OAK RIDGE National Laboratory

Fault-tolerant Grid Measurements During System Transients

Award #: DE-EE00034232

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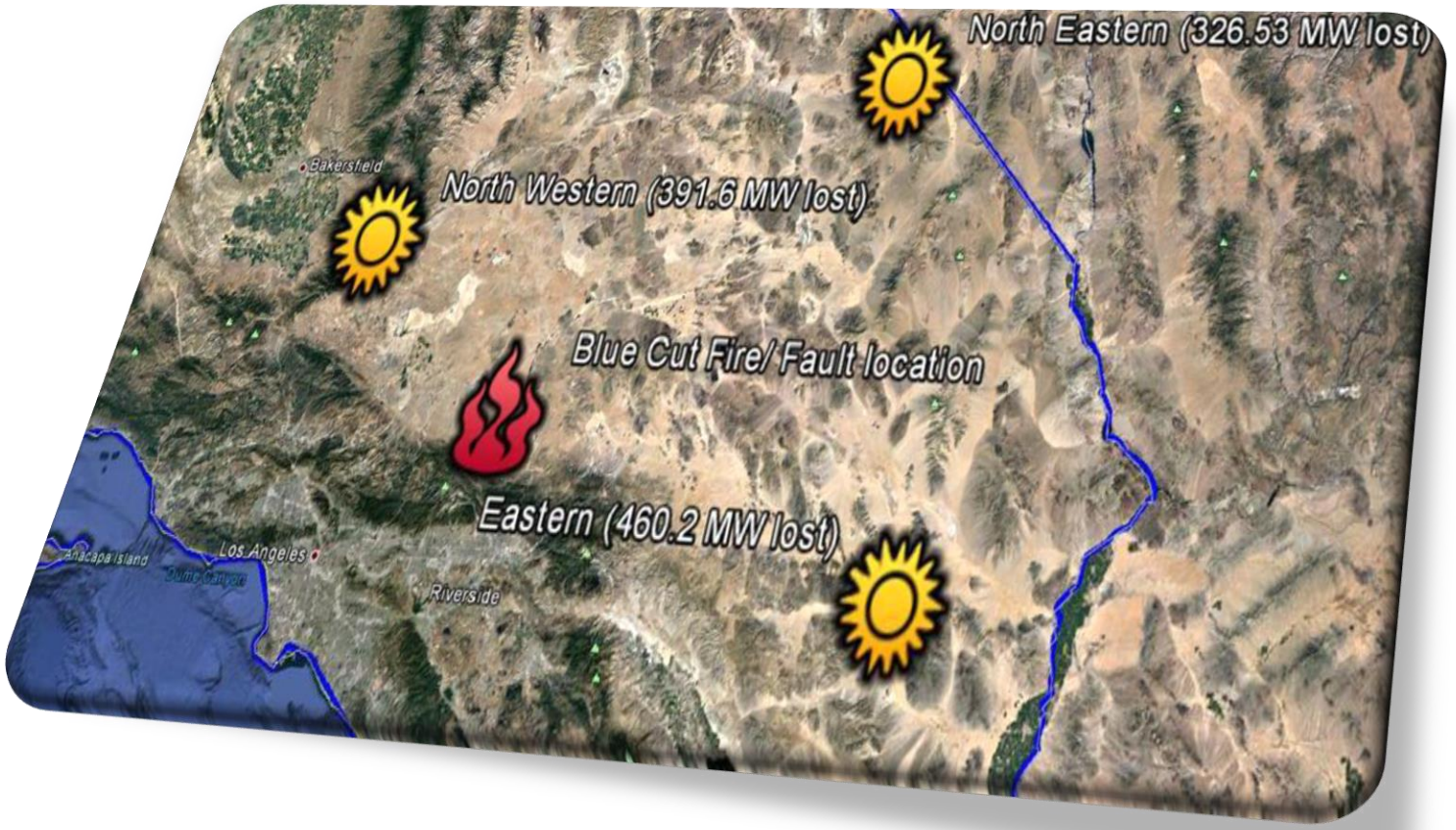
Project Motivations

- 1,200 MW solar inverters tripped. 700 MW directly caused by incorrect frequency measurement from solar inverters. (**Measured: < 57 Hz. Actual: 59.87 Hz**.)
- Many such events at lower voltage levels happened based on records from NERC.



Blue Cut Fire, Aug. 16, 2016*

* Picture retrieved from "1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report", NERC, June, 2017.

State-of-the-Art

Temporary correction and drawbacks

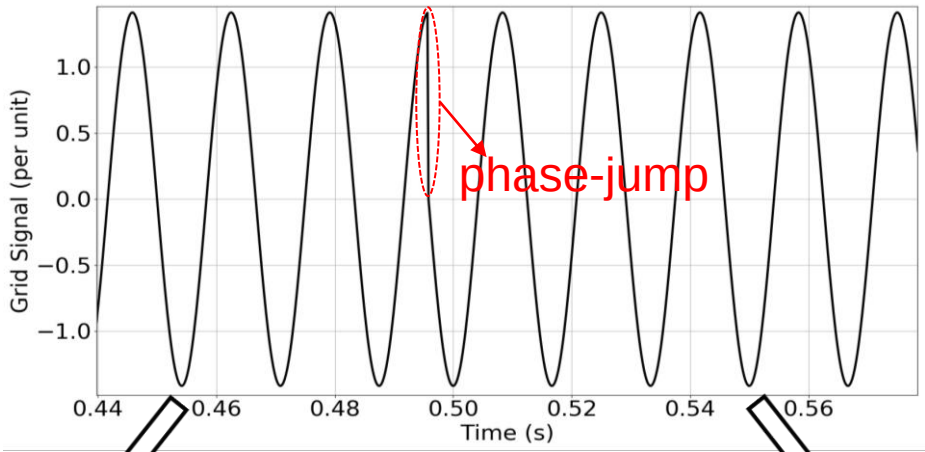
- ***Temporary correction recommended by NERC***: Add a five (two) - second time delay for low (high) frequency tripping protection.
- ***Drawbacks:***
  - × Unable to take protective action in time.
  - × Not essentially solve the frequency measurement problem.

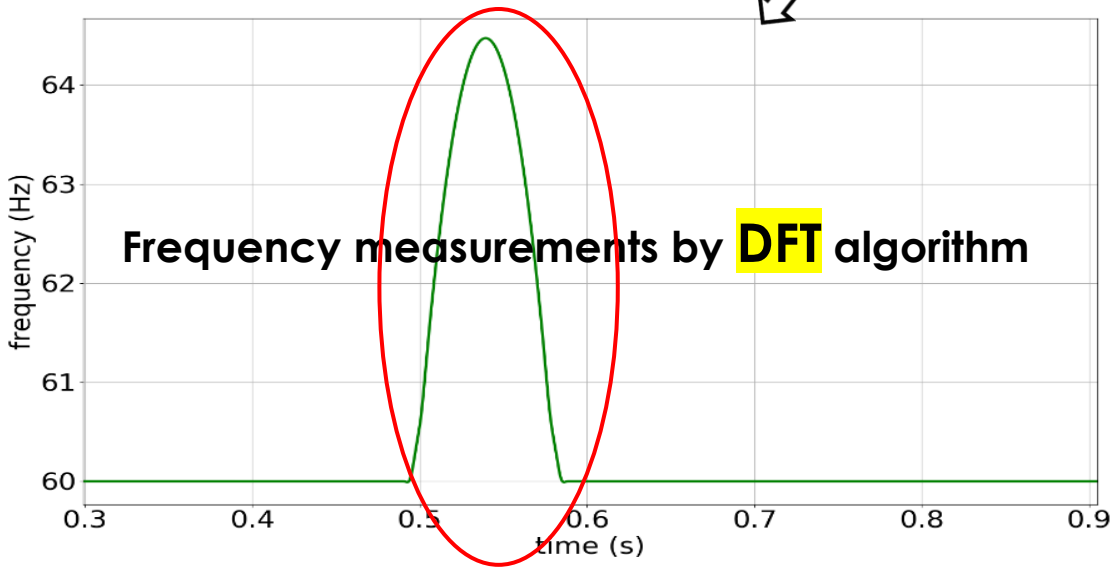
Existing algorithms

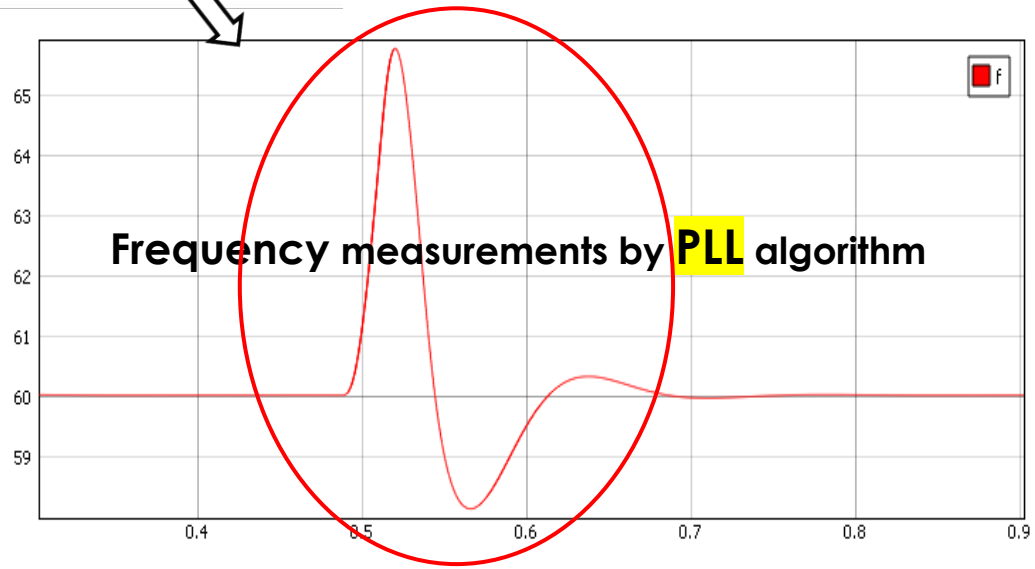
- × Assume grid signals are steady and continuous. (Aug. 16, 2016 event: signals have discontinuities due to "phase-jump".)
- × Uncertain measurement behavior under system transient faults due to the unpredictability and complexity of transient fault signals.

Existing Algorithms

Grid signal with phase angle step change







large measurement errors at the presence of phase angle jump/signal discontinuity.

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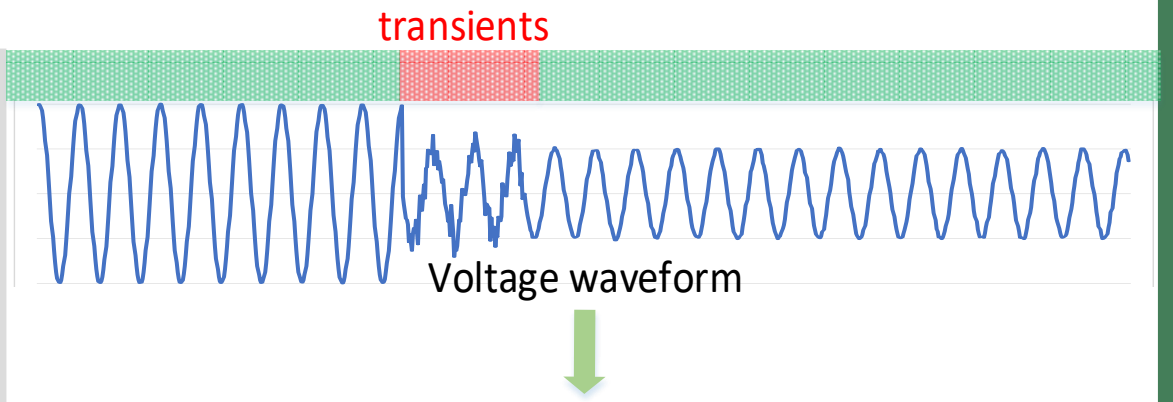
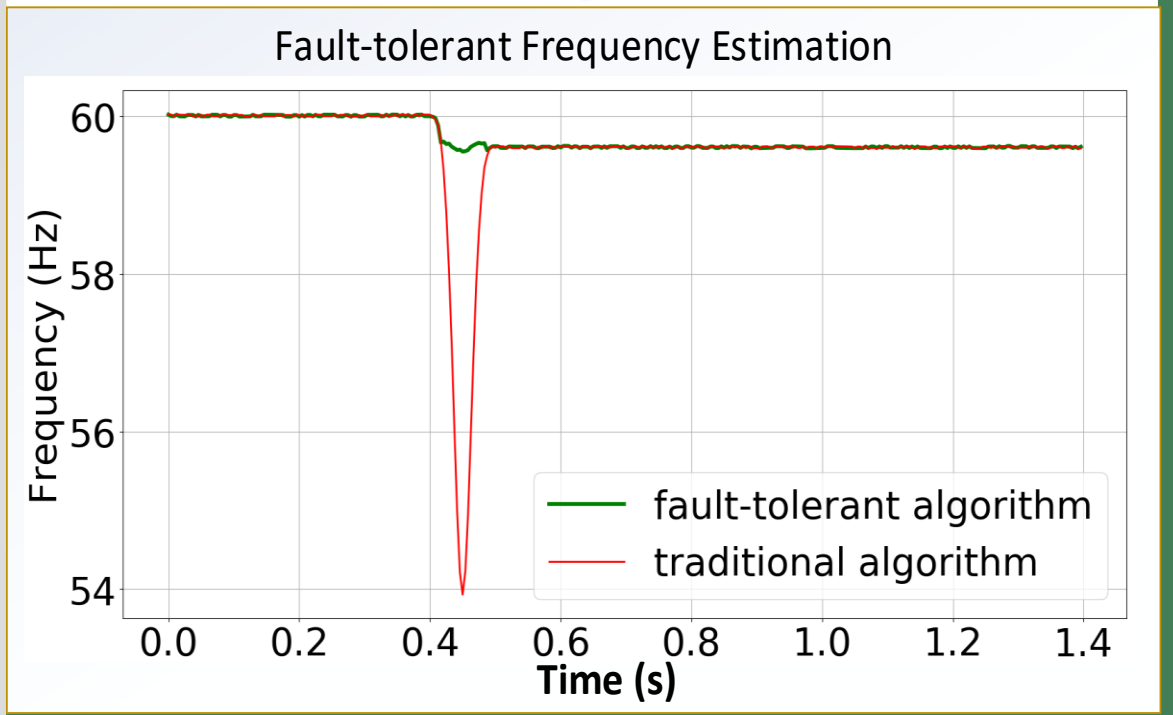
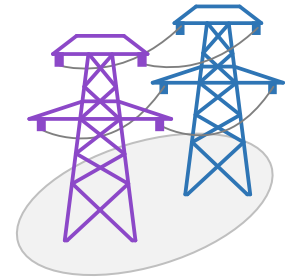
Project Objective

- ***Objective***: provide a fundamental solution to grid measurements challenges by developing fault-tolerant frequency measurement technologies.
- ***Key features***:
  - ✓ Fundamental solution
  - ✓ Fault-tolerant
  - ✓ High accuracy
  - ✓ Low computational complexity

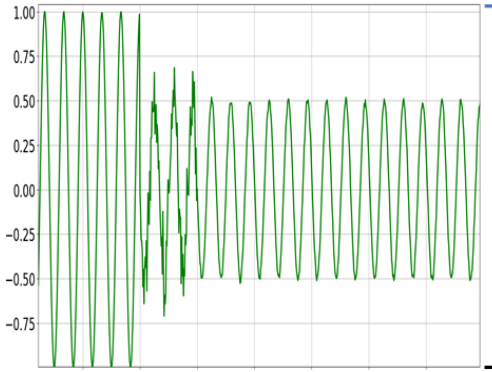


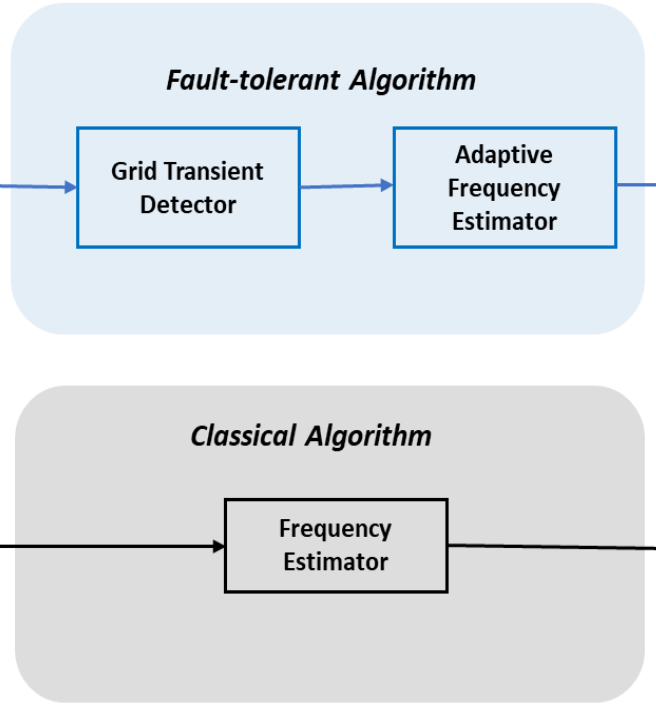


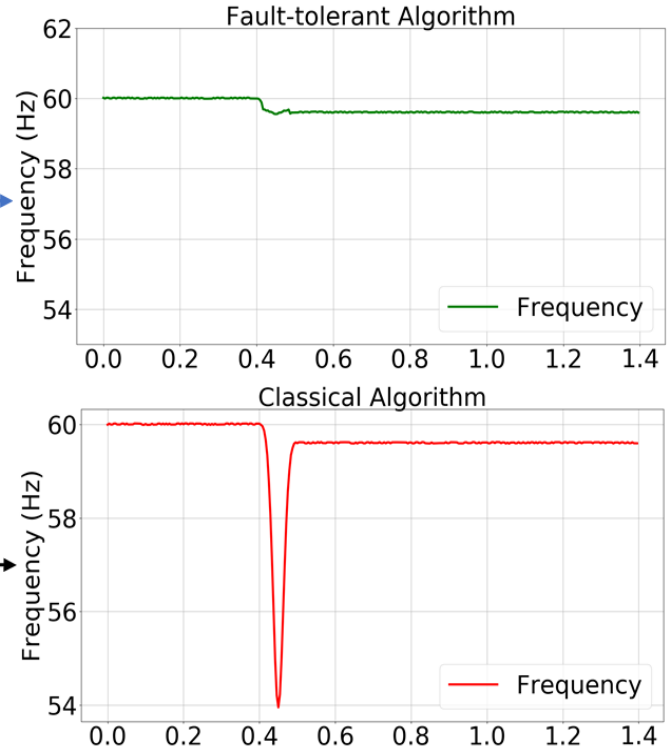
Technical Approach



Power grid





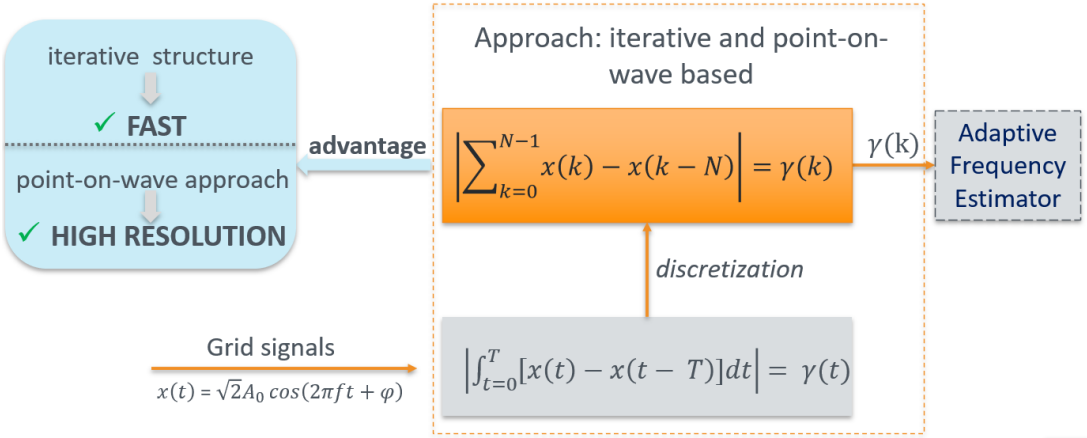


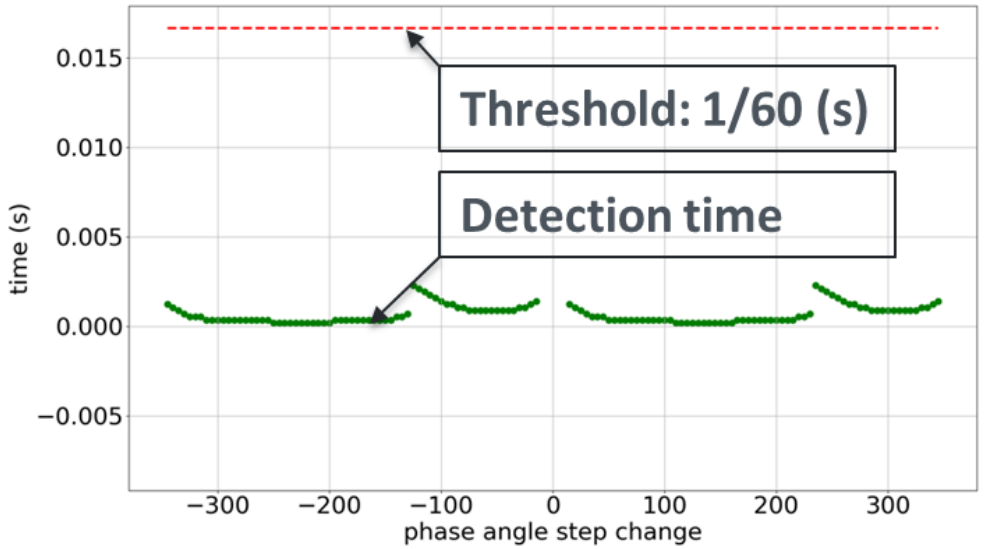
Two-stage and Adaptive Fault-tolerant Algorithm

- point-on-wave grid transient detector: detects grid transients in real-time.
- adaptive frequency estimator: measures grid frequency adaptively according to the detection of grid transients.

Transient detector

- Principle: monitor the periodicity of waveforms, and alarm when periodicity does not exist.
- Advantage:
  - ✓ Iterative structure --> fast
  - ✓ Use Point-on-wave waveforms --> high resolution
- Performed different types of tests: noise, harmonics, phase angle step change.
  - ✓ Detector immune to noise, and harmonics
  - ✓ Detector sensitive to step change events

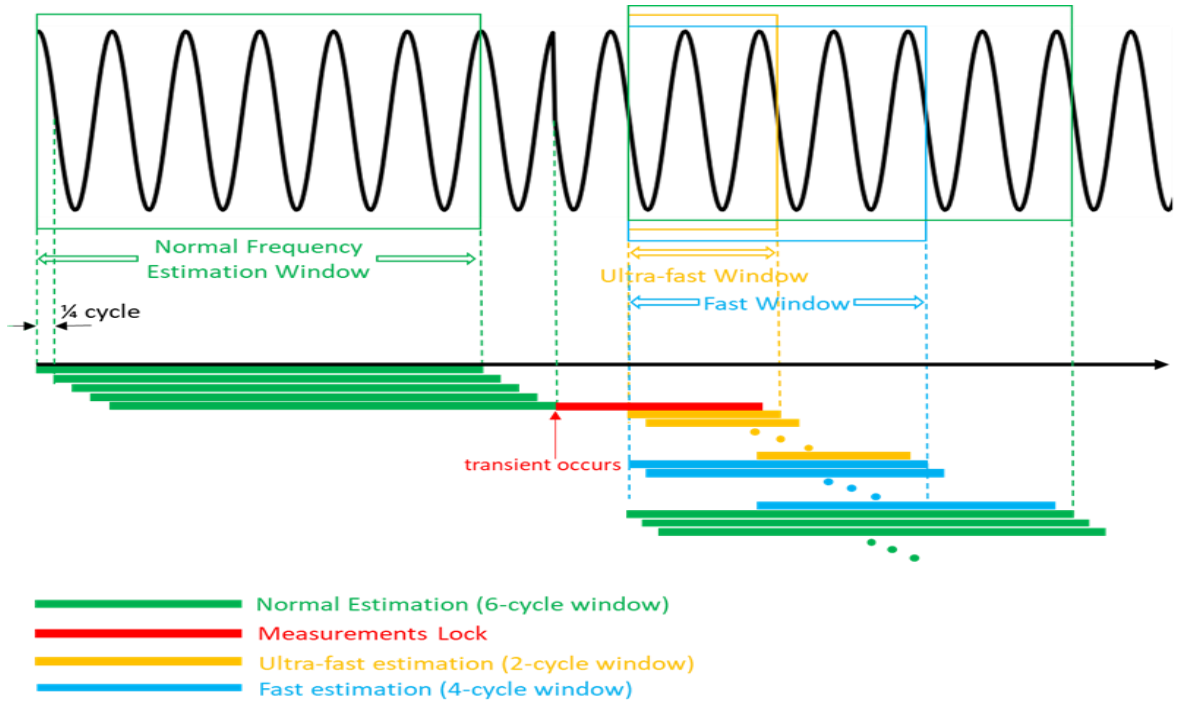


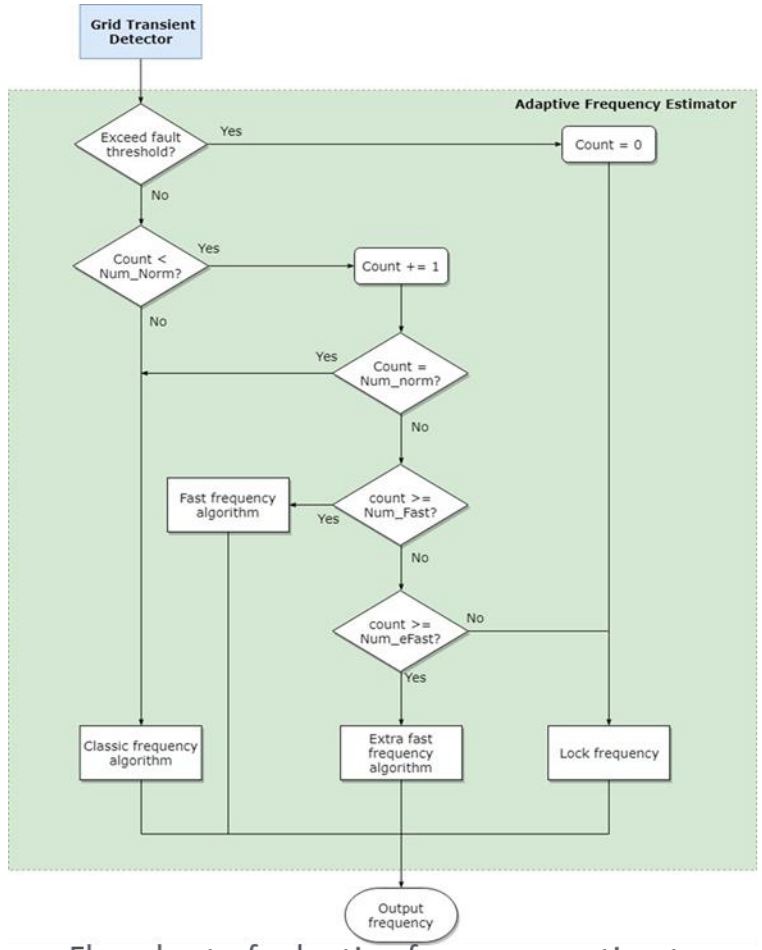


Detection time at different step change levels

Adaptive Frequency Estimator

- ✓ Make estimation whenever possible (adaptive window to balance between response time and accuracy)
- ✓ Lock measurements when accurate estimation is impossible (i.e., system transients)





Flowchart of adaptive frequency estimator

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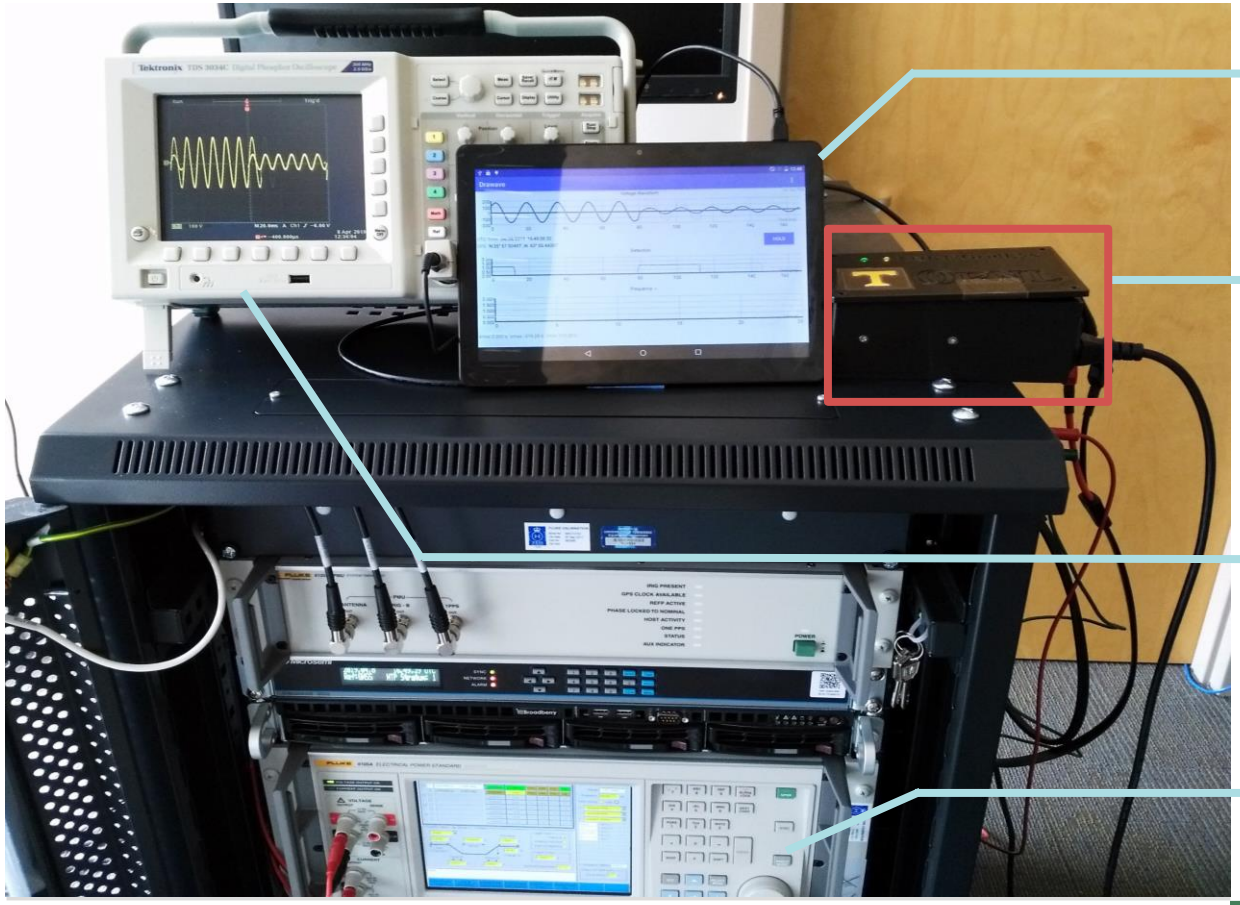
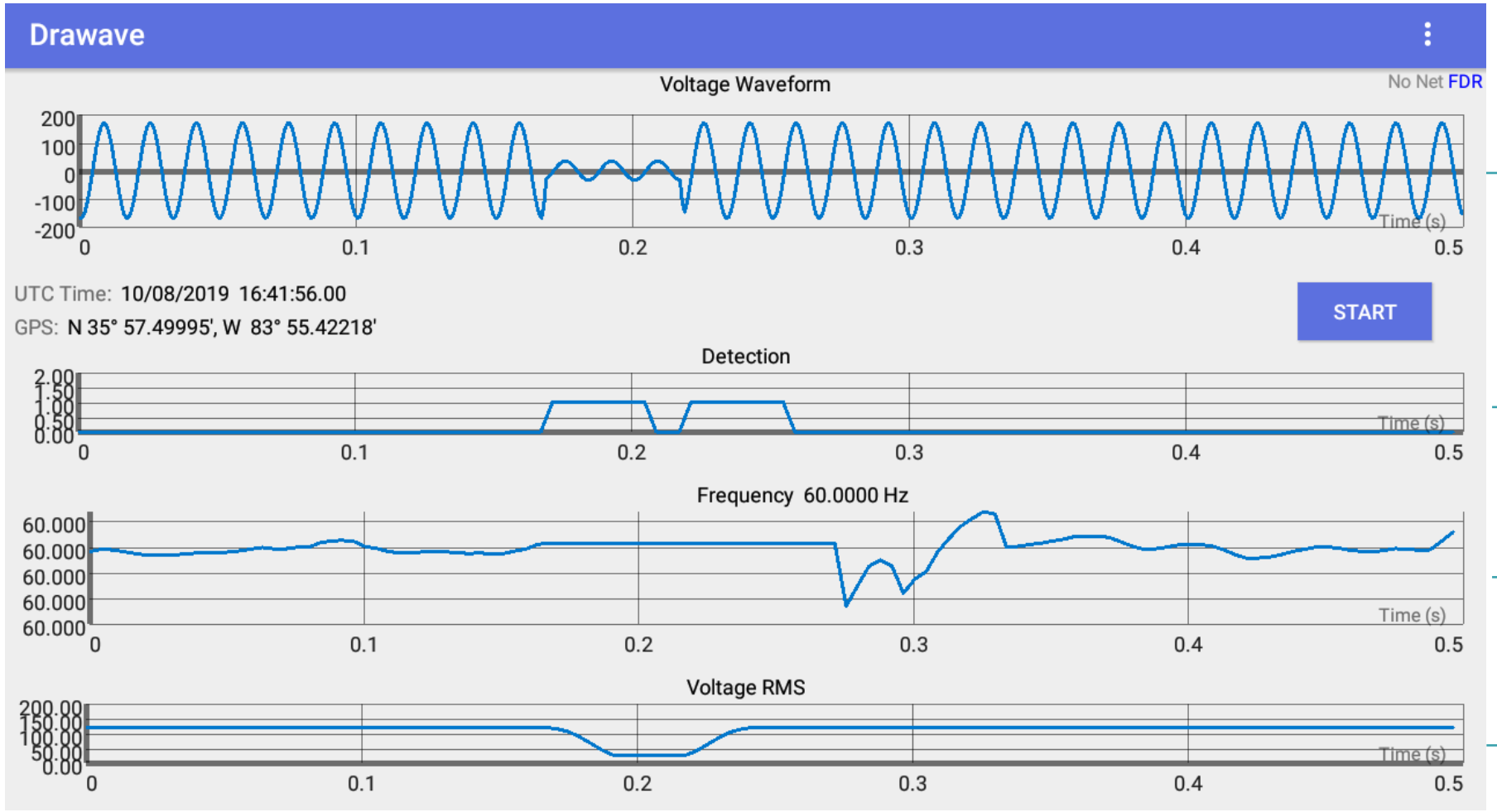
Fault-tolerant Grid Monitor



- Tablet displaying waveforms and fault detection results
- **Fault-tolerant Grid Monitor**
- Oscilloscope displaying raw POW directly from calibration system
- Fluke 6135A/PMUCAL PMU Calibration System

Experiment setup

Hardware test - Transient Event



→ Grid Voltage

→ **Transient detected**

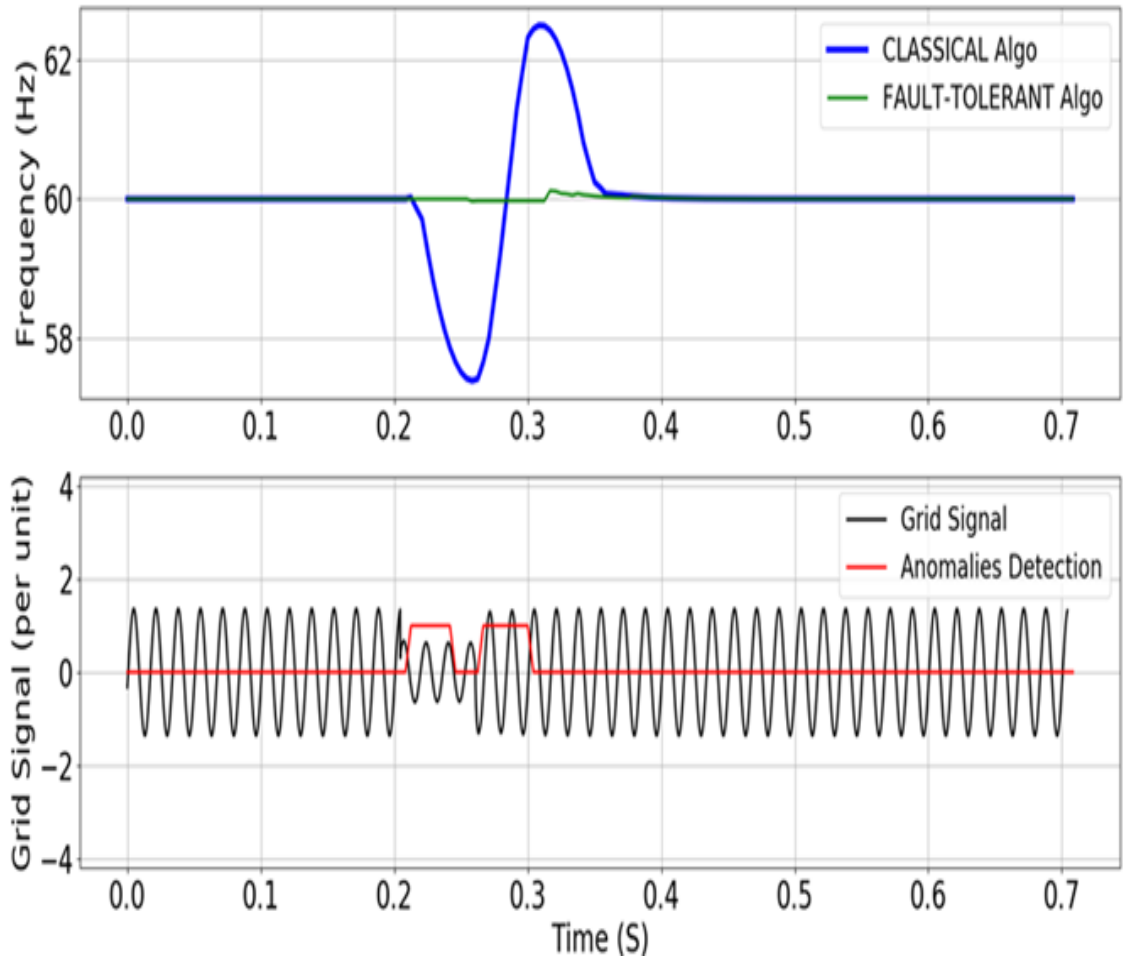
→ Frequency estimation

→ Voltage RMS

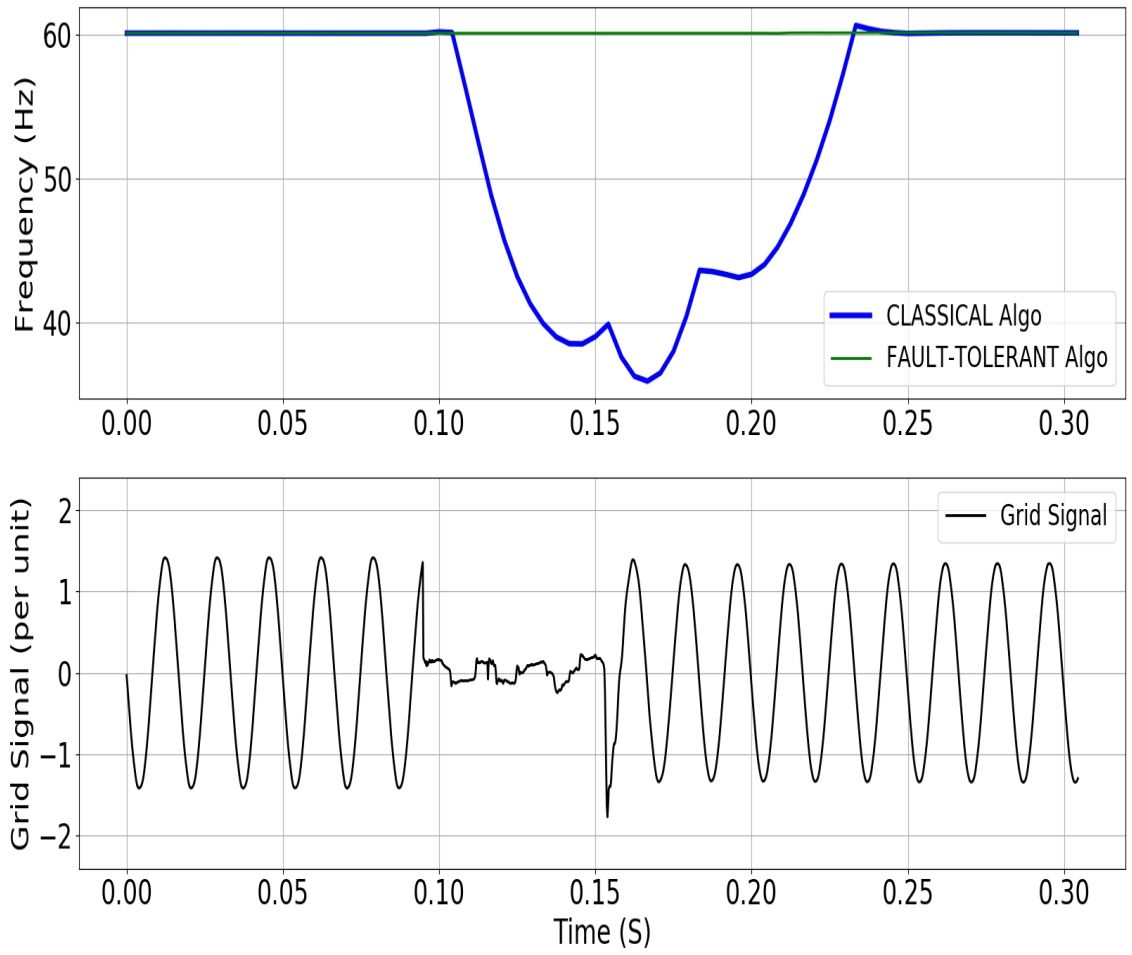
Test Signal: 80% magnitude step change.
Transient was detected and frequency was locked right away.
The slight frequency variation after transient was due to gradual window increase.

Fault-tolerant measurements – simulation & field data

System transient fault – simulation (PSCAD)



System transient fault – field data (DFR)



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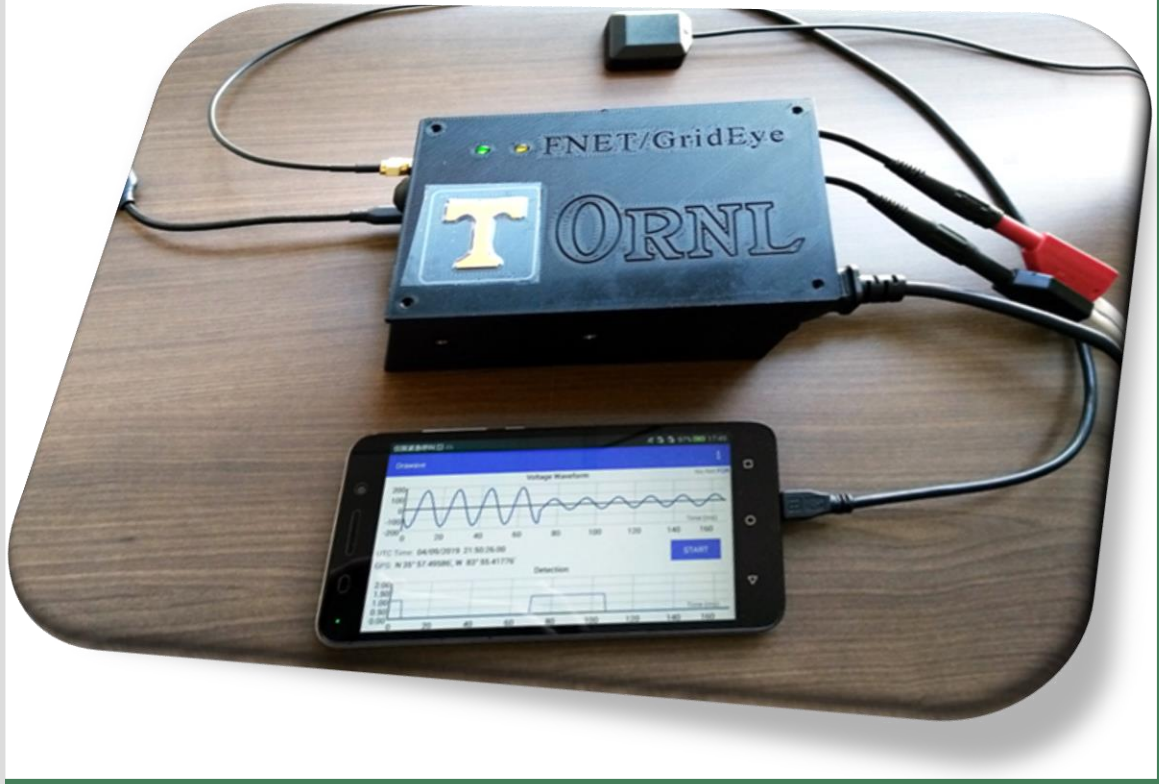
Summary

- Developed a fault-tolerant frequency estimation algorithm to mitigate measurement errors under transient faults while maintaining high accuracy.
- Verified performance under different tests and data source.
- ✓ ***Provide a fundamental solution to the grid protection and controls that rely on grid frequency.***



Thank You

Question?