Towards High-Res Grid Measurements at kHz Level: Algorithm Development and Hardware Demonstration

PI: Lingwei Zhan[1]

Main contributors: Bailu Xiao[1], He "Henry" Yin[2], Yilu Liu[1,2]

1. Oak Ridge National Laboratory

2. The University of Tennessee, Knoxville

Washington DC

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Acknowledgement and Disclaimer

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High-Res Grid Measurements

- *Project Objective: Increase grid visibility orders of magnitude higher by achieving grid measurement at a rate of kHz (vs rate of commercial devices: 60 Hz).*

- *Project Benefits: allow to understand grid behaviors at a new level: high-frequency wide-area events, renewable transient behaviors, fast system stability predication, etc.)*

- *Project Deliverables:*
  - ✓ High-speed grid measurements technology.
  - ✓ Performance benchmarking and value demonstration.

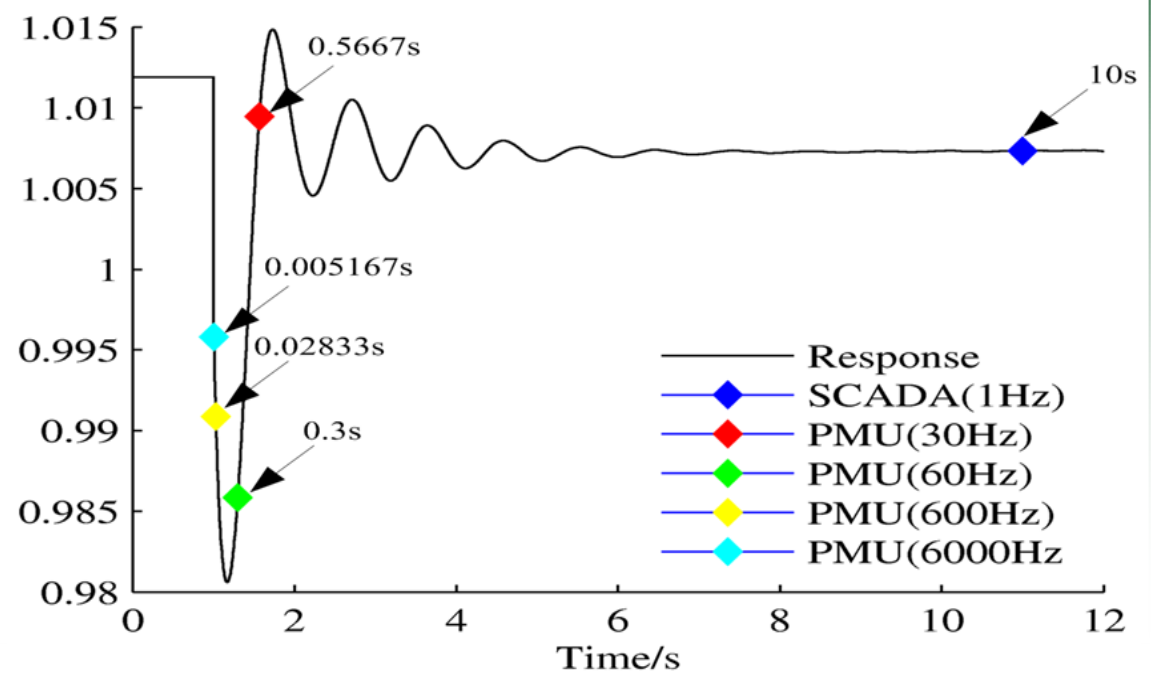
Technical Goal

State-of-the-Art
X **Slow**
X **Grid Visibility Resolution: ~0.02s**

Goal:
✓ **Fast**
✓ **Grid Visibility Resolution: <0.001s**

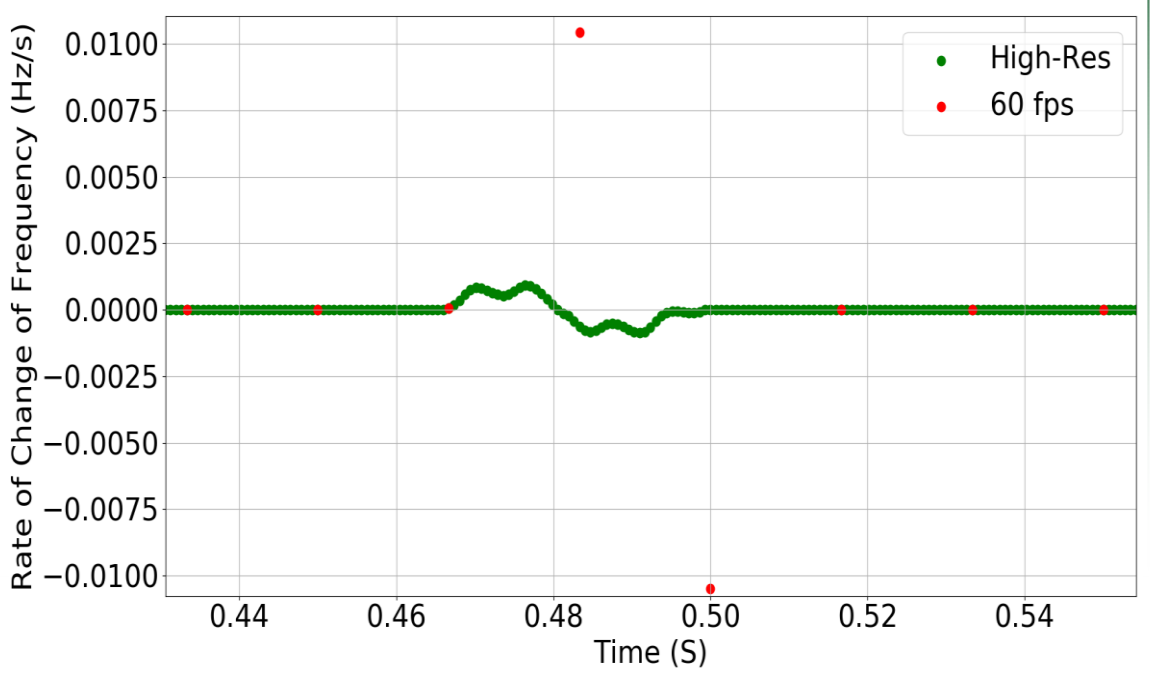
Value of High-Res Grid Measurements - Examples

System Stability Predication



Prediction time approaching ¼ cycle as the PMU data rate increase

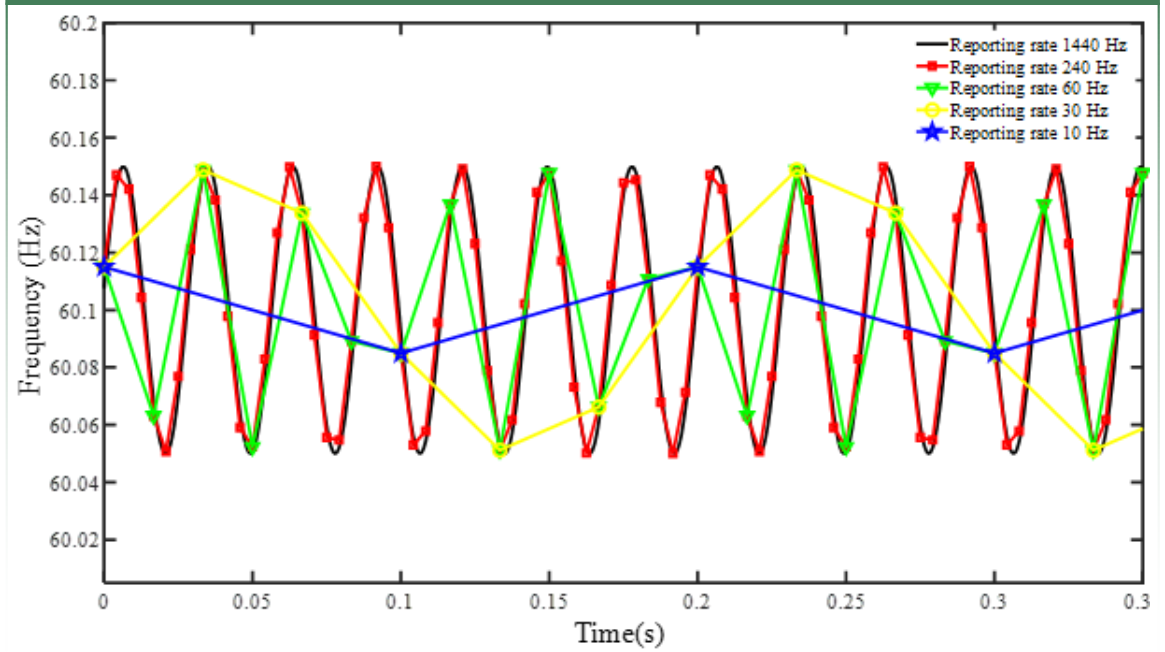
Grid Protection



Rate of Change of Frequency Instantaneous and accurate detection

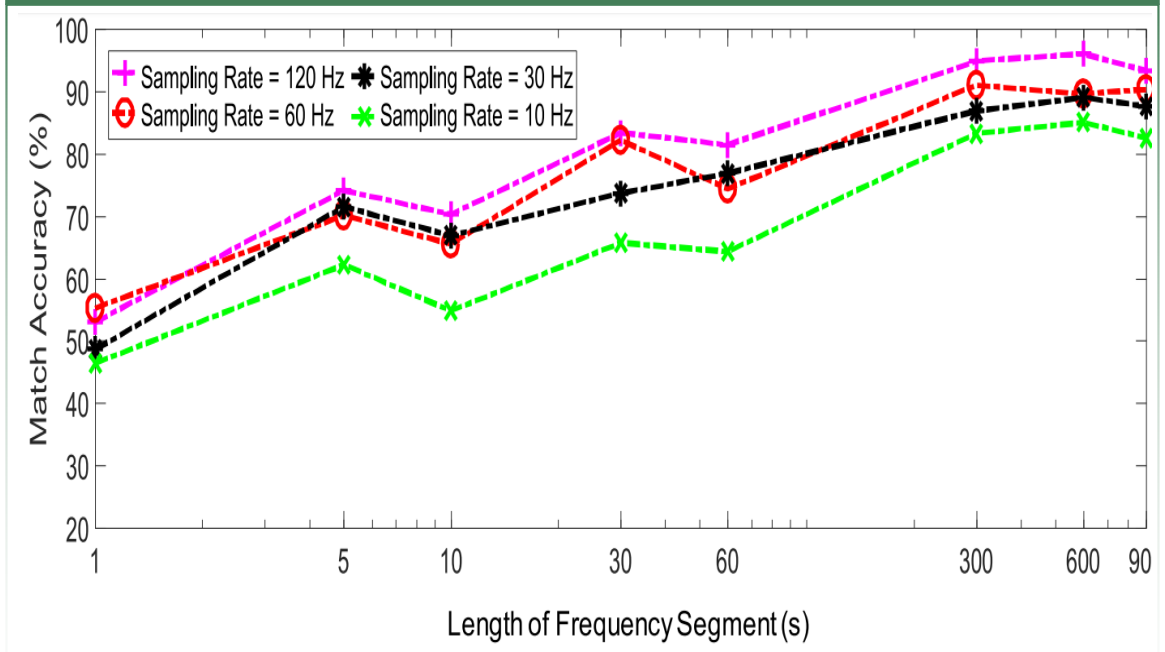
Value of High-Res Grid Measurements - Examples Cont.

Grid Visibility



Observation of sub-synchronous resonance oscillation

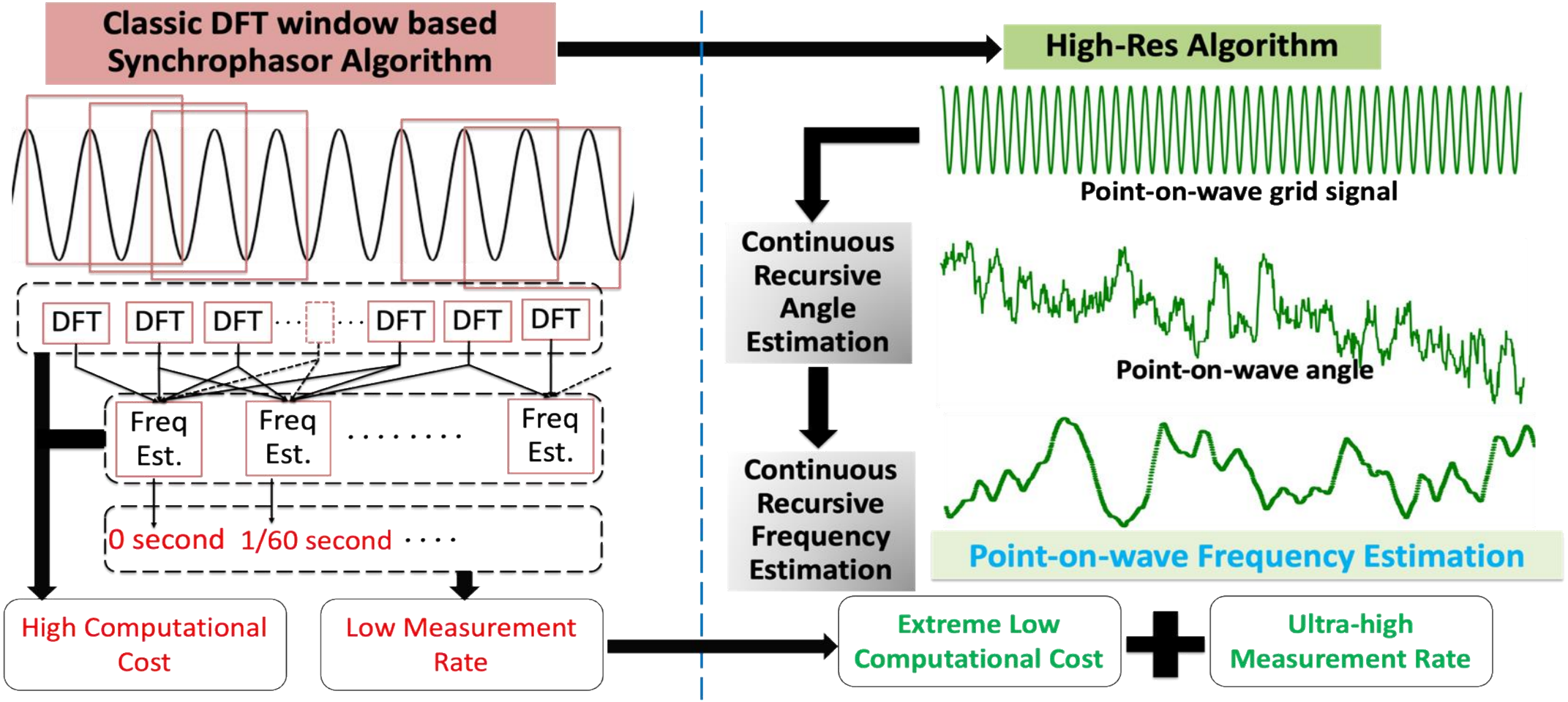
Cyber Security



Spatial Signatures of Power ENF Signal for Measurement Source Authentication [1]

[1] Yi Cui et al., "Exploiting Spatial Signatures of Power ENF Signal for Measurement Source Authentication", Technologies for Homeland Security (HST) 2018 IEEE International Symposium on, pp. 1-6, 2018.

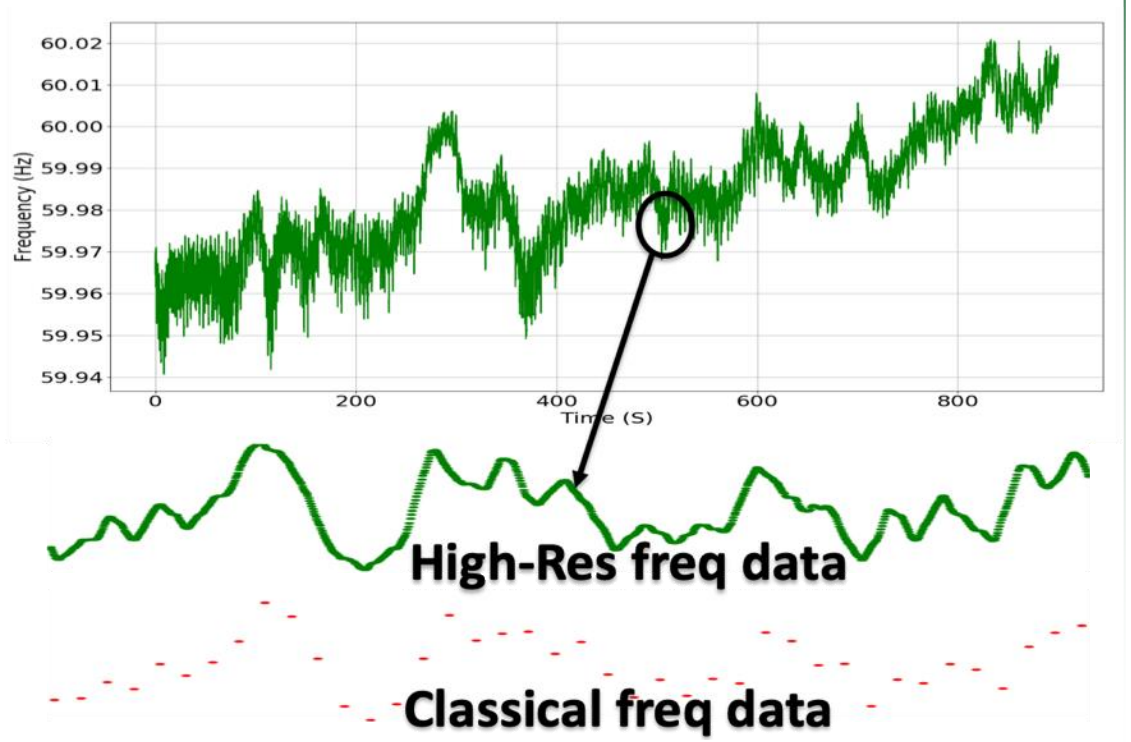
Technical Approach – Novel Recursive Architecture



High-Res Algorithm evolves from the measurement algorithm used by FNET/GridEye Frequency Disturbance Recorders whose measurement accuracies and reliability have been proven by 300 units deployment across the nation's grid and over 15 years field operation.

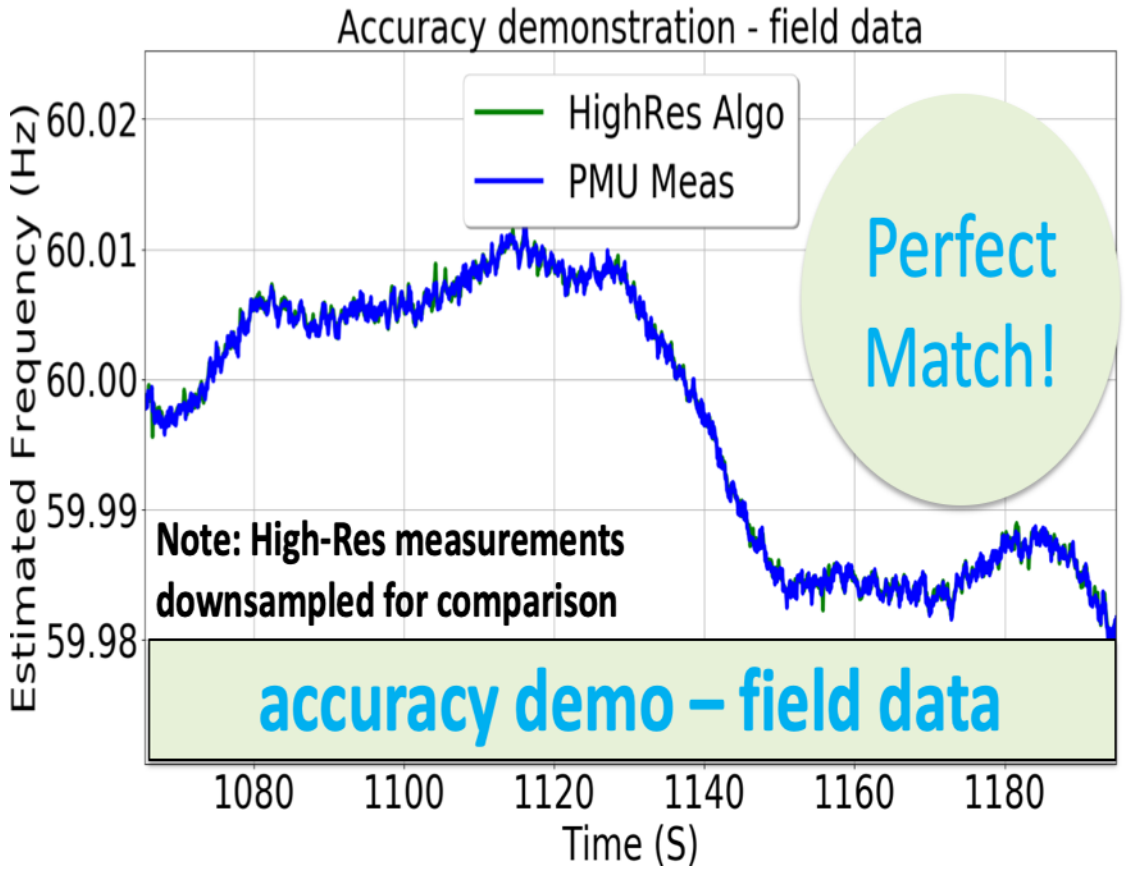
Algorithm Benchmark – Grid Visibility and Measurement Accuracy – field data

Grid Visibility – field data



orders of higher grid visibility

Measurement Accuracy – Compare with PMU



accuracy demo – field data

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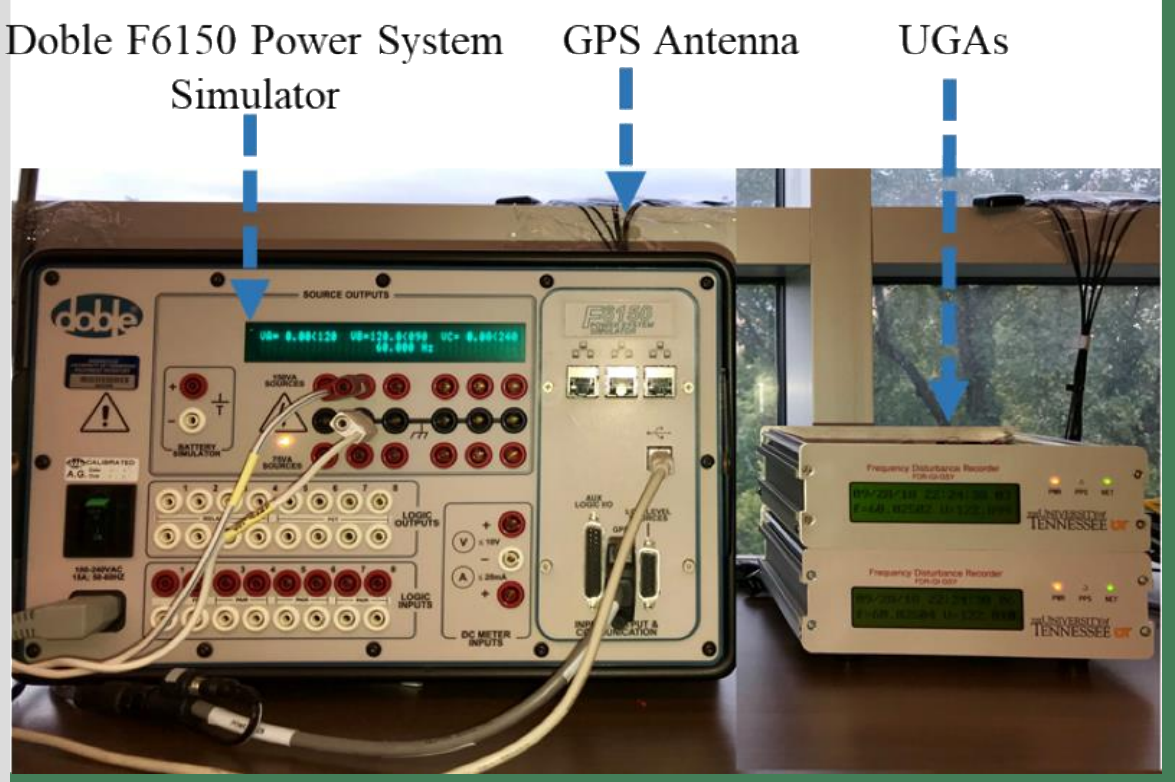
Hardware Demonstration

A prototype developed based on the FNET/GridEye Multi-functional PMU, Universal Grid Analyzer.

- ✓ Measurement error: 0.075 mHz (vs. 5 mHz IEEE Std.)
- ✓ Measurement rate: 1.5 kHz (vs. 60 Hz commercial PMU)
- ✓ Measurement performance verified by noisy field data at distribution level (120-V).



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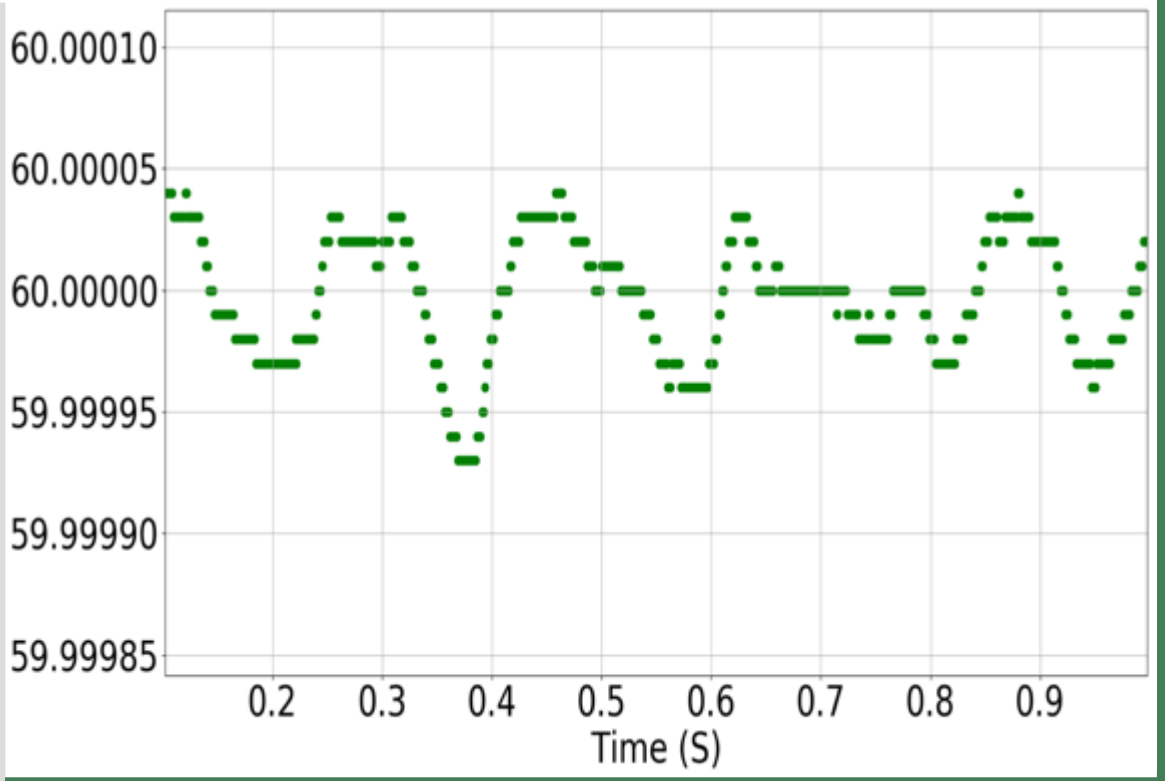

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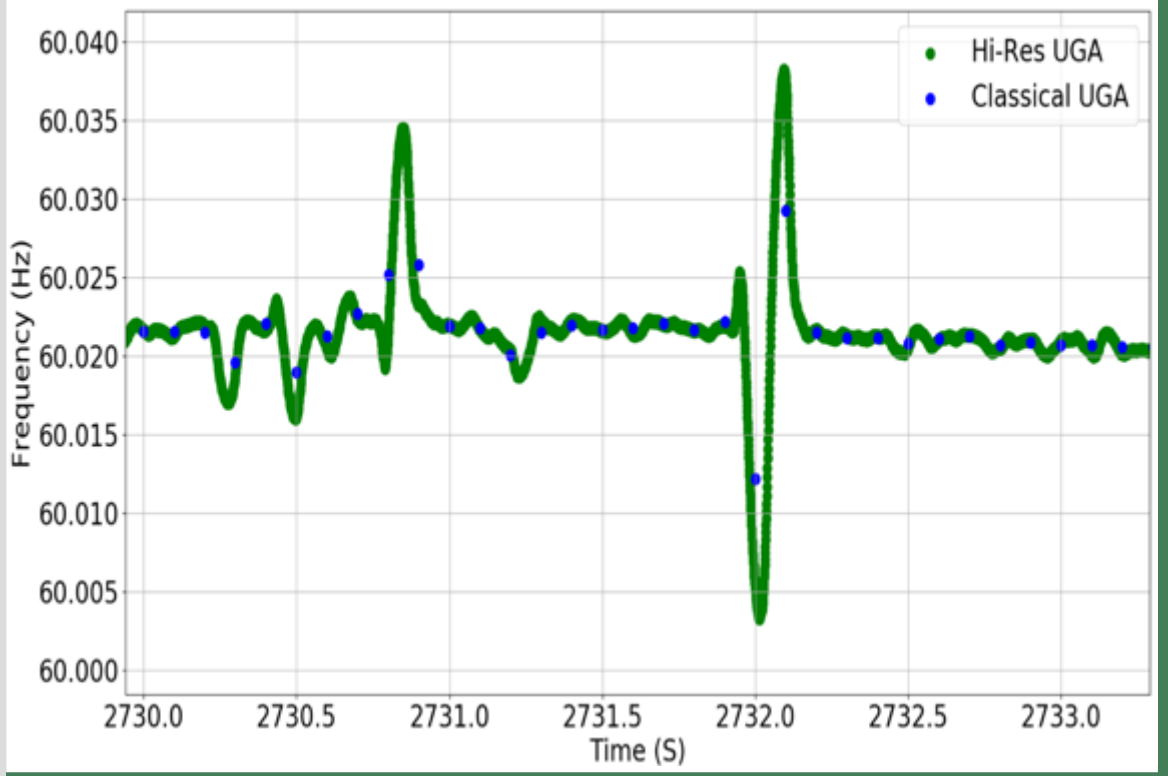

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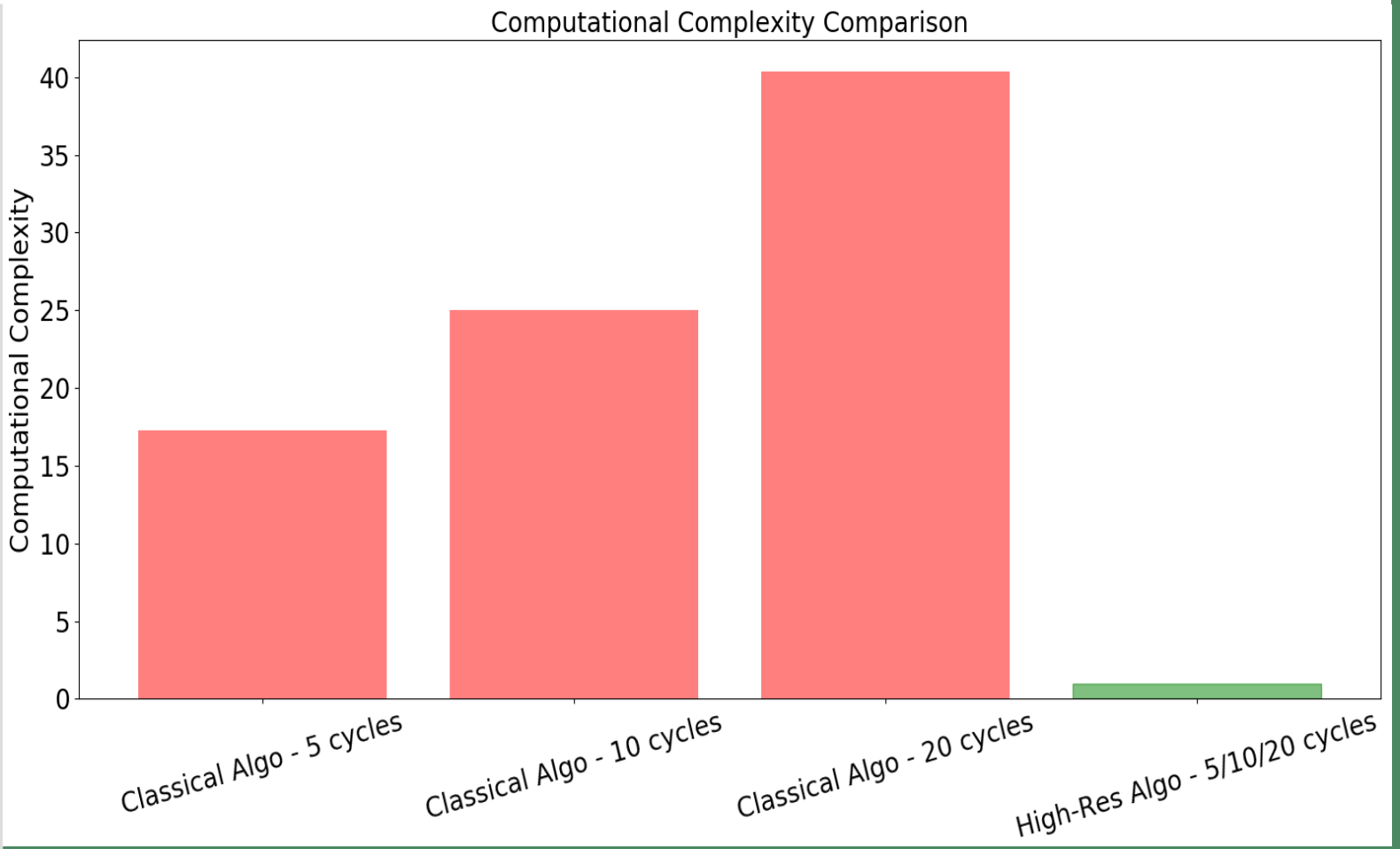
Computational Complexity

- ✓ Ultra-low computational complexity
  - > Extreme low-cost
  - > Large volume deployment possible
  - > More measurement functions possible
  - > Easily to be integrated into grid devices (DERs, etc.)
- ✓ Independent of window size
  - > Accuracy improvement does not increase cost.



Summary and Future Work

- ✓ Developed high resolution (Hi-Res) grid frequency measurement algorithm.
- ✓ Demonstrated high measurement accuracy using both PMU calibrator and noisy field data. PMU data used for comparison.
- ✓ Increased grid frequency measurement rate to kHz level: 1500 Hz measurement rate demonstrated on hardware.
- → Go higher measurement rate!!!
- → Deploy multiple high-res sensors at distribution system and collect long-term data.
- → Leverage the high-res measurements to estimate other parameters (e.g. high-res rate of change of frequency).

Thank You