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CENTER FOR ULTRA-WIDE-AREA RESILIENT ELECTRIC ENERGY TRANSMISSION NETWORKS

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Online Inertia Estimation From PMU measurements

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Acknowledgement

- DOE Solar Technology Office funding 2019-2021 via NREL
- DOE Water Power Technology Office funding 2022-2023 via ORNL
- UTK/ ORNL and *CURENT* industry for FNET/GridEye support
- UTK researchers Howei Li, Yi Cui, Steve You, Joy Zhao
- NREC for interconnection inertia data

Accurate inertia estimation is important

Higher renewable penetration → lower inertia → lower frequency nadir

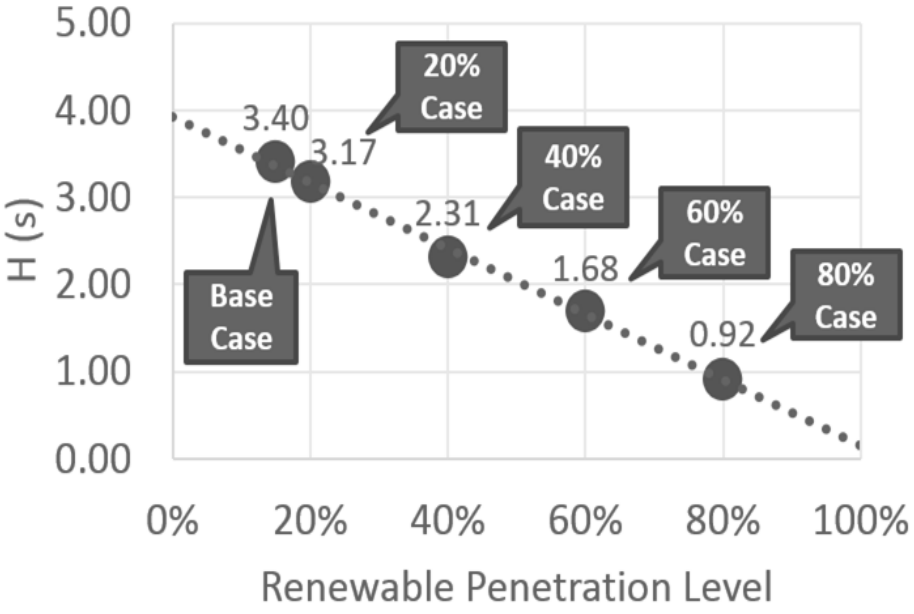
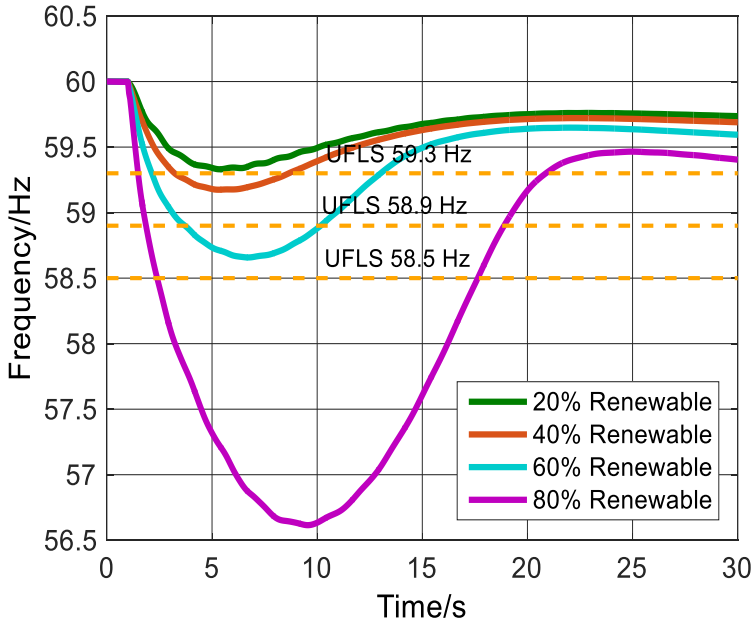
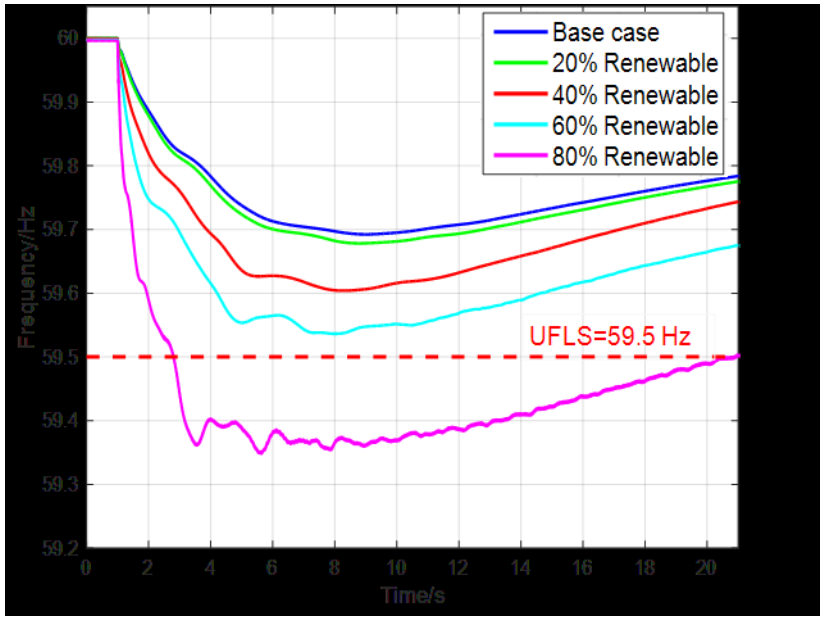


Fig. System equivalent inertia at different renewable penetration levels [SuNLAMP]



a. The ERCOT simulated frequency responses (2,750 MW generation loss)

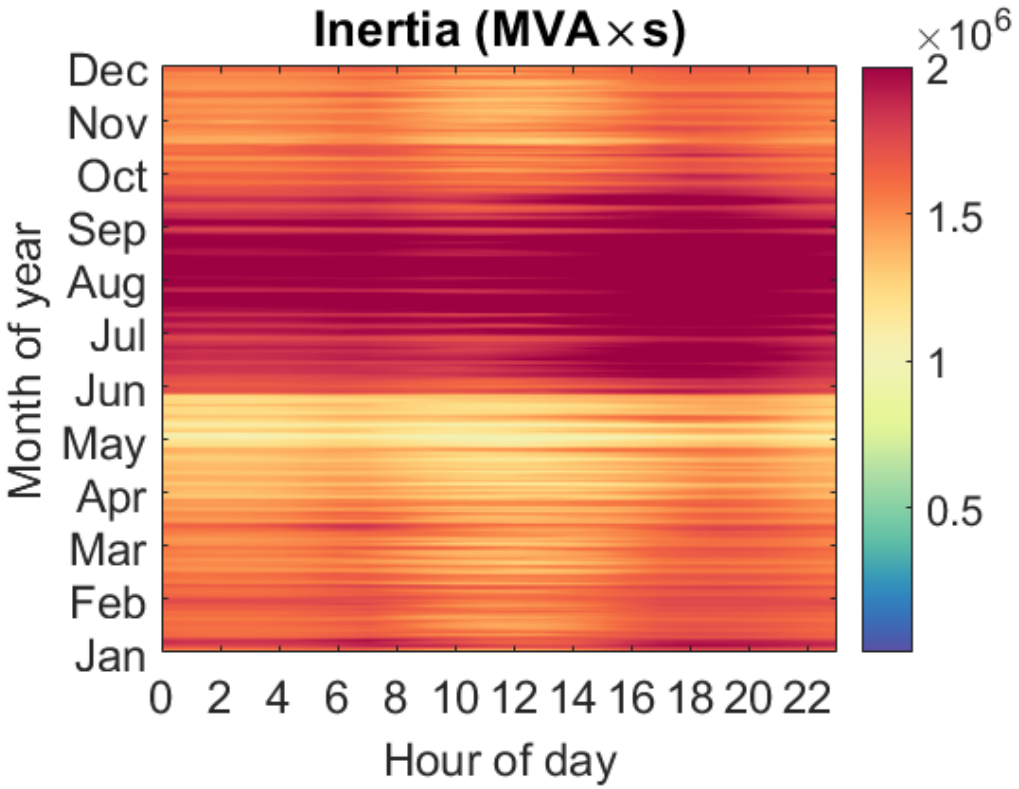


b. The WECC simulated frequency responses (2, 625 MW generation loss)

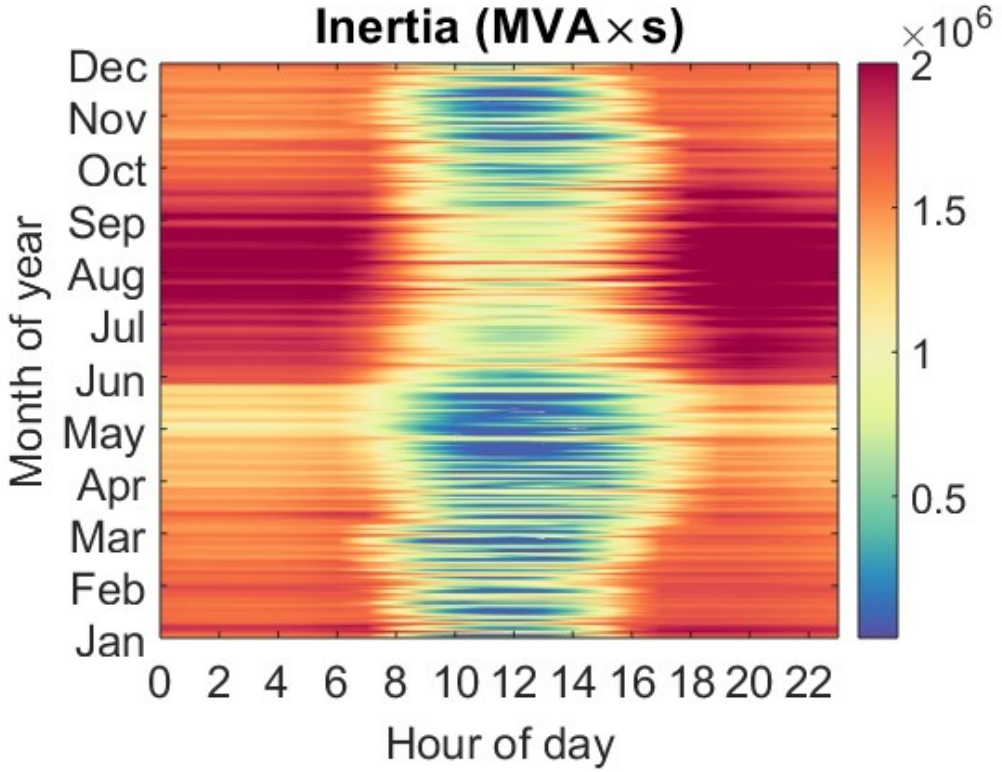
Fig. Frequency response under different renewable penetration levels

Problem Background

- **Renewable energy increase will significantly amplify the volatility and uncertainty of system inertia.**



Inertia change in the EI system in one year with **10% PV penetration**



Inertia change in the EI system in one year with **50% PV penetration**

Inertia Estimation Techniques

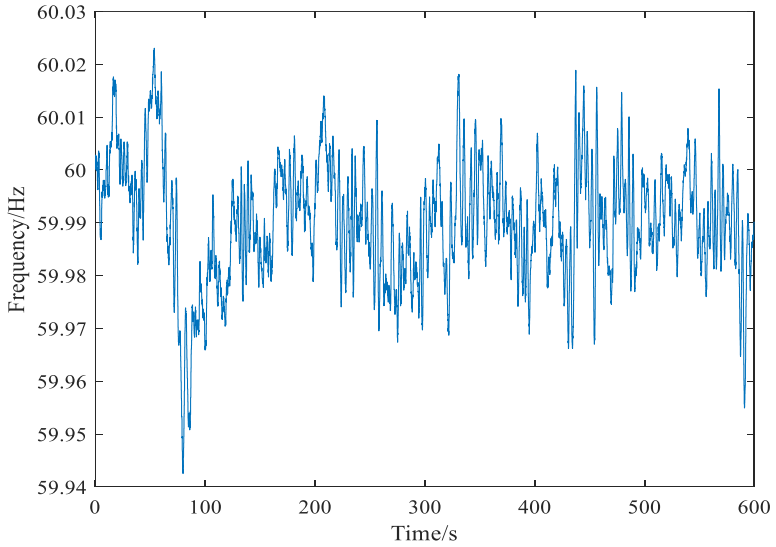
Methods	Input data			Performance		Comments
	EMS	PMU	Event information	Includes load, IBR, and other behind-the-meter inertia	Results impacted by FFR and load damping	
Dispatch-based	√	×	×	1	×	Easy to do, but IBR control, load, other artificial inertia may be lost
Event-driven	×	√	√	√	√	Most accurate, needs to wait for events,
Probing signal	×	√	×	√	√	Better accuracy than ambient, real time, invasive, added costs
Ambient signal	×	√	×	√	√	Real time, low cost, data processing has challenges

1 The dispatch-based inertia can include the behind-the-meter inertia by including correction factors, but these behind-meter inertias are not measured directly.

Ref:http://cigre.ru/research_commitets/ik_rus/c2_rus/materials/library/WBN022%20-%20C2.C4.41%20-%20Dec20.pdf

UTK Inertia Estimation Using Ambient Frequency Signal

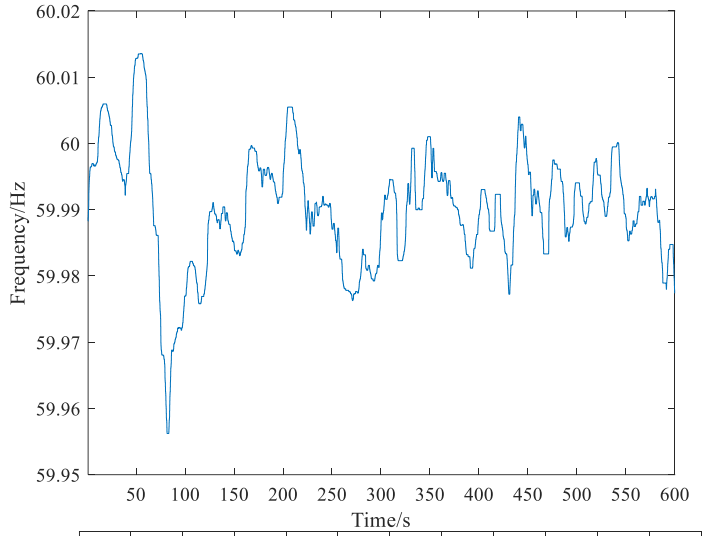
Extract ambient frequency signal



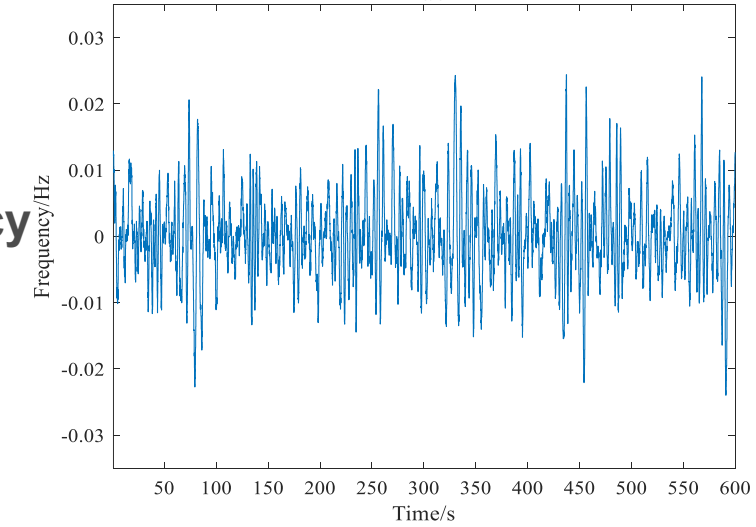
Raw data

Slow trend
(Moving window filter)

Ambient frequency signal
(Detrend data)



Slow



Fast

Fig. Ambient frequency signal extraction

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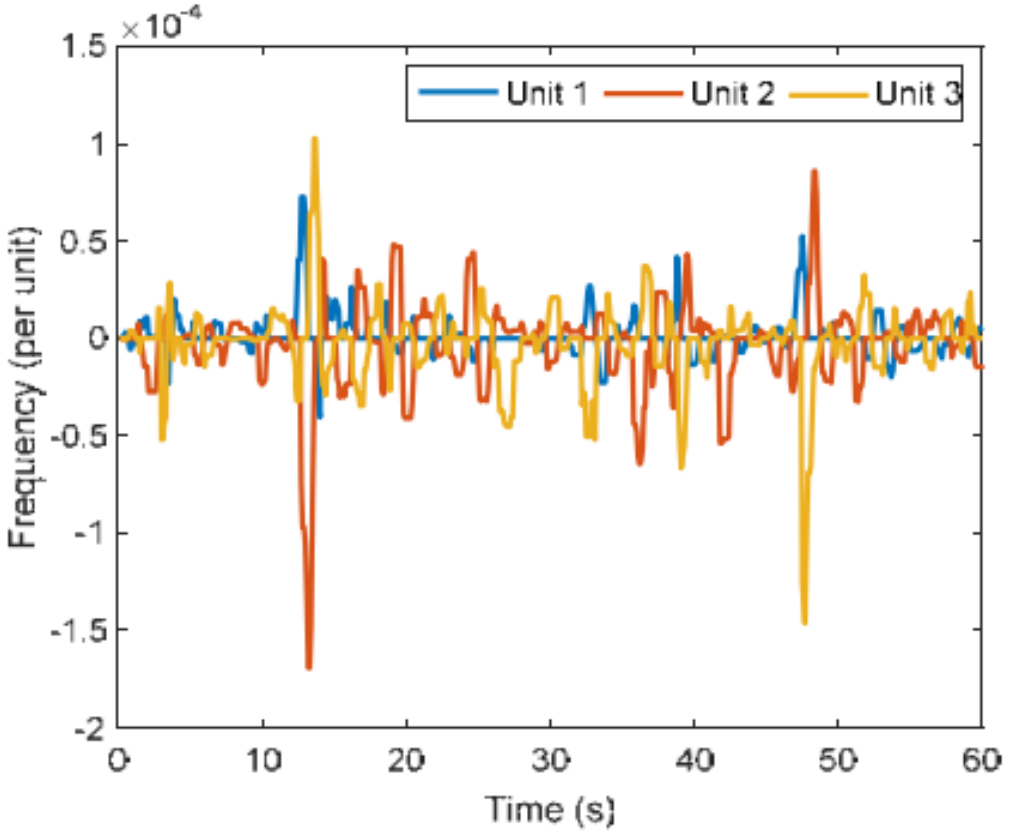
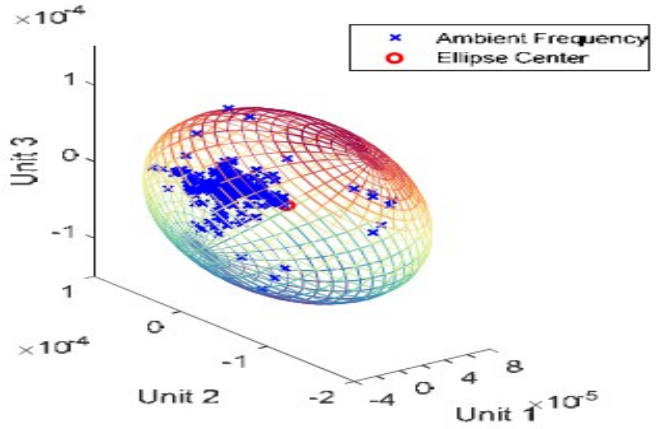
UTK Inertia Estimation Using Ambient Frequency Signal

Machine learning based method

- Minimum Volume Enclosing Ellipsoid (MVEE) from ambient-frequency features



MVEE



Features	Dimension
Ellipsoid volume	1
Ellipsoid eccentricity	1
Ellipsoid centers	20
Projection of the longest axis	20
Daily average temperature	1
Load profile	1
Total dimension	44

https://ieeexplore.ieee.org/document/9281662

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Weather correlation

- Correlation Between Inertia and Weather Condition
- Average temperature of six cities in WECC: Los Angeles, Phoenix, Salt Lake City, Denver, Las Vegas and Seattle.

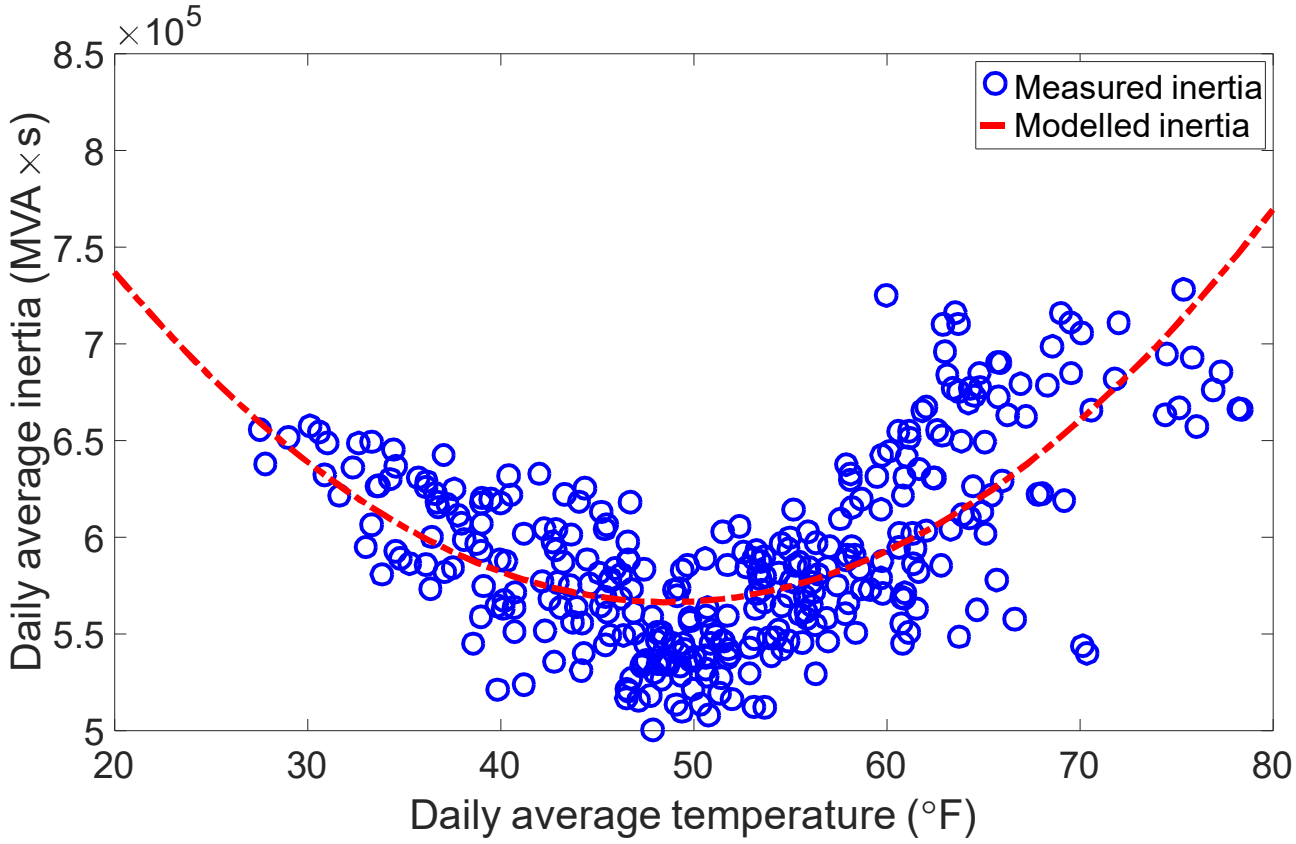


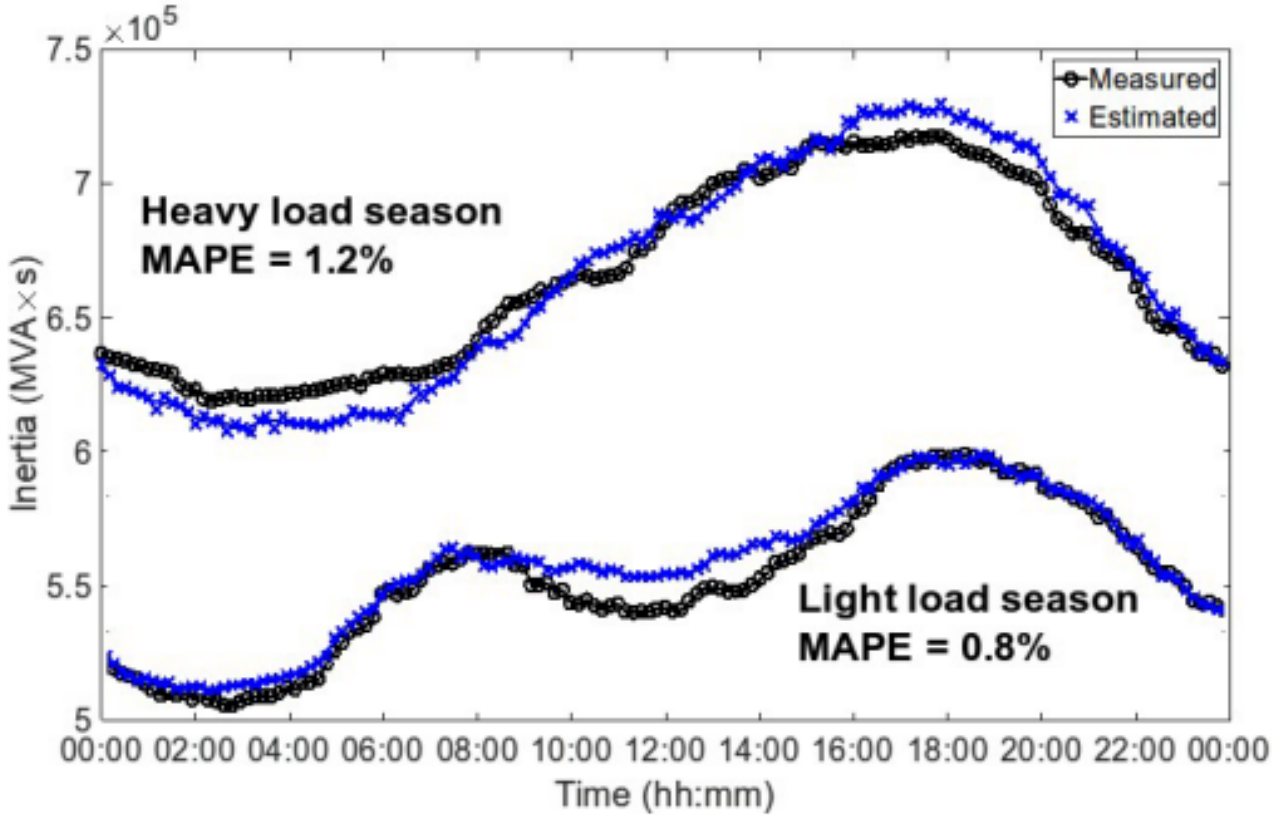
Fig. Correlation between daily average inertia and daily average temperature

UTK Inertia Estimation Using Ambient Frequency Signal

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

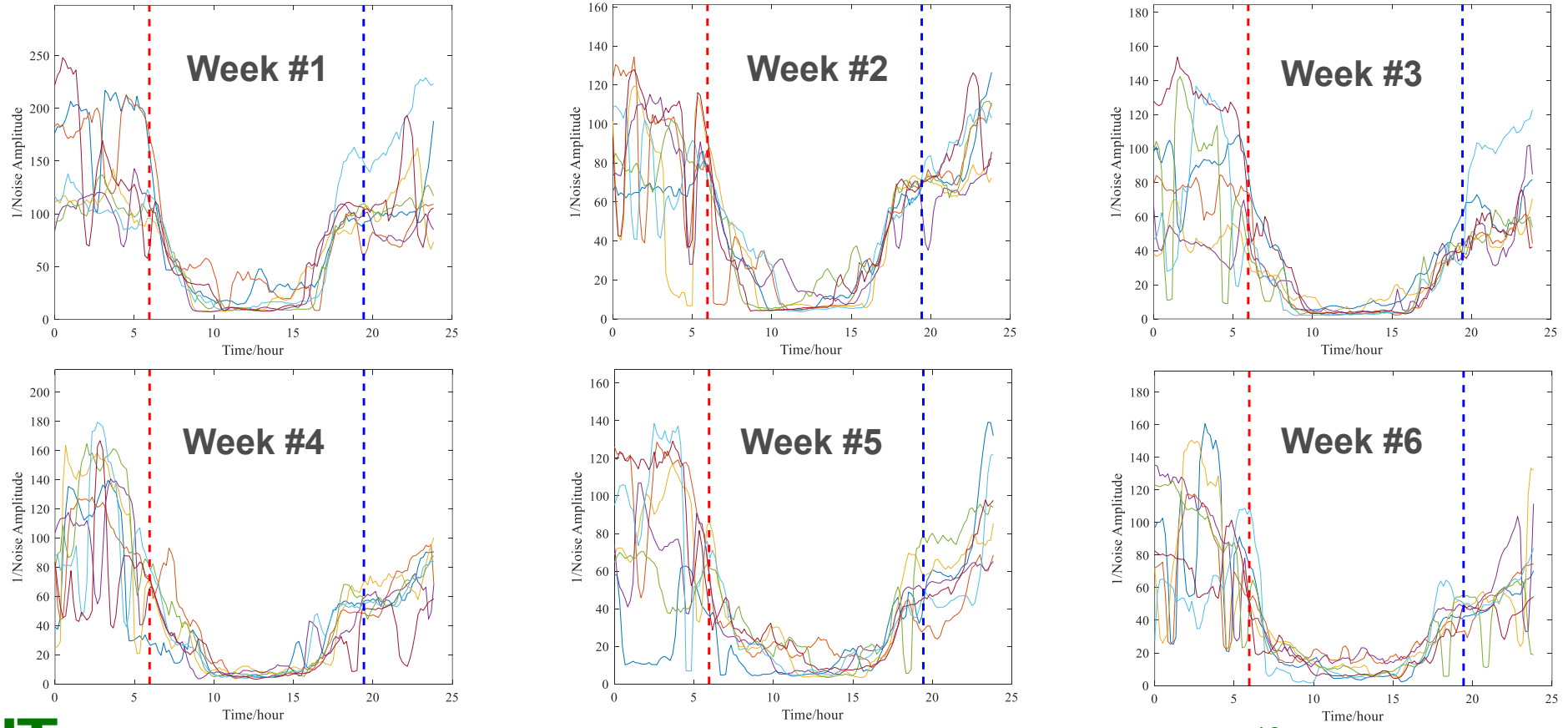
UTK Inertia Estimation Using Ambient Frequency Signal

Data + Physics based method

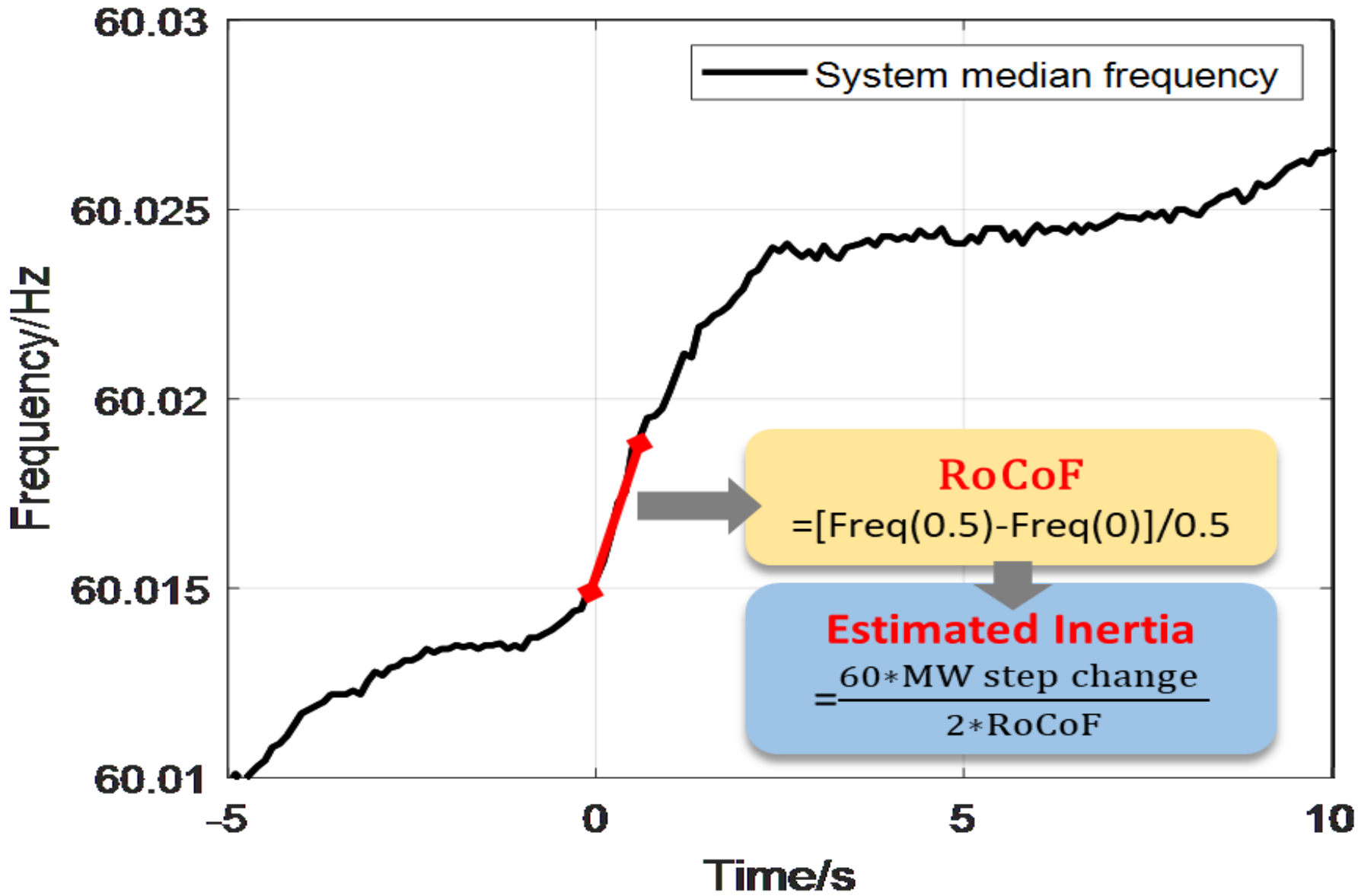
- ‘relative inertia’ results from island #1

------ Local sunrise time

------ Local sunset time

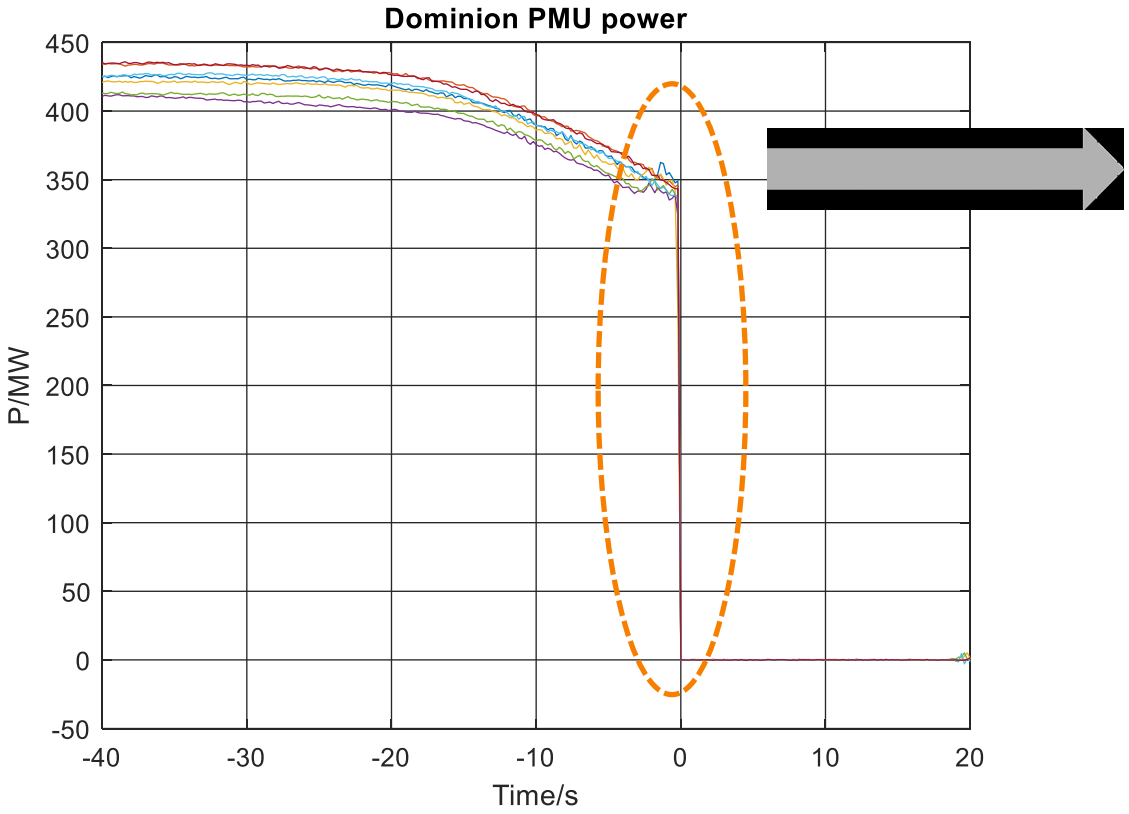


Potential Solution from Pumped Storage Hydro



Potential Solution from Pumped Storage Hydro

PMU data of ten 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%**

OAK RIDGE National Laboratory

Online Inertia Estimation System Design