Advanced Measurements for Resilient Integration of Inverter-Based Resources

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IBRs are vital to the nation’s clean energy goals
Risk of negative impacts to the bulk power system must be mitigated
Measurements can help mitigate risks
Initiated in April 2022
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Joint effort between PNNL, LBNL, ORNL, and NREL with cost share from McEachern Laboratories

Objectives:
- Develop advanced measurement capabilities and analytics
- Accelerate adoption of IBRs
- Improve the reliability and resilience of the BPS
Project Structure

Gap Analysis (PNNL, ORNL, NREL)
- Survey of utility partners’ measurement capabilities: BPA, WAPA, KIUC (Kaua‘i, Hawaii)
- Review of measurement-based IBR application requirements

GridSweep Instrument (LBNL)
- System probing and waveform measurement with unprecedented precision
- Data collection and processing from two sites

Application Development and Demonstration
- Develop nine measurement-based applications to support integration of IBRs
  - Field demonstration of a synchrophasor-based application
  - Testbed demonstrations of two waveform-based applications
- Release software tools for GridSweep analysis

Year 1

Year 2
Gap Analysis
Synchrophasors
- Systems are mature and readily accessible
- Information about system limitations is scarce, or at least not readily available to the measurement users

Waveforms
- Accessibility varies widely among Transmission System Operators (TSOs)
- Conventional use will continue to dominate (trigger-based recording)
- Value proposition for highly accessible (e.g., streaming) waveform measurements is not strong enough yet to justify expenses: bandwidth, network management, security, storage
- Labeled event data to support AI/ML is lacking (for now)

Plant owners are hesitant to share measurements
- Concerns similar to those surrounding models: IP, liability
- No requirements to justify expense

Source: NERC
## Review of IBR Application Requirements

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<tr>
<th>Application Family</th>
<th>Applications</th>
<th>IEEE Std 2009 Compliance</th>
<th>Measurement Type</th>
<th>Measurement Location or RPA</th>
<th>Meas. RR</th>
<th>TRL</th>
<th>References</th>
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<td>Monitoring</td>
<td>SSO Monitoring</td>
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<td>POW</td>
<td>GridMatrix</td>
<td>Multiple locations in TS</td>
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<td>Inertia Estimation (Transient)</td>
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<td>Inertia Estimation (Ambient)</td>
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<td>Impedance-based Stability Analysis</td>
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<td>Harmonic Stability Analysis</td>
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<td>Electronic Magnetic Stability Analysis</td>
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<td>Inverter Synchronization Stability Analysis</td>
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<td>Disturbance Monitoring</td>
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<td>Many kHz</td>
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<td>Power Quality Monitoring</td>
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<td>Modeling</td>
<td>Discrete-Time Modeling – Reduced Order Model</td>
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<td>Discrete-Time Modeling – Impedance Spectrum Model</td>
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<td>EM Model Calibration and Validation</td>
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<td>Fall of Primary Frequency Response</td>
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<td>Reactive Power Control</td>
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<td>Automatic Voltage Regulation</td>
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<td>Planning</td>
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**References:**
- [Baker et al., 2021]
- [NERC, 2017]
- [Energy, 2012]
- [Kropek, 2014]
Develop a stronger value proposition for expanding the use of waveform measurements

- Identify cost effective approaches for improving accessibility
  - Synchrophasor-first architectures
  - Automated polling from local storage
  - Distributed solutions

- As barriers to model sharing are addressed, consider plant-level measurements as well

Clearly identify the user for proposed applications

- Who does the value proposition apply to?
- Do they have access to the necessary measurements?
Recommendations

- Address the need for event records with high-quality labels
  - Show the value of existing signature libraries by using them in your research
    - https://pqmon.epri.com/
    - https://gsl.ornl.gov/
  - If your organization sees potential in AI/ML applications, be strategic in how you store and label event data
    - Develop tools to make labeling and organization easier for these utilities
    - Contribute events to existing libraries

Grid Signature Library (GSL) label:
“While attempting to close back in transmission line a fault occurred tripping the breaker at substation.”
Be aware of the measurement system’s limitations
- Environmental conditions
- Frequency response
- Calibration
- Accuracy class

PNNL report with limitation checklist coming April 2023
GridSweep
Individual inverters are stable when connected to a strong grid. But what happens with [a] an interconnected population of inverters that [b] have diverse PID weights and diverse control loop speeds and are [c] weakly connected to each other?

- Resonance, Damping, and Inertia
  - IBR’s are generally worse than rotating generators.
- How much energy required to initiate oscillation?
  - Much less for IBR’s than rotating generators…
- Accidental vs Intentional (hostile act) oscillations
  - Intentional requires knowledge of
    - Subsynchronous resonant frequency
    - Subsynchronous phase angle
    - Bulk grid parameters may be covertly visible from outlets.
Research instrument for **subsynchronous resonance risk** on grids.

- Probes grid with current: 0.1Hz – 40.0 Hz amplitude-modulated 60 Hz.
- Measures voltage response at a different location on the grid.
- Parts-per-billion voltage resolution (100,000 times more precise than the very best meters)

New DOE GridSweep® Instrument

Early stage deployments at Hawaiian Electric, Idaho Power, Dominion Energy, etc.
GridSweep probing signal
Broad spectrum AM noise columns: probably voltage steps?

Background silence?

Workday signals?
Research in progress now.

IBR population oscillation risks need to be understood.

Risk of sub-60-Hz oscillation can be measured via frequency source impedance.

Distribution grid characteristics can be measured from 120V outlets.
- Real-time Bulk grid parameters may be measurable from 120V outlets...

Consider this population stability risk in IBR standards?

Awareness of risk: intentionally-provoked oscillations
- Population-of-loads vector?
- Phase related defenses
Questions?