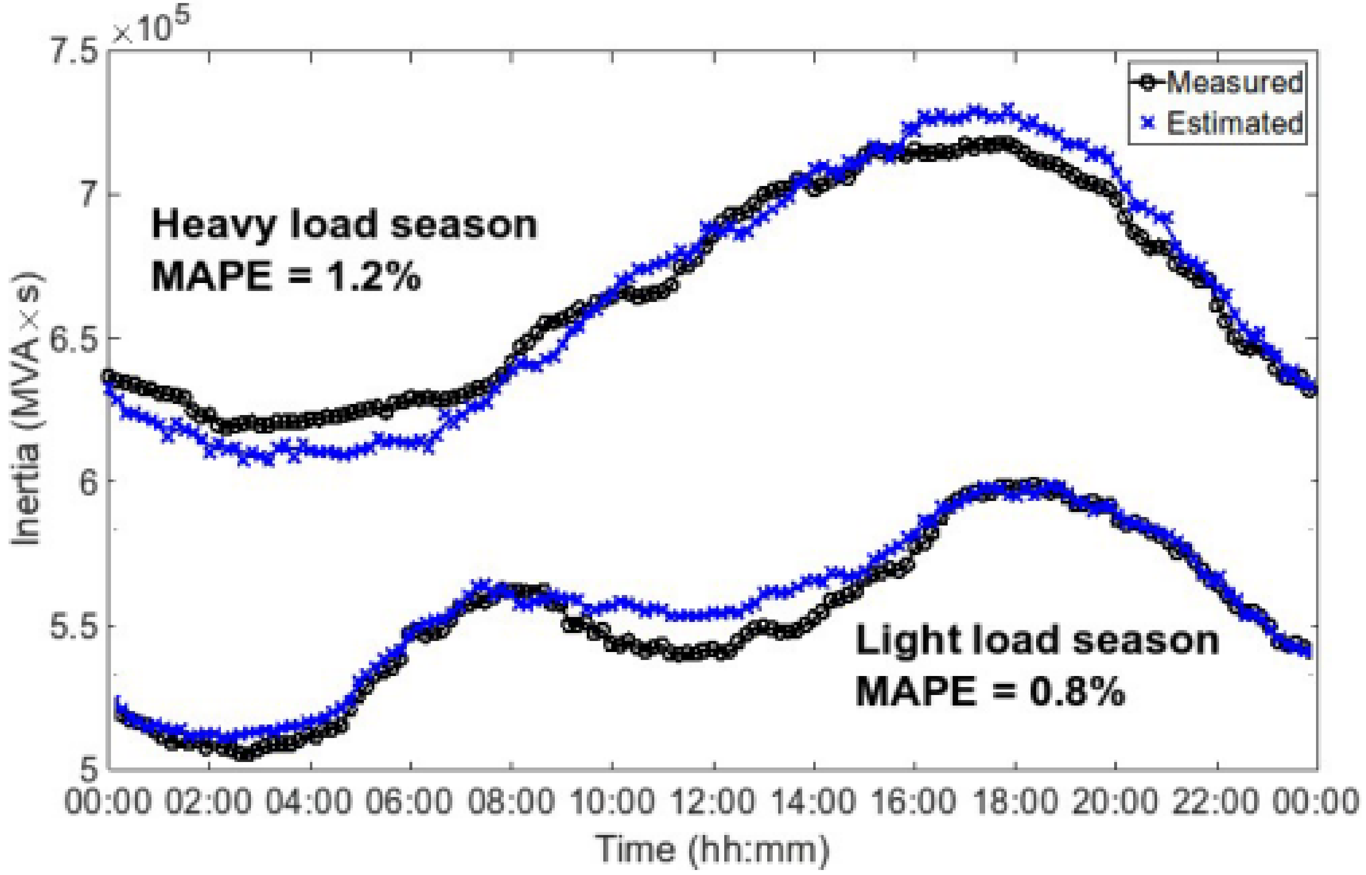




Inertia Estimation Using Ambient Frequency

Machine learning – WECC results vs NERC Data

Inputs to ML:
- Ambient frequency
- Weather
- Typical load profile

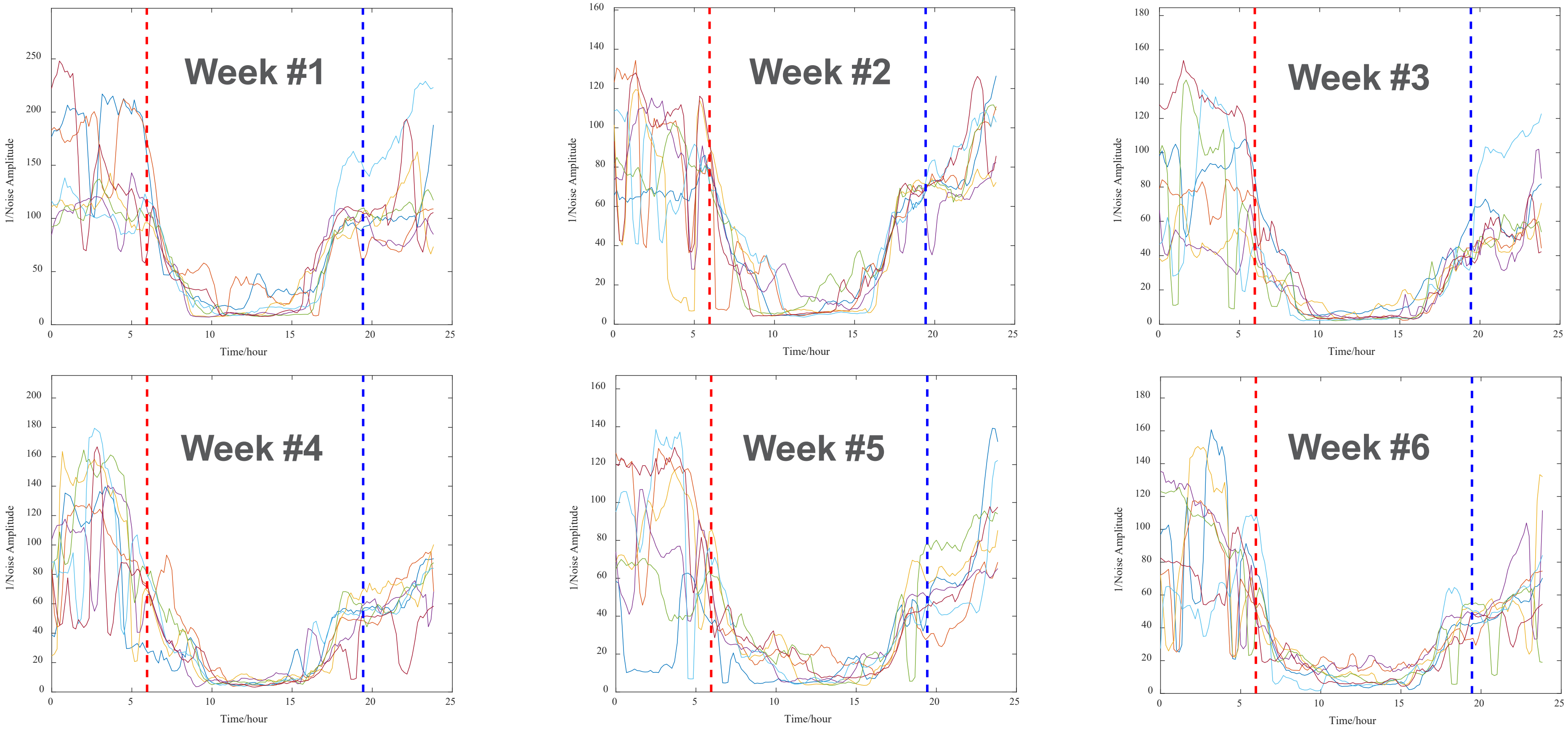


Performance of the machine-learning based inertia estimation using ambient frequency signal

Inertia Estimation Using Ambient Frequency Signal

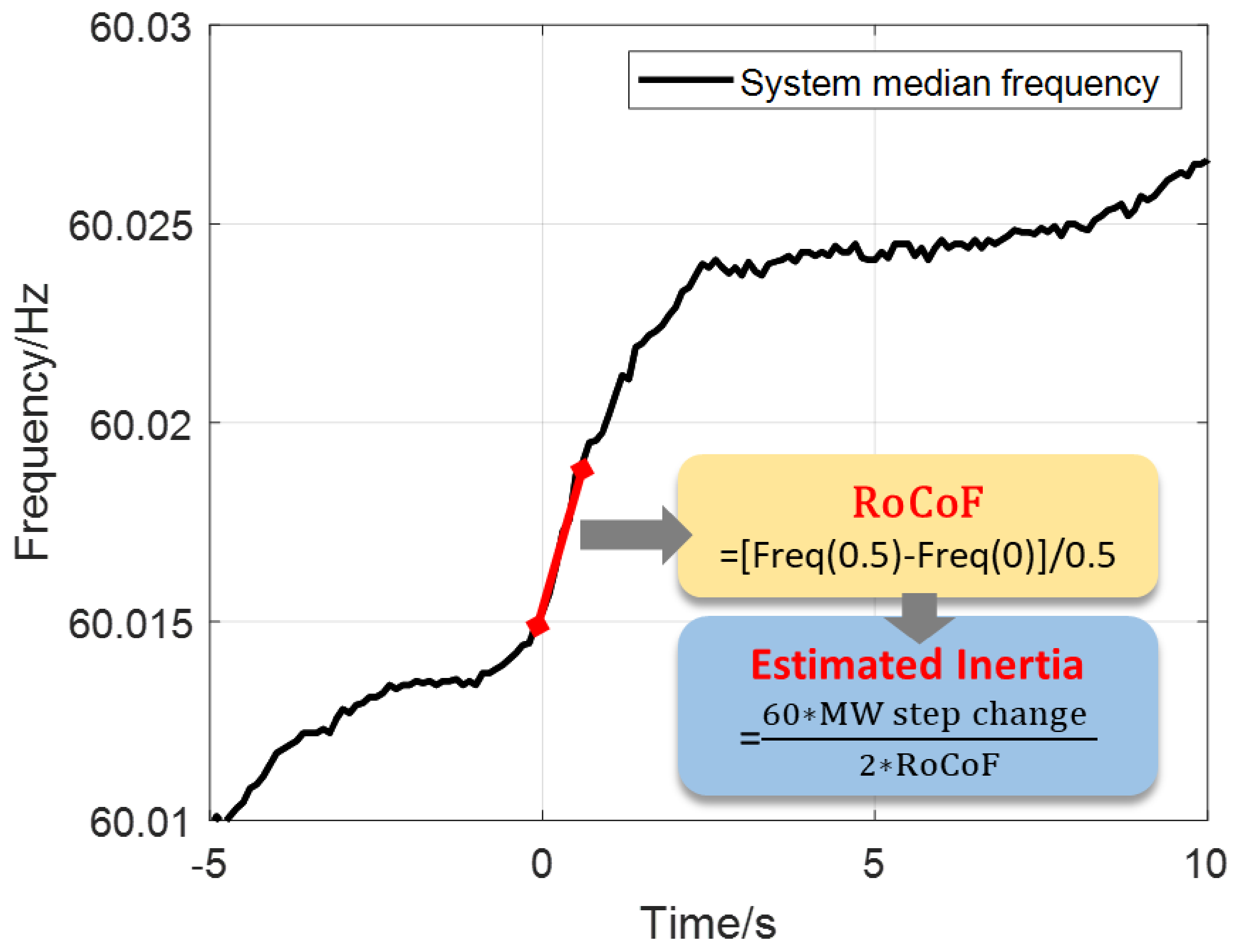
- ‘relative inertia’ results from one island

------ Local sunrise time
------ Local sunset time



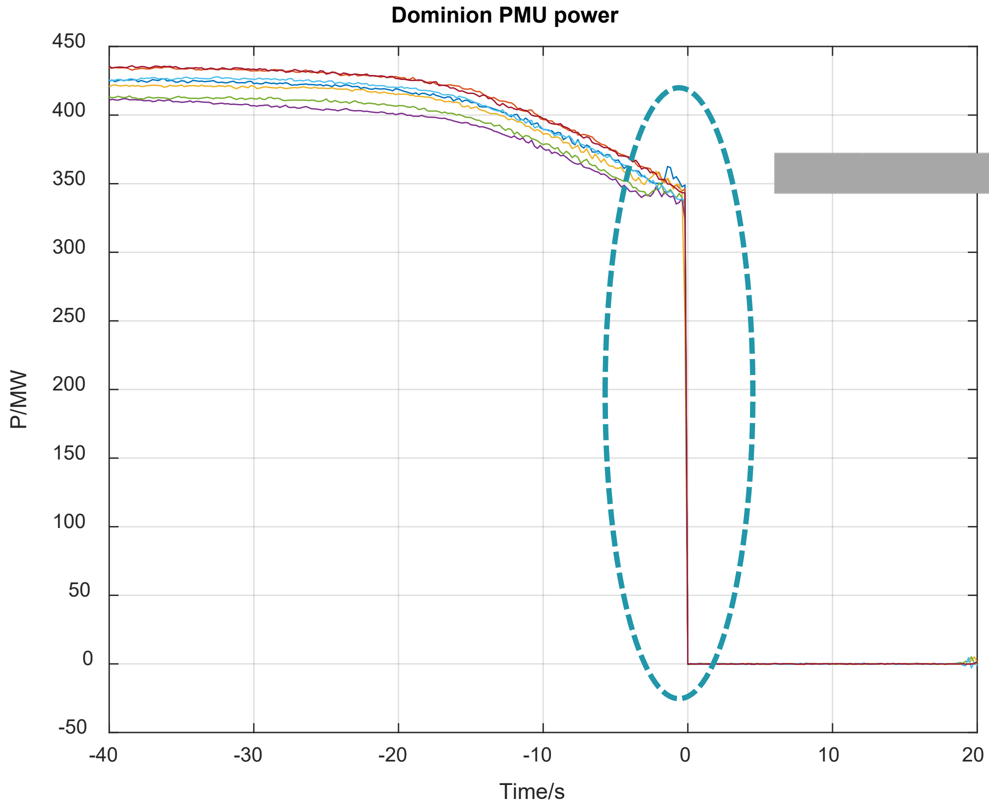
Event based Method from Pump Hydro Operations

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 Provide Probing Signal

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%**

Monitors Deployed near Helms Pump Storage Plant

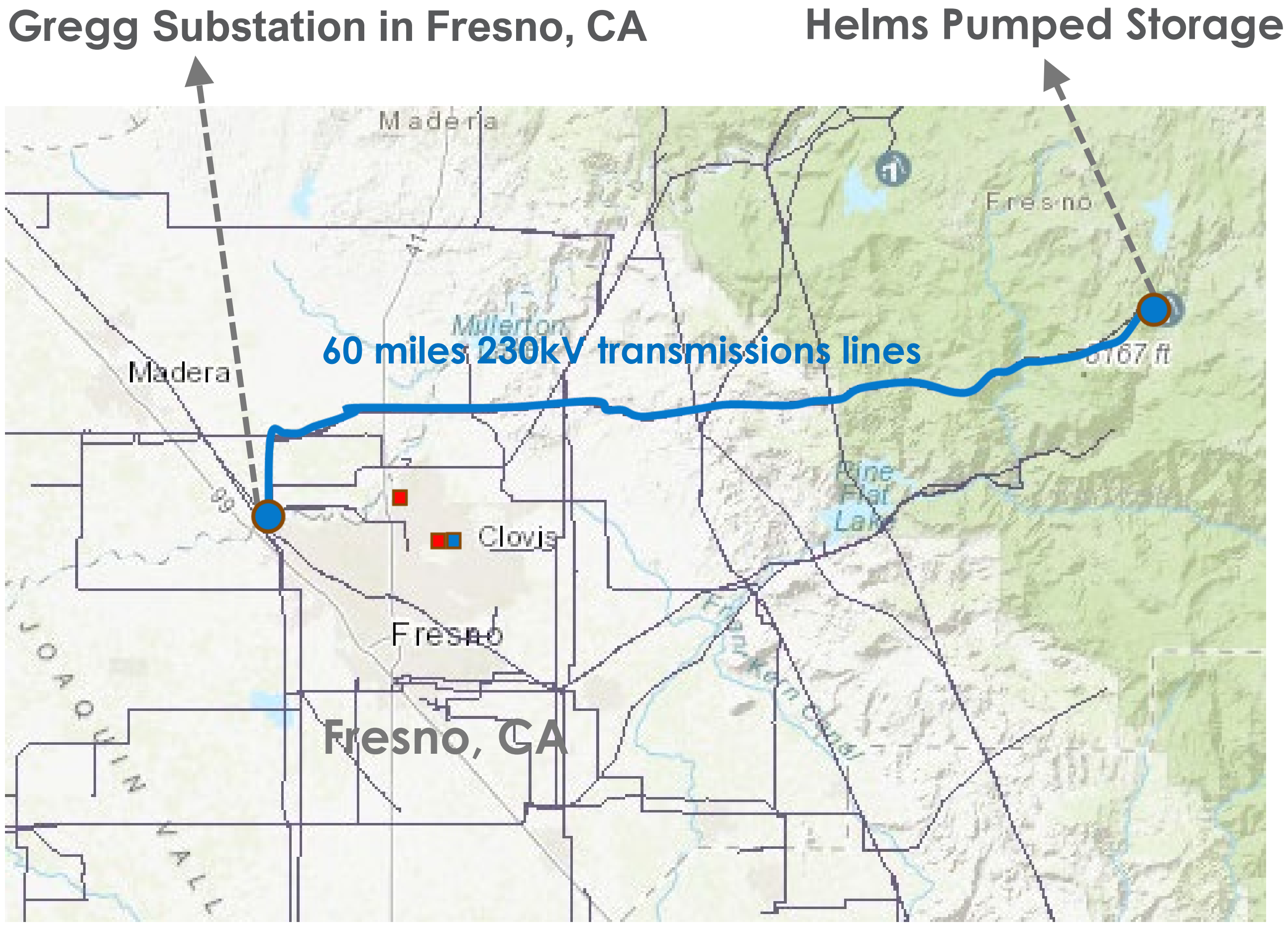
- Three monitors deployed in Fresno City near Helms pump storage plant:
  - One UGA-POW and one FDR: Prof. Carlos Perez, a faculty from Fresno City College.
  - One UGA-POW: Dr. Ram Adapa, Technical Executive, EPRI

FDR

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

UGA-POW

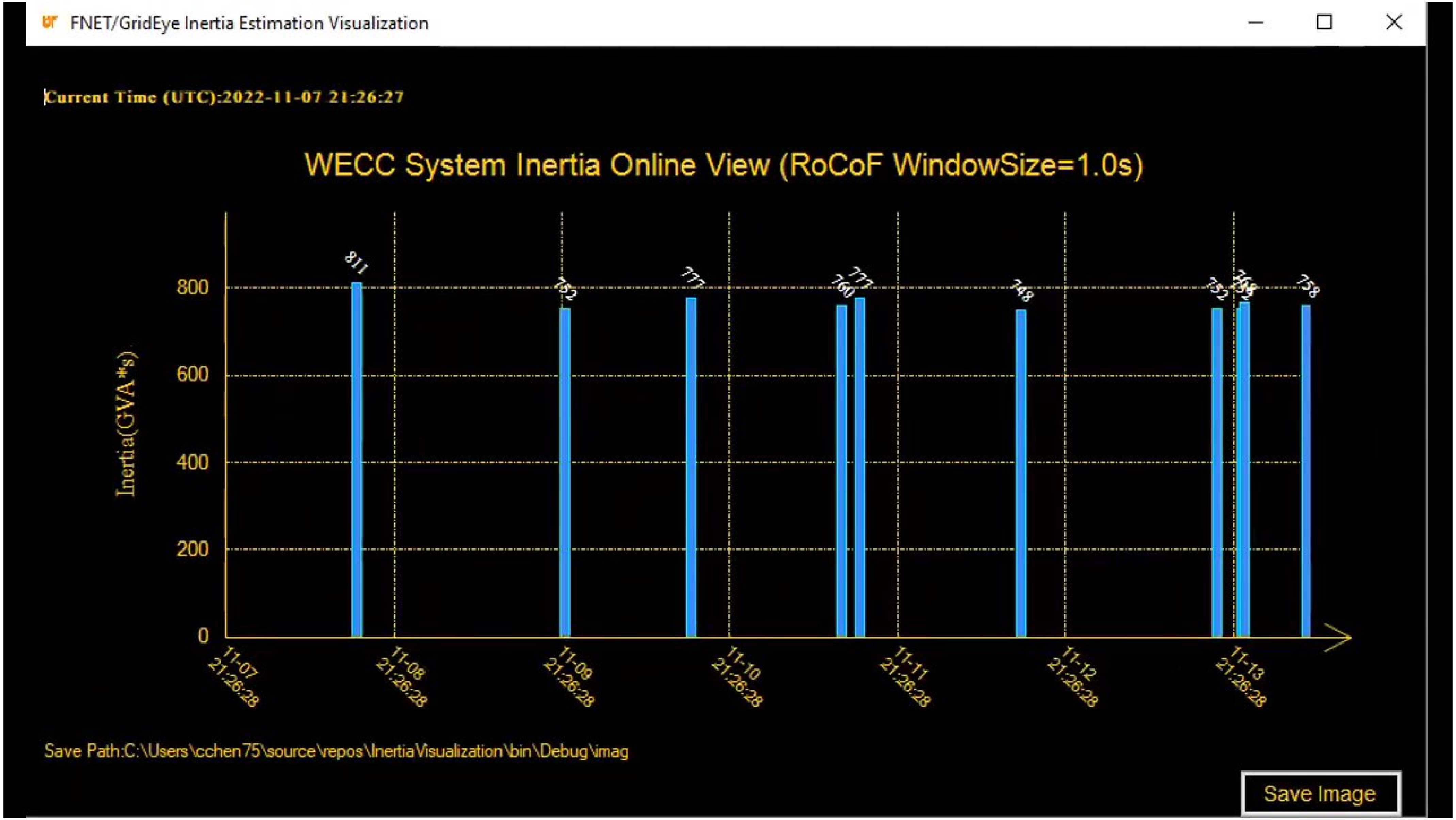
Measured Signal	Resolution (points/s)
Phase data (POW voltage)	**1440**
Frequency	**120**
Voltage	10
Angle	10



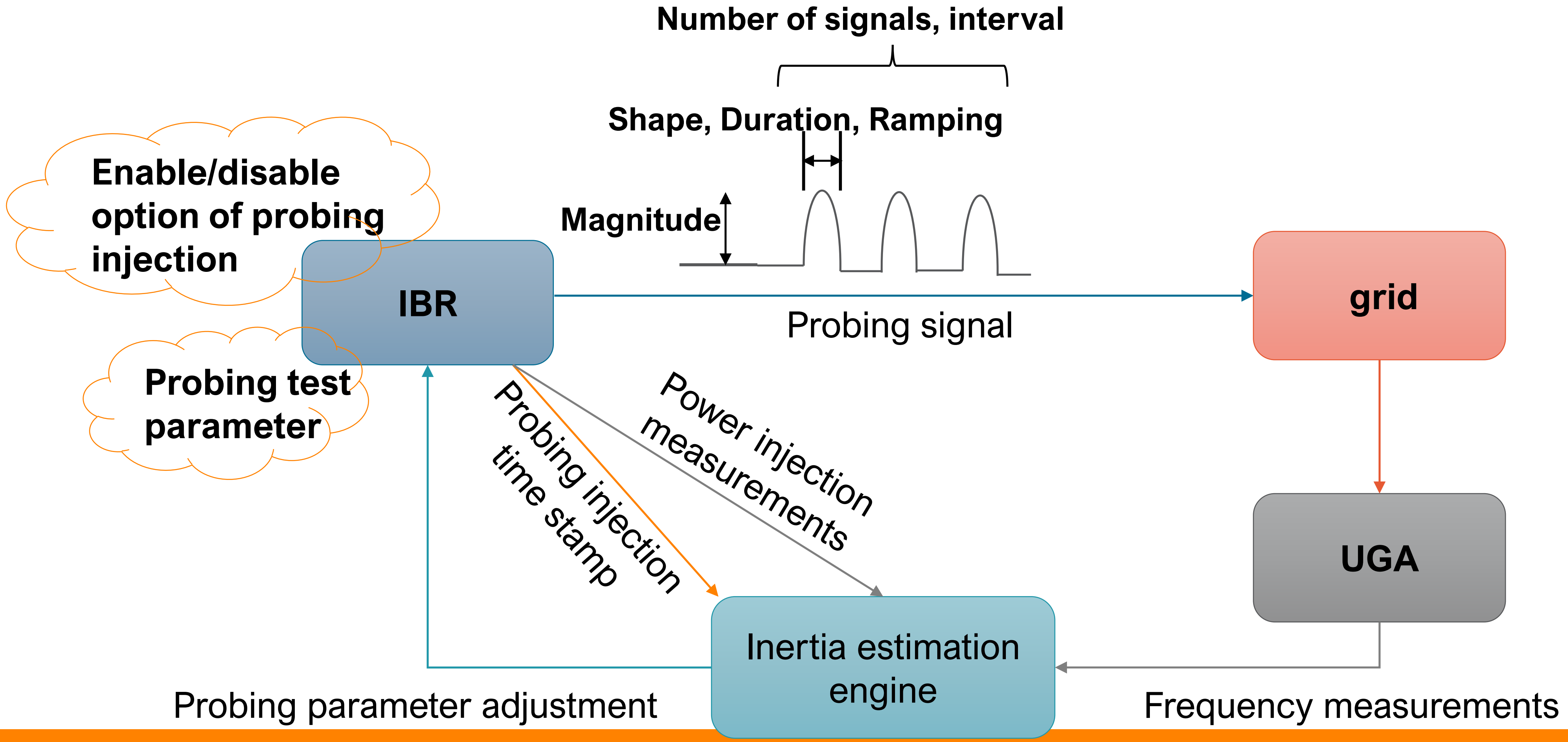
Available from EIA U.S. Energy Mapping System: https://www.eia.gov/state/maps.php

UGA-POW FDR

Inertia Estimation Visualization

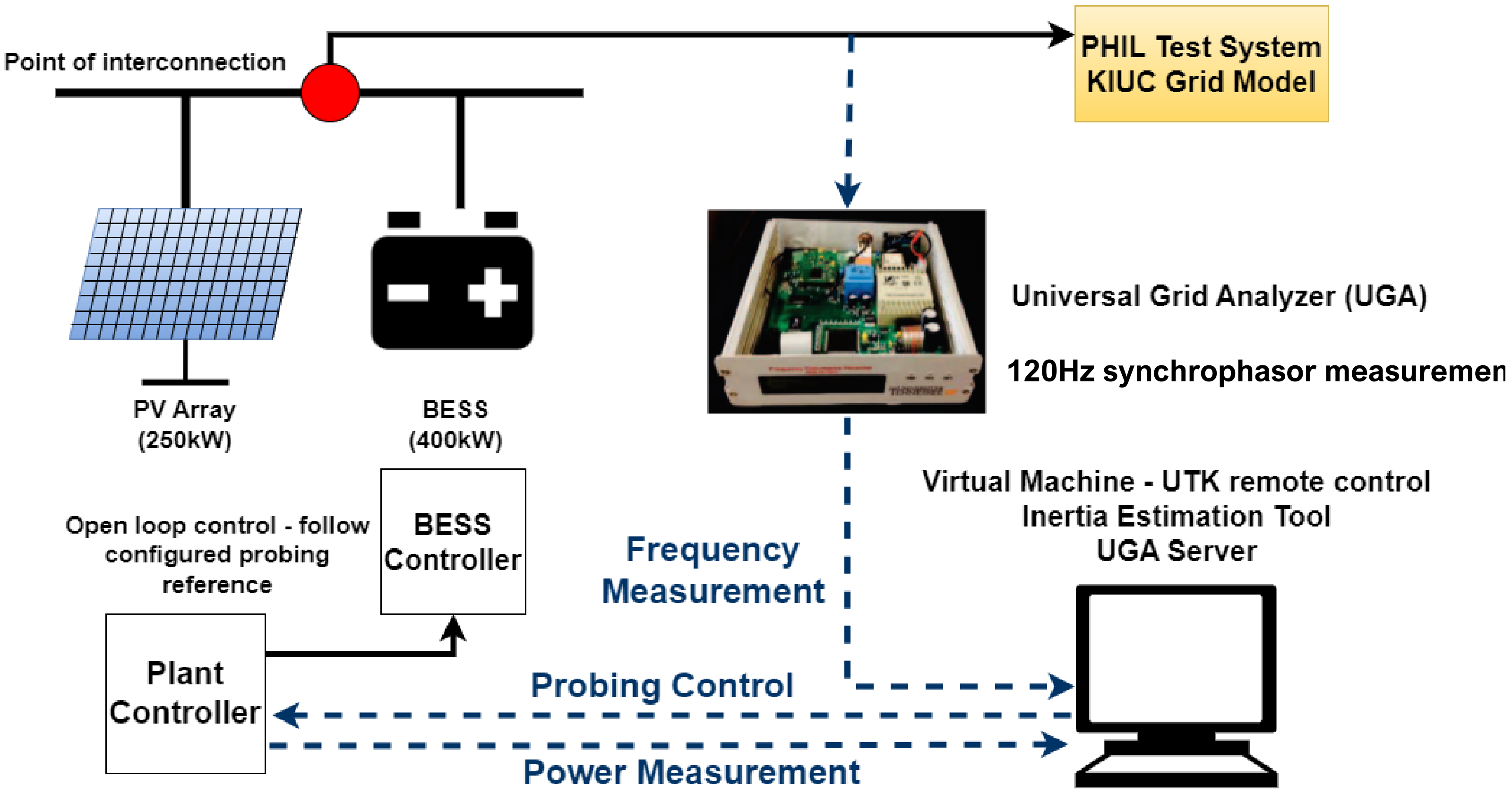


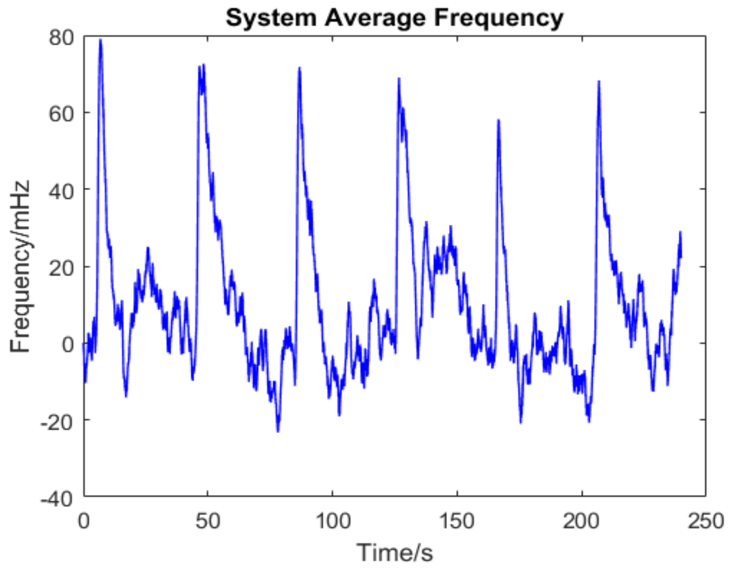
Probing based Inertia Estimation



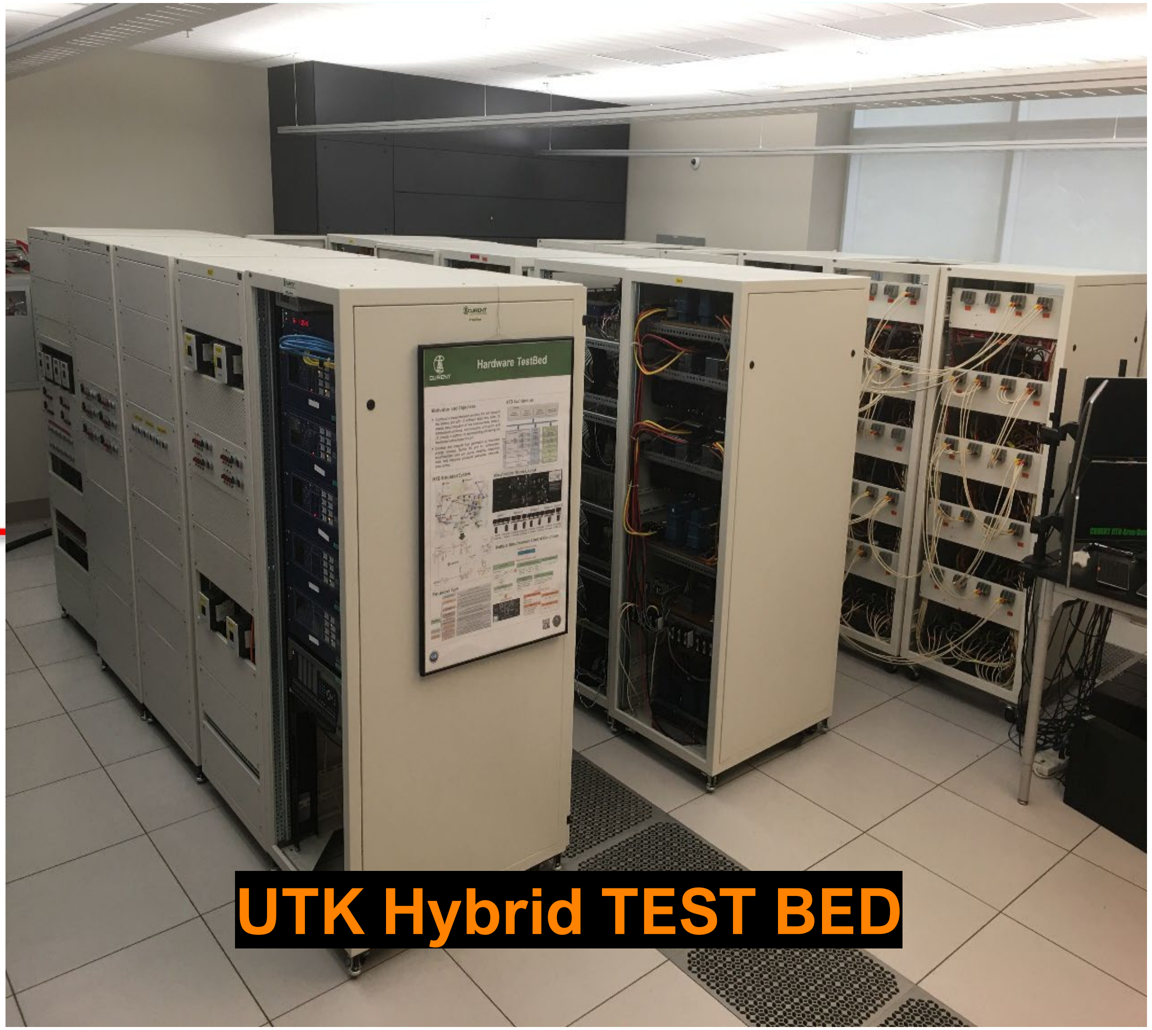
Power-hardware-in-the-loop (PHIL) Test System

- PHIL test system with identical hardware and control as the actual Kauai Island power grid is being set up at the NREL Flatirons campus.





Power-HIL System Setup at NREL



PHIL Test Results Summary – 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 Summary – 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%**

PHIL TEST Acknowledge

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