High Speed Sensor Development and Deployment Panel Discussion

NASPI Panel Session

November 5, 2020

U.S. DEPARTMENT OF ENERGY

High Speed Sensor Development and Deployment

- **Tom King,** Moderator and Highlight GMLC sensing activities
- **Yilu Liu and Eric Zhan, University of Tennessee & ORNL**: Introduction to high speed sensors, point on wave measurements and data compression
- **Farnoosh Rahmatian, NuGrid Power Corp**: Higher speed measurements along with supra-harmonic measurements (9 kHz – 150 kHz) with improved accuracy
- **Kyle Thomas, Dominion Energy:** Dominion Energy's Experience with Optical Sensors
- **Marissa Morales, ORNL**: Optical Sensor Deployment & Signature Library

DOE's Grid Modernization Laboratory Consortium – 14 National Labs – 100+ Partners

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

AMES LABORATORY
Creating Materials & Energy Solutions
U.S. DEPARTMENT OF ENERGY

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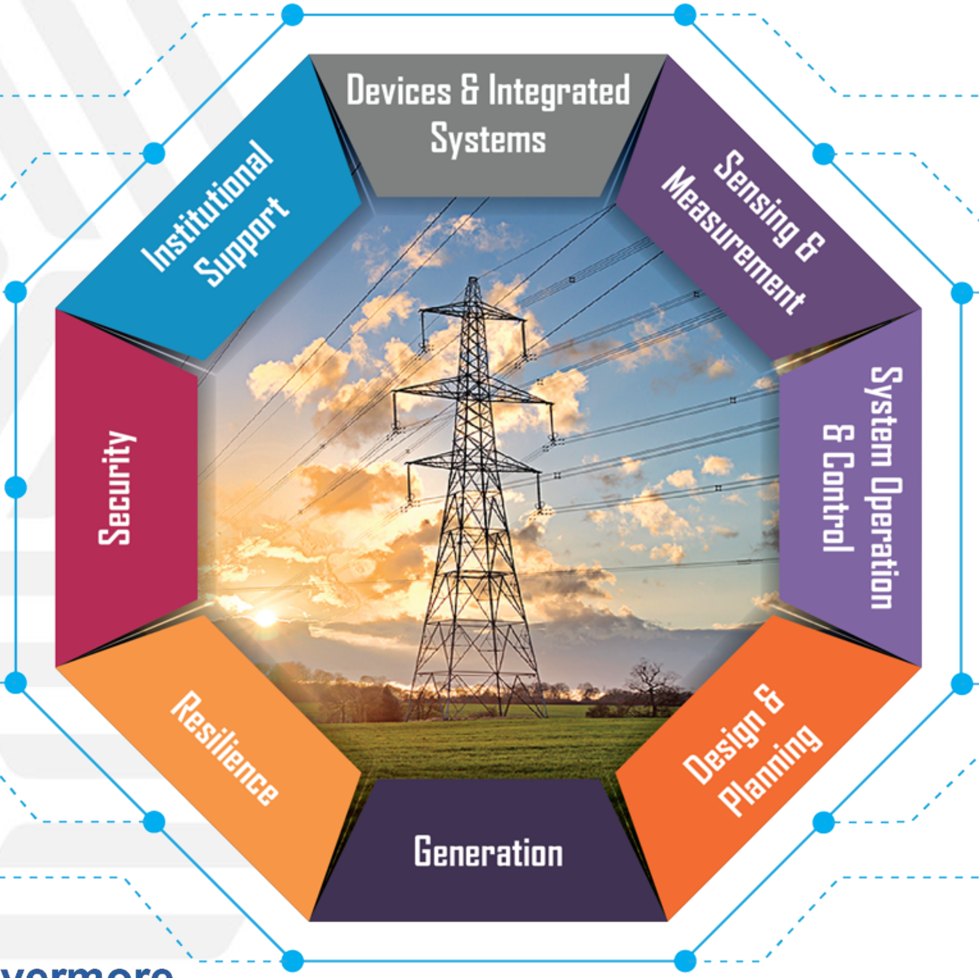


NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

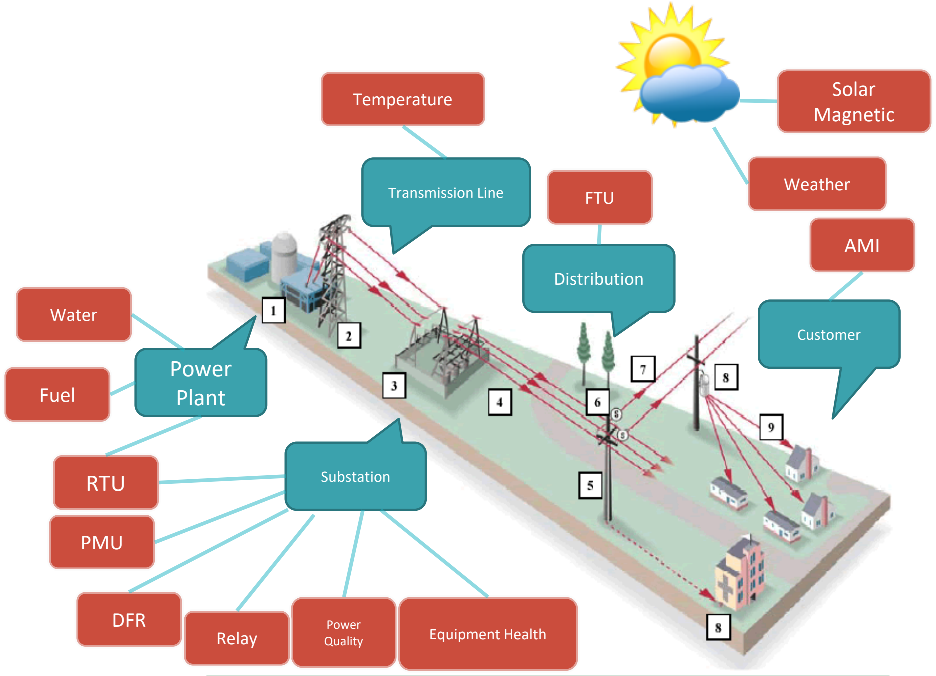
SLAC NATIONAL ACCELERATOR LABORATORY

SRNL

Sensing and Measurement Technical Team

Key Projects and Accomplishments

- Sensing & Measurement Strategy
  - Developed state of the art document, extended grid state, sensor placement tool and created roadmap providing a foundation for the multi-year plan
- Advanced Sensor Development
  - Advancement of 13 different technologies across end-use sector, transmission & distribution and asset monitoring; six invention disclosures and 5 patents, R&D100 award; 9 publications
- Integrated Multi Scale Data Analytics and Machine Learning for the Grid
  - Develop real-time data management and data exchange frameworks that enable analytics to improve prediction and reduce uncertainty; 12 conference journals, 3 technical reports and 2 patents filed on topology detection and event analytics



Modified from Duke Energy
https://www.progress-energy.com/florida/home/safety-information/storm-safety-tips/restoration.page?

High Speed Sensor Development and Deployment

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High-speed Advanced Grid Measurements

Yilu Liu, UTK, ORNL
Lingwei Zhan, ORNL

11/03/2020, NASPI

Extended Universal Grid Analyzer (UGA) expanding functions

- Normal UGA
  - Synchrophasor measurement
  - Power quality parameter measurement
- Extended UGA
  - Synchrophasor measurement
  - Power quality parameter measurement
  - **Point on Wave (POW) data record**
  - **Anomaly detection**

Normal UGA

Synchrophasors
- Frequency
- Phase angle
- Voltage magnitude

Power quality parameters
- Harmonics,
- Sag, Swall,
- SNR,
- Voltage flickers

POW
- 1440Hz POW data continuous streaming
- 64 kHz burst

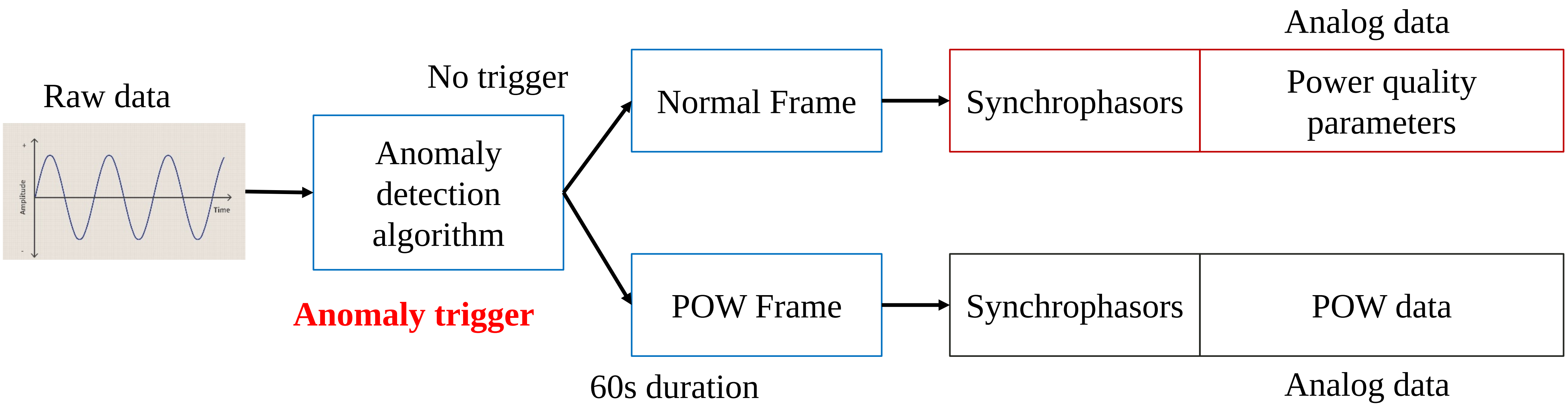
Anomaly detection
- Real time waveform trigger

Extended UGA

Lingwei Zhan, ORNL. Yilu Liu, UTK/ORNL

Anomaly detection and POW record

- Anomaly detection
  - Time domain real time anomaly detection
  - 30s POW record before and after anomaly trigger
- Frame types
  - Two kinds of data / configuration frame following IEEE C37.118.2 protocol
  - The power quality parameters and POW data are put in analog data sections



Anomaly detection algorithm can be found:
Zhan L, Xiao B, Li F, Yin H, Yao W, Li Z, Liu Y. Fault-tolerant grid frequency measurement algorithm during transients. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States); 2020 Jan 10.

Anomaly detection algorithm

- Anomaly detection algorithm
  - Capable to detect
    - Phase shift
    - Temporary voltage drop / increase
    - Voltage RMS drop / increase

Phase shift

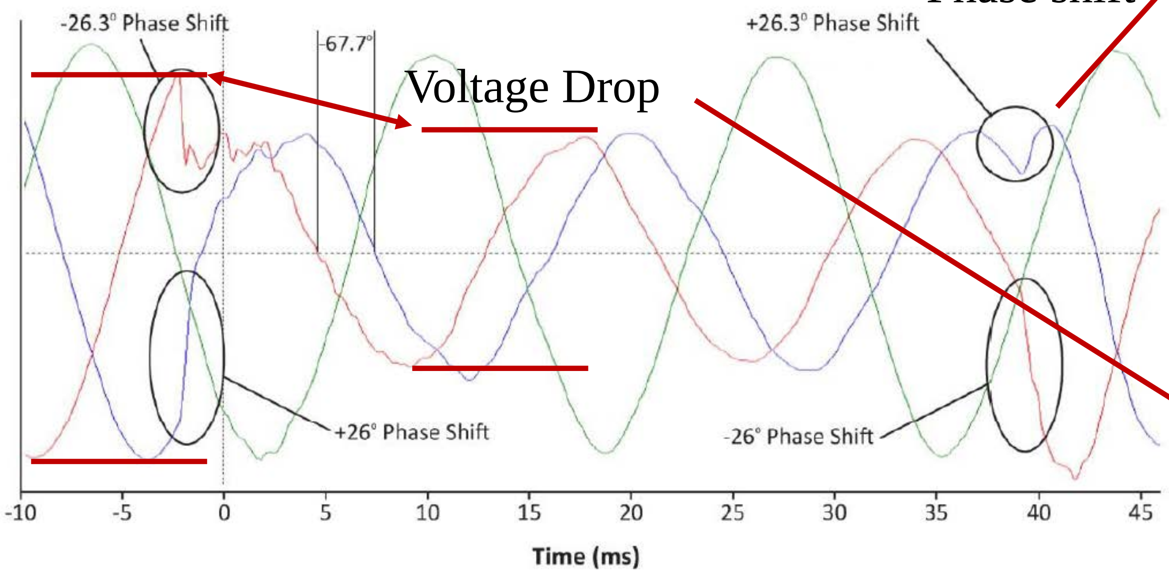
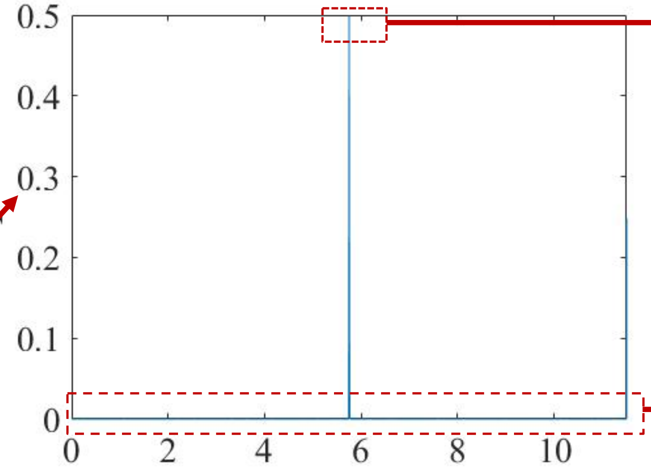


Figure comes from: 1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

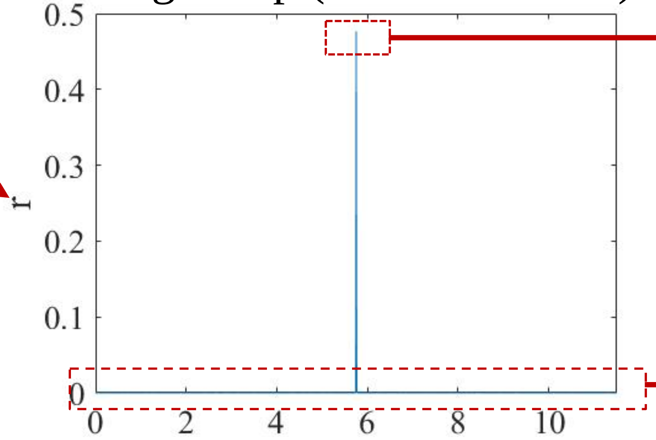
Minimum detectable
Phase shift (0.6 degree)



Trigger value under fault case

Trigger value under Normal cases

Minimum detectable Temporary Voltage drop (1.2% reduction)



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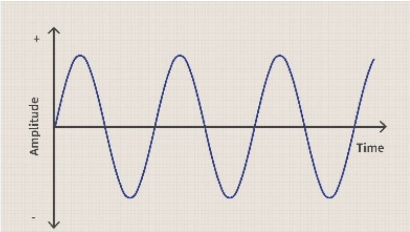
Data Compression in UGA

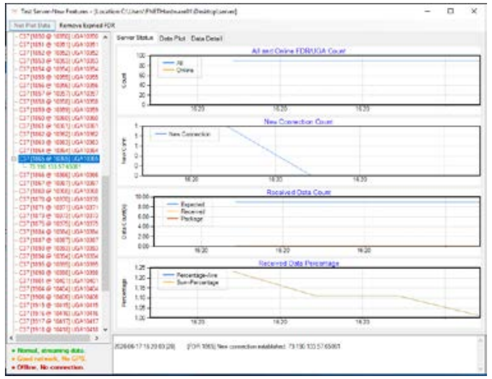
- To reduce the data stream between server and UGAs
- Two stage compression algorithm for both synchrophasor and POW data



voltage signals

Synchronized phasor estimation algorithm

POW data recording algorithm



FNET servers

Synchronized phasors

POW data

Prediction/preprocess stage

- Delta encoding
- Difference encoding

Compression stage

- Entropy encoding
- Run-length encoding

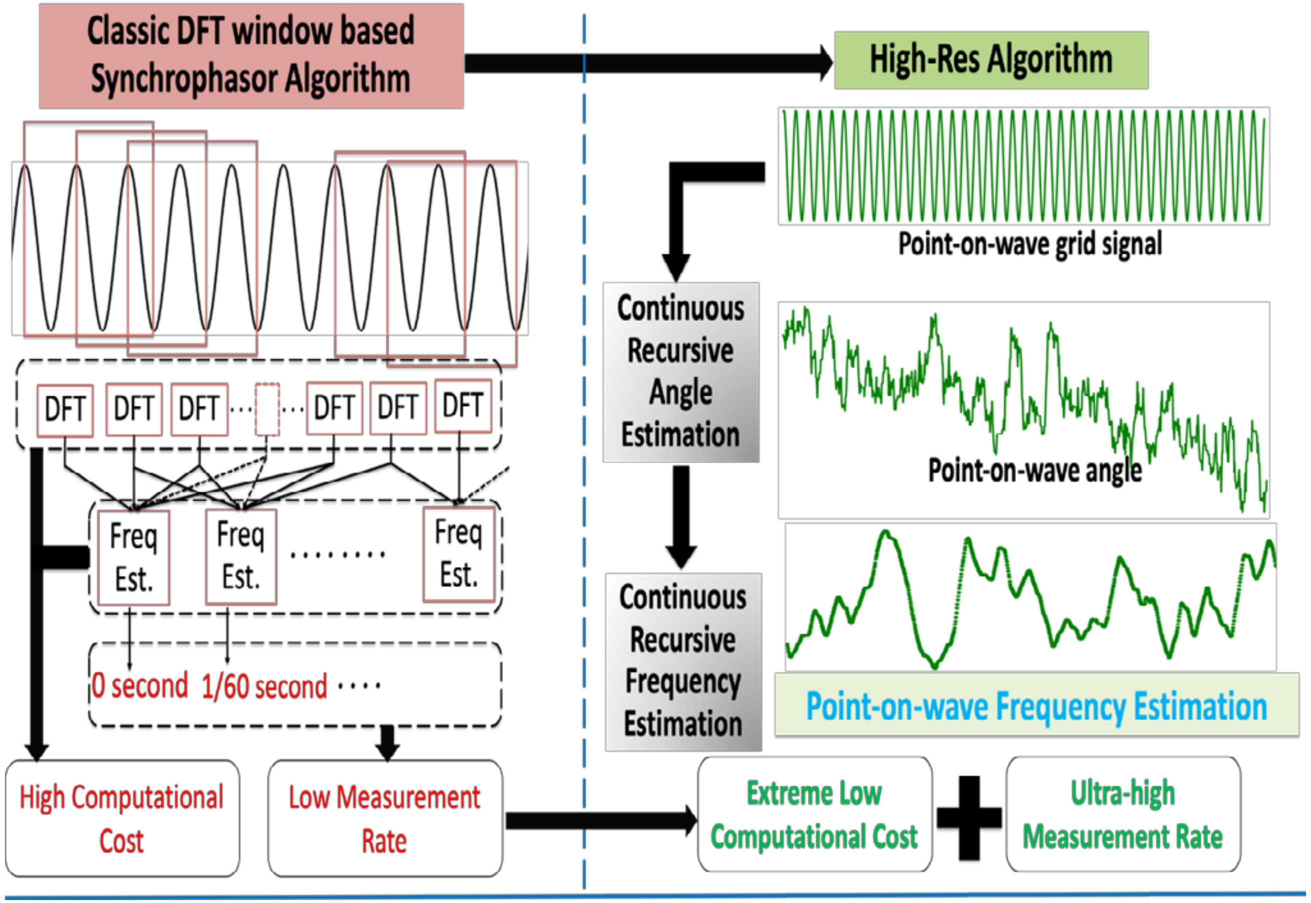
Compressed Synchronized phasors

Compressed POW data

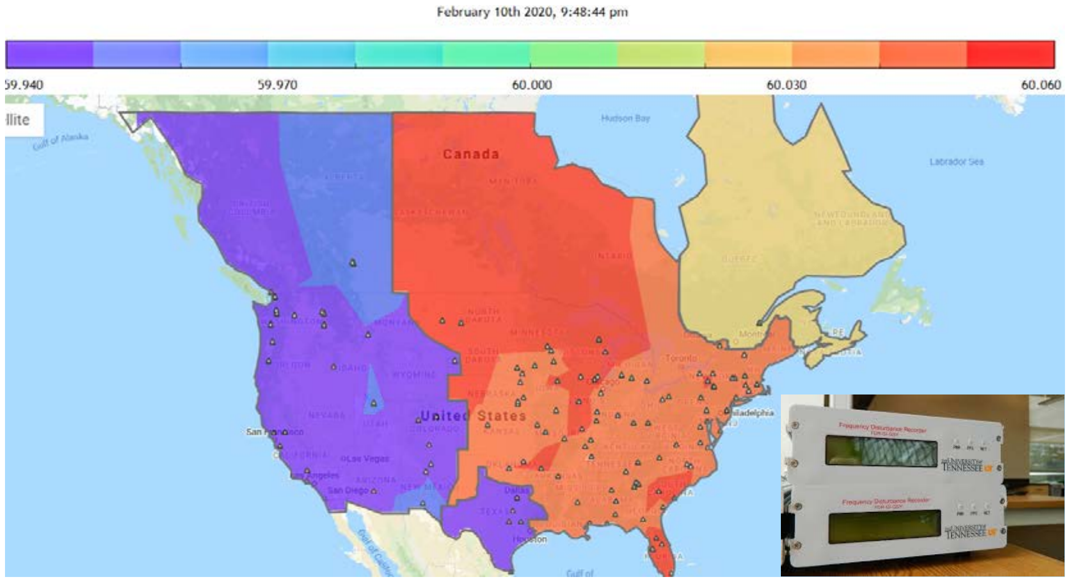
OAK RIDGE National Laboratory   CURENT

High-speed Grid Frequency Measurement Approach: **Recursive Computation**

Frequency Estimation Rate = Data Sampling Rate



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



High-speed Grid Frequency Measurement Advantage: **Extremely low computational cost**

Extremely low computational cost

- ✓ O(1) time complexity no matter window size or data sampling rate.
- ✓ ~ 3 orders of computation time reduction compared to popular DFT based algorithms.

Benefits

- ✓ **Measurement rate**: Orders of higher grid measurement rate (kHz vs typical 60 Hz)
- ✓ **Hardware friendly**: easy hardware integration into grid edge devices.
- ✓ **Grid Applications**: enhanced grid visibility, high-frequency event detection, accurate oscillation source location, accurate RoCOF estimation, fast DER control/protection, stability predication, etc.

Number of numerical operations per estimation

Variable	Equation	count of `+` and `-`	count of `*`	count of arctan
$X_r(m), m \geq 0$	(4)	2	1	0
$X_i(m), m \geq 0$	(4)	2	1	0
$\varphi(m), m \geq 0$	(5)	0	0	1
$\varphi_{sum}(j-1), j \geq 2$	(29)	2	0	0
$\alpha_1(j), j \geq 1$	(28)	3	2	0
$f(j), j \geq 0$	(10)	1	1	0
$f_e(j), j \geq 1$	(31)	2	1	0
Total	N/A	12	6	1

Extremely Low Computation Cost

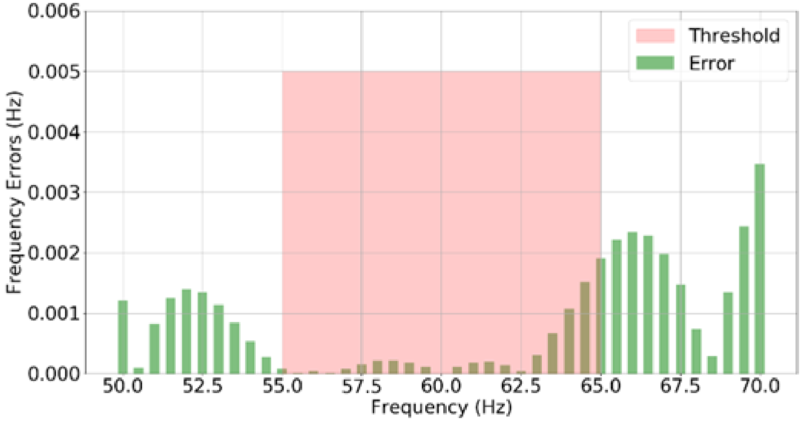
Sampling Rate	Window Size (cycle)	Computation Time (second)		Faster
		DFT Algorithm	Proposed Algorithm	
1440 Hz	5	1.279	0.002	650x
	10	2.396	0.002	1200x
	20	4.611	0.002	2300x
2880 Hz	5	2.590	0.002	1300x
	10	4.870	0.002	2400x
	20	9.240	0.002	4600x

Lingwei Zhan, ORNL. Yilu Liu, UTK/ORNL

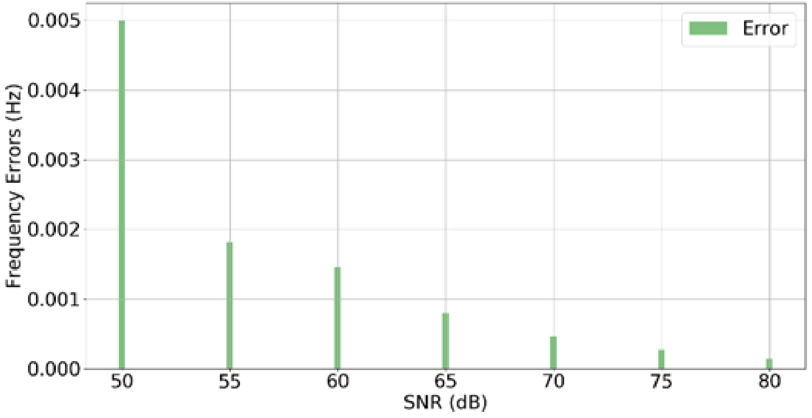
High-speed Grid Frequency Measurement Accuracy: **Assessed Following IEEE/IEC 60255-118-1-2018**

Steady-state

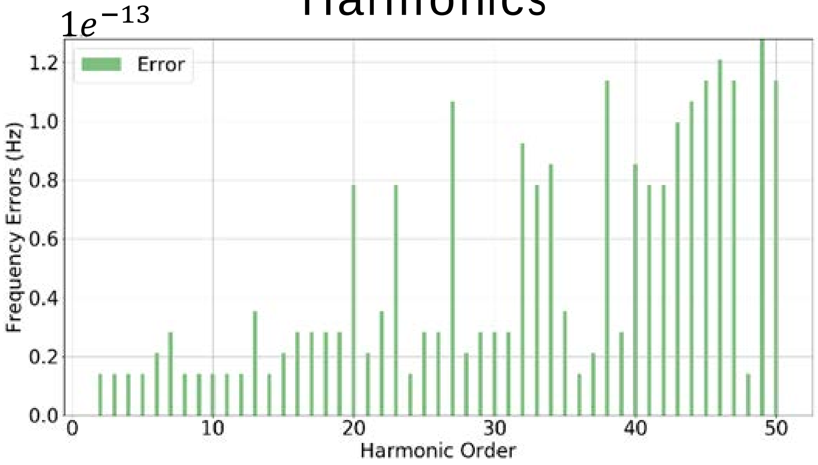
Frequency offset



Noise

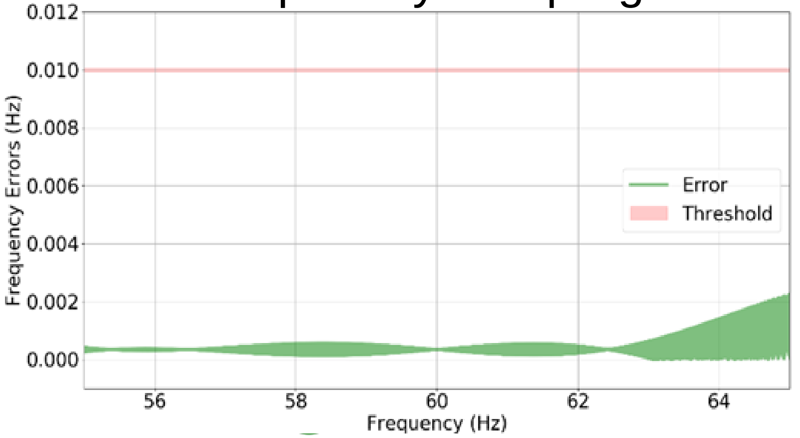


Harmonics

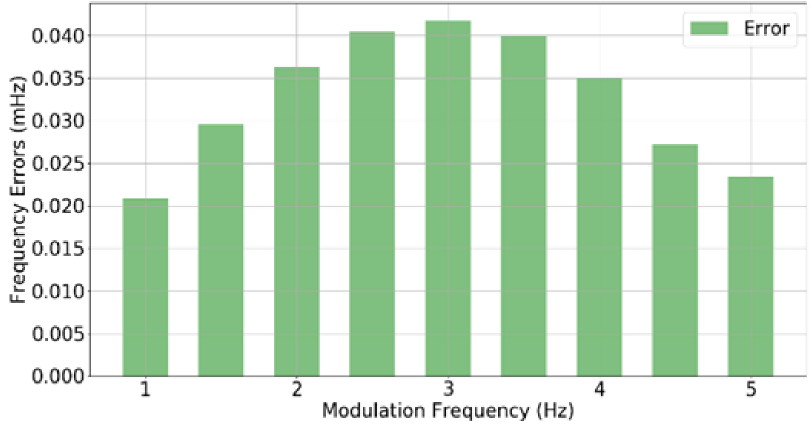


Dynamics

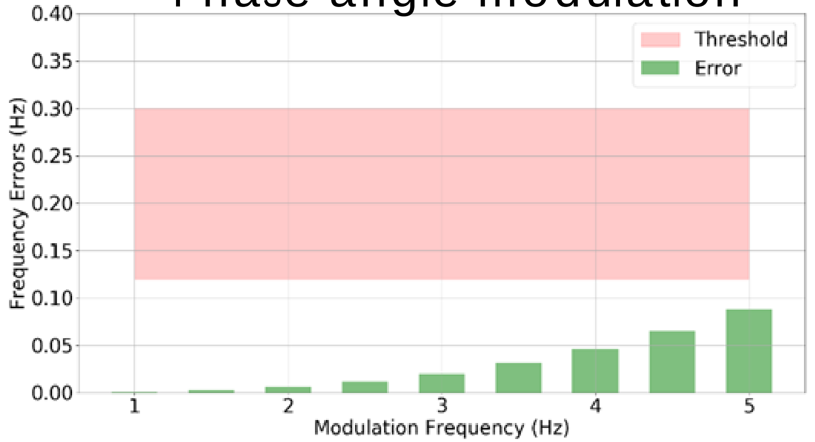
Frequency ramping



Magnitude modulation



Phase angle modulation

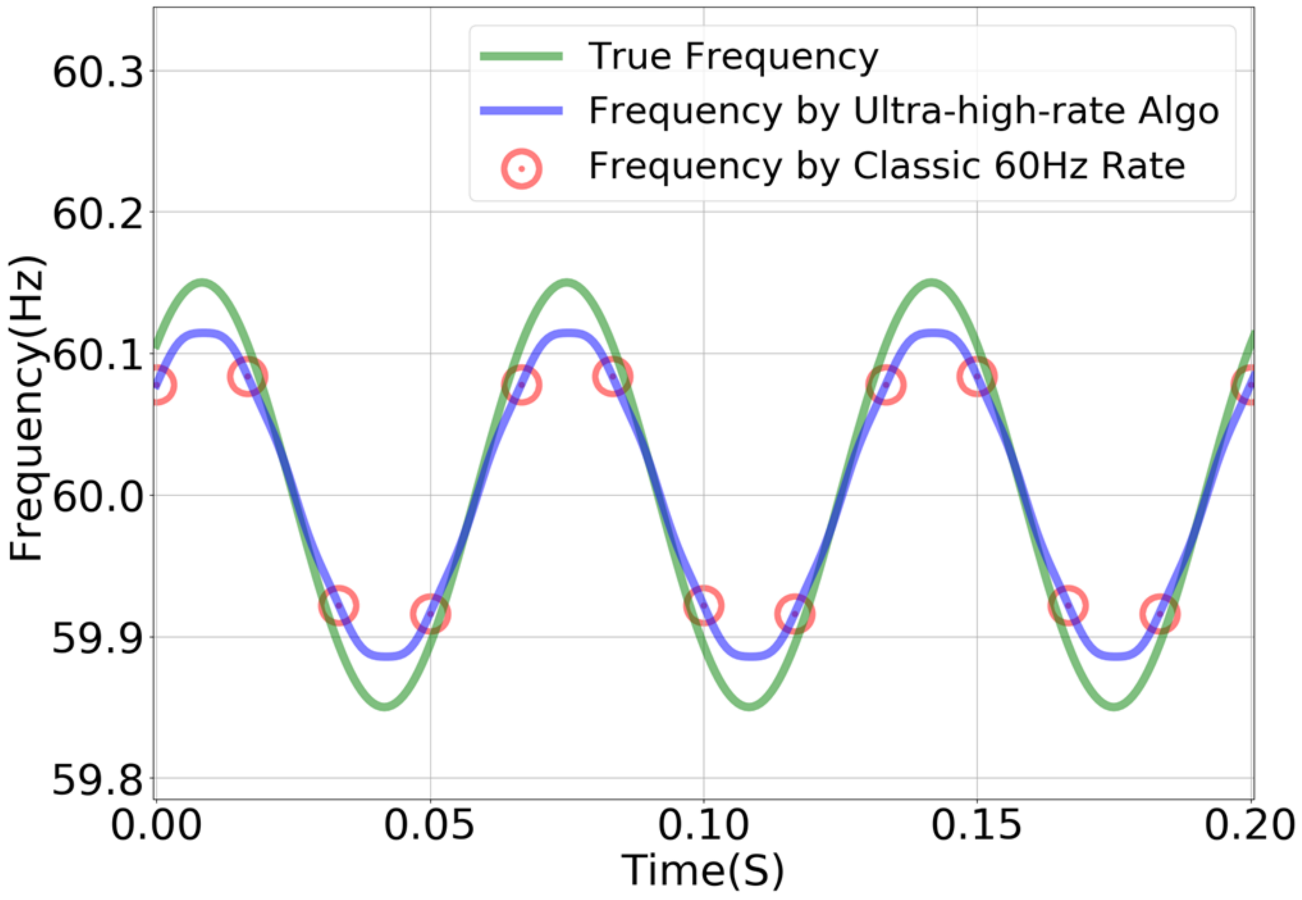


Application Example: **High-Frequency Event Detection**

× Traditional **state-of-the-art** 60 measurements per second failed to capture the high-frequency oscillation due to low measurement rate.

✓ Ultra-high-rate frequency measurement algo successfully captured the high-frequency oscillation.

15 Hz high-frequency oscillation



Window size: 1.5 cycles

High-speed Grid Phase Angle Measurements

Recursive computation also makes high-speed phase angle measurements possible.

Sampling Rate	Window Size (cycle)	Computation Time (second)		Faster
		classical	new	
1500 Hz	1	7.23	0.59	**12x**
	3	18.4	0.57	**32x**
	6	35.6	0.58	**61x**

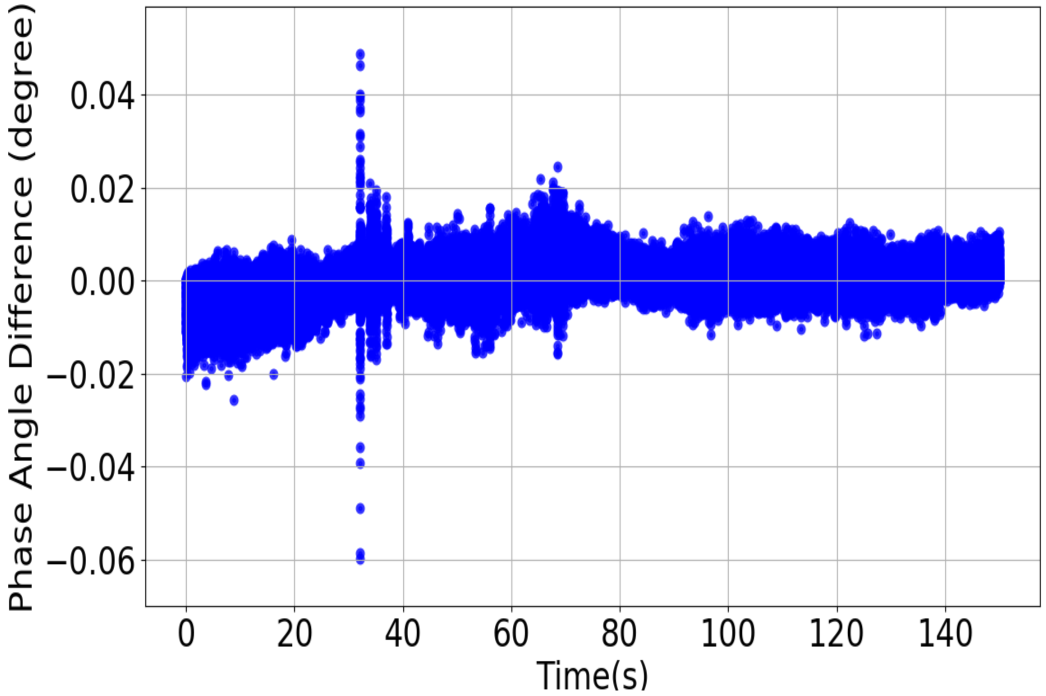
How much faster in general?

Answer: 8 * N * fs

N: window size. fs: sampling rate in kHz

240x faster @6 cycles, 5 kHz.

800x faster @10 cycles, 10 kHz.



Ignorable measurements differences between new method and classical method using real grid data

Thank You

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