Comparison of Synchro-Waveform Application Requirements with Utility Capabilities

Jim Follum, PNNL

Synchro-Waveforms: Principles, Data-Analytics, and Applications

PNNL-SA-185868

DOE's Objective

Use advanced measurements to mitigate risks of rapid IBR deployments

NERC
1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California 8/16/2016 Event
June 2017

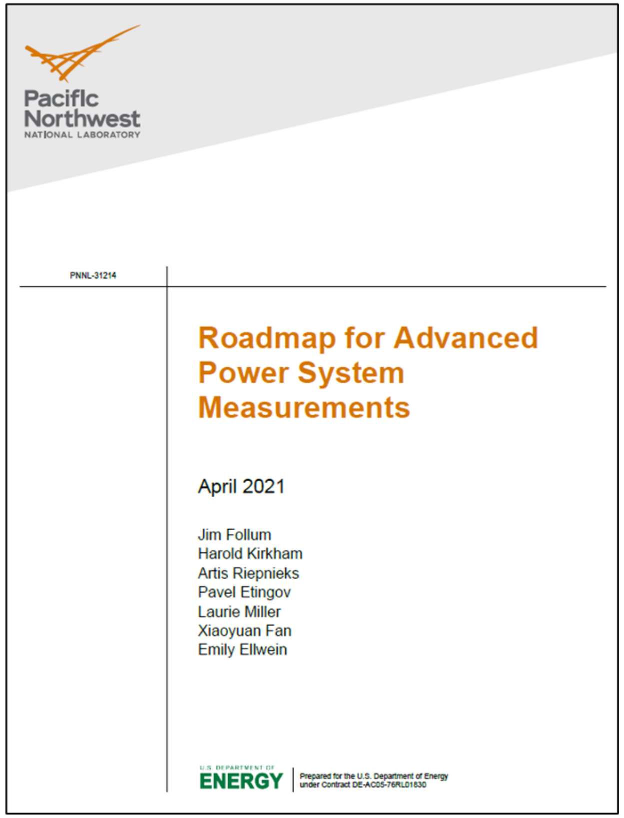
NERC
San Fernando Disturbance
Southern California Event: July 7, 2020
Joint NERC and WECC Staff Report
November 2020

NERC
900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report
February 2018

NERC
Odessa Disturbance
Texas Events: May 9, 2021 and June 26, 2021
Joint NERC and Texas RE Staff Report
September 2021

NERC
April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report
Southern California Events: April 20, 2018 and May 11, 2018
Joint NERC and WECC Staff Report
January 2019
RELIABILITY | ACCOUNTABILITY

NERC
Panhandle Wind Disturbance
Texas Event: March 22, 2022
Joint NERC and Texas RE Staff Report
August 2022
RELIABILITY | RESILIENCE | SECURITY



Pacific Northwest National Laboratory
PNNL-31214
Roadmap for Advanced Power System Measurements
April 2021
Jim Follum
Harold Kirkham
Artis Riepnieks
Pavel Etingov
Laurie Miller
Xiaoyuan Fan
Emily Ellwein
U.S. Department of Energy
Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

https://doi.org/10.2172/1871292

PROGRESS MATRIX

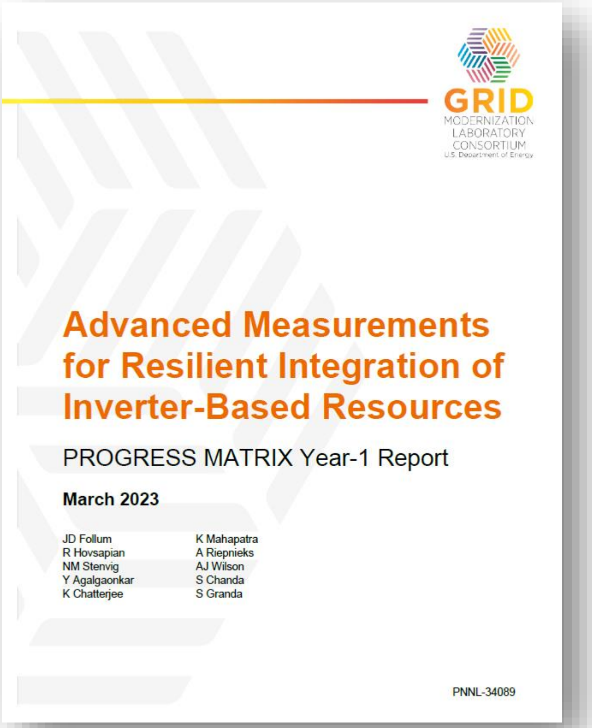
Overview

- Jointly funded by DOE’s Office of Electricity (OE) and Solar Energy Technologies Office (SETO)
- Objectives:
  - Develop advanced measurement capabilities and analytics
  - Accelerate adoption of IBRs
  - Improve the reliability and resilience of the bulk power system

PROGRESS MATRIX

Gap Analysis

- Survey of utility partners' measurement capabilities
  - Bonneville Power Administration (BPA) – PNNL
  - Western Area Power Administration (WAPA) – NREL
  - Kaua'i Island Utility Cooperative – ORNL
- Literature review of measurement-based IBR application requirements
- Identify barriers preventing utilities from using advanced measurements (PMU and POW) to integrate IBRs


GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Advanced Measurements for Resilient Integration of Inverter-Based Resources

PROGRESS MATRIX Year-1 Report

March 2023

JD Follum
R Hovsapian
NM Stenvig
Y Agalgaonkar
K Chatterjee
K Mahapatra
A Riepnieks
AJ Wilson
S Chanda
S Granda

PNNL-34089

Literature Review

Evaluated 26 proposed applications

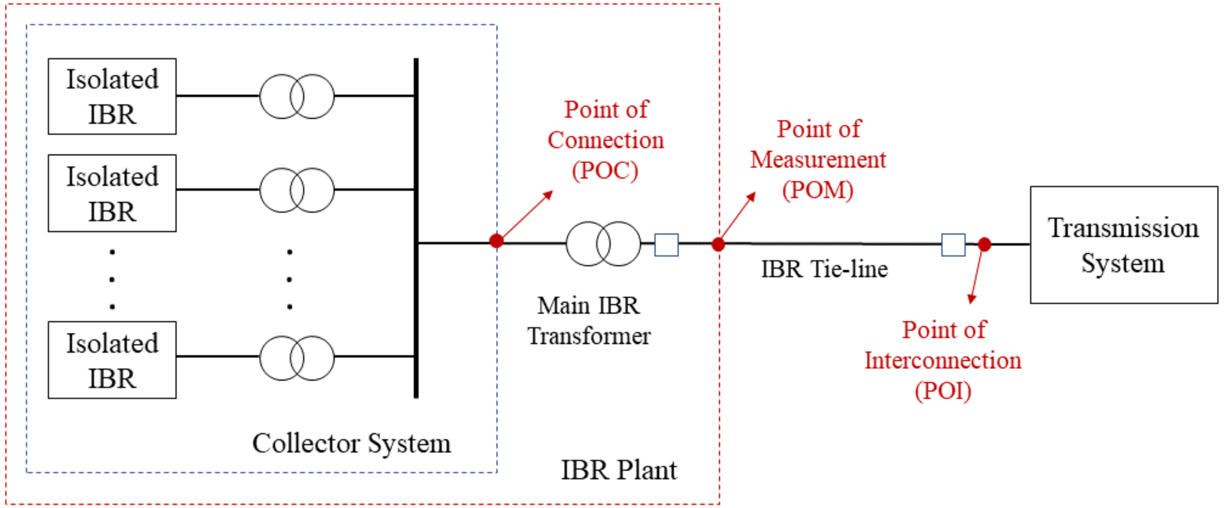
Application Family	Applications	IEEE Std 2800 Compliance	Measurement Type	Measurement Location or RPA	Meas. RR[a]	TRL	References
Monitoring	Inertia Estimation (Transient)	NR[b]	Synchrophasors	Multiple locations in TS	30Hz	8	[Ashton et al., 2015] [Digital, 2022]
	Inertia Estimation (Ambient)	NR	POW GridMetrix Meas.	Multiple locations in TS	kHz (for GridMetrix)	9	[Kimme
			Synchrophasors	Tie lines, SGs, and IBRs	30 Hz	2	[Tu
	SSO Metering	NR	POW	POI	120 Hz	9	[Cheng et
	SSO Source Localization	NR	POW	POI	120 Hz	2	
	Impedance-based Stability Analysis	NR	POW	POI	20kHz	7	[Shah et al.
	Harmonic Stability Analysis	R	POW	POM, POI	2.75kHz	5	[Mate [Wan
	Electromagnetic Stability Analysis	R	POW	POI	1Hz-10kHz	5	[ESIG, 2 [NERC,
	Inverter Synchronization Stability Analysis	R	Synchrophasors POW	POM, POC	60Hz, 10kHz	3	[Global
	Disturbance Monitoring	NR	Synchrophasors, POW, Oscillography	POM,POI,POC	Many kHz	2-9	[NERC
	Power Quality Monitoring	R	POW	POM, POI	8 kHz	7	[E [Ente
Modeling	Data-driven Modeling – Reduced Order Model	NR	Synchrophasors	POI, POM, POC	60 Hz	4	[
	Data-driven Modeling – Impedance Spectrum Model	NR	POW	POC	20kHz	2-9	[
	EMT Model Calibration and Validation	NR	POW	POC	20kHz	9	[AECOM, [DOE, 2012 [Badrza
	Admittance Model Identification for SSR Screening	NR	POW, Synchrophasors	POM	2kHz	1	[
	dq Admittance Model Identification	NR	POW	POM, POI	2kHz	3-4	[Fan and Miao, 2020]

Application Family	Applications	IEEE Std 2800 Compliance	Measurement Type	Measurement Location or RPA	Meas. RR	TRL	References
Control	Plant Level Control Design	R	POW, Synchrophasors	POI,POM	4 kHz	3-9	[Baker et al., 2021]
	Fast or Primary Frequency Response	R	POW, Synchrophasors	POM	20kHz	5	[NERC, 2020a]
	Virtual Inertia Based Control	NR	POW, Synchrophasors	POC	3-20kHz	2	[Yap et al., 2019]
	Reactive Power Control	R	POW, Synchrophasors	POI, POM	3-20kHz	3-4	[Entergy, 2022] [Brown, 2020] [WECC, 2020]
	Automatic Voltage Regulation	R	POW, Synchrophasors	POC and/ POM	3-20kHz	3-4	[Entergy, 2022, Guo et al., 2021]
	Ride-through Controls	R	POW, Synchrophasors	POI	3-20kHz	1-3	[Baker et al., 2021] [ESIG, 2020] [Hart et al., 2022]
Protection	Anti Islanding	R	Synchrophasors POW	POI, POM	3-20kHz	3-8	[Kroposki, 2016], [da Cunha Lima et al., 2021] [Solectria, 2016] [Nassif et al., 2022] [Haddadi et al., 2021], [Mills-Price et al., 2011]
	Line Current Differential Protection with IBRs	R	POW	POC, POI	1kHz	2	[Haddadi et al., 2021] [Chowdhury et al., 2022]
	Utility end distance Protection	R	POW	POC, POI	1MHz	2	[Paladhi and Pradhan, 2020] [Nagpal et al., 2020] [Bini, 2022]
	Sequence Current Limiting Protection	R	POW	POM, POI	3-20kHz	2	[Mahamedi et al., 2018]
Planning	Weak Grid Studies	R	POW, Synchrophasors	POM, POI	Many kHz	2	[Nordgård et al., 2011] [Muljadi, 2016]

Literature Review

Unwarranted assumptions about POW measurements

- Continuously streamed
- Available at inverter terminals or plant's Point of Connection (POC)
- Shared by plant owners
    - Hesitancy of plant owners to share detailed models is discussed often
    - This hesitancy extends to sharing POW measurements with transmission system operators
- Labeled to support AI/ML



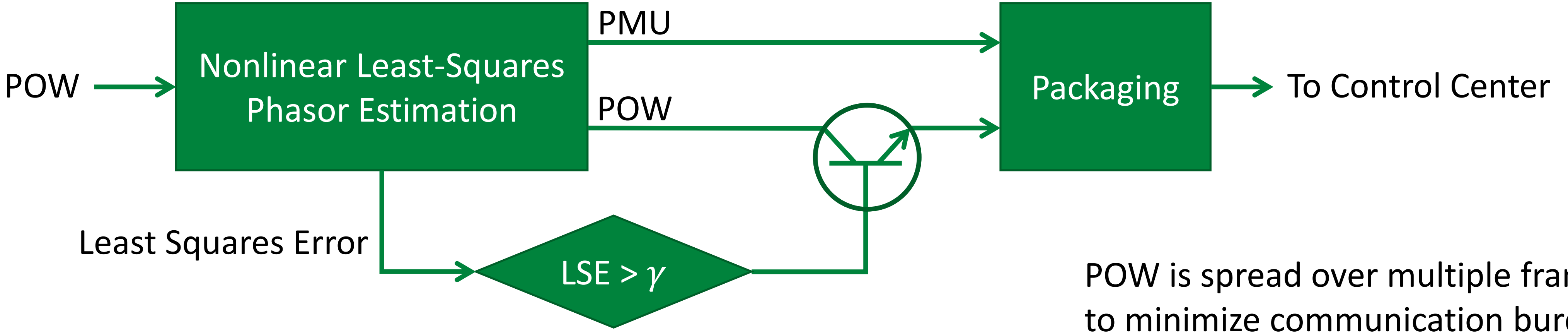
Review with BPA

Seeking an application for demonstration

- Six POW applications considered most viable for demonstration:
  - Subsynchronous Oscillation (SSO) Source Localization
  - Disturbance Monitoring
  - Data-Driven Modeling for Stability and Control
  - Monitoring Support for Ride-Through Control Capability
  - Anti-Islanding Protection
  - Weak Grid Planning
- Reasons none moved forward to field demonstration:
  - PMU-based alternatives much easier to implement, though less performant
  - POW streaming not feasible
  - No practical way to automate collection of snapshots

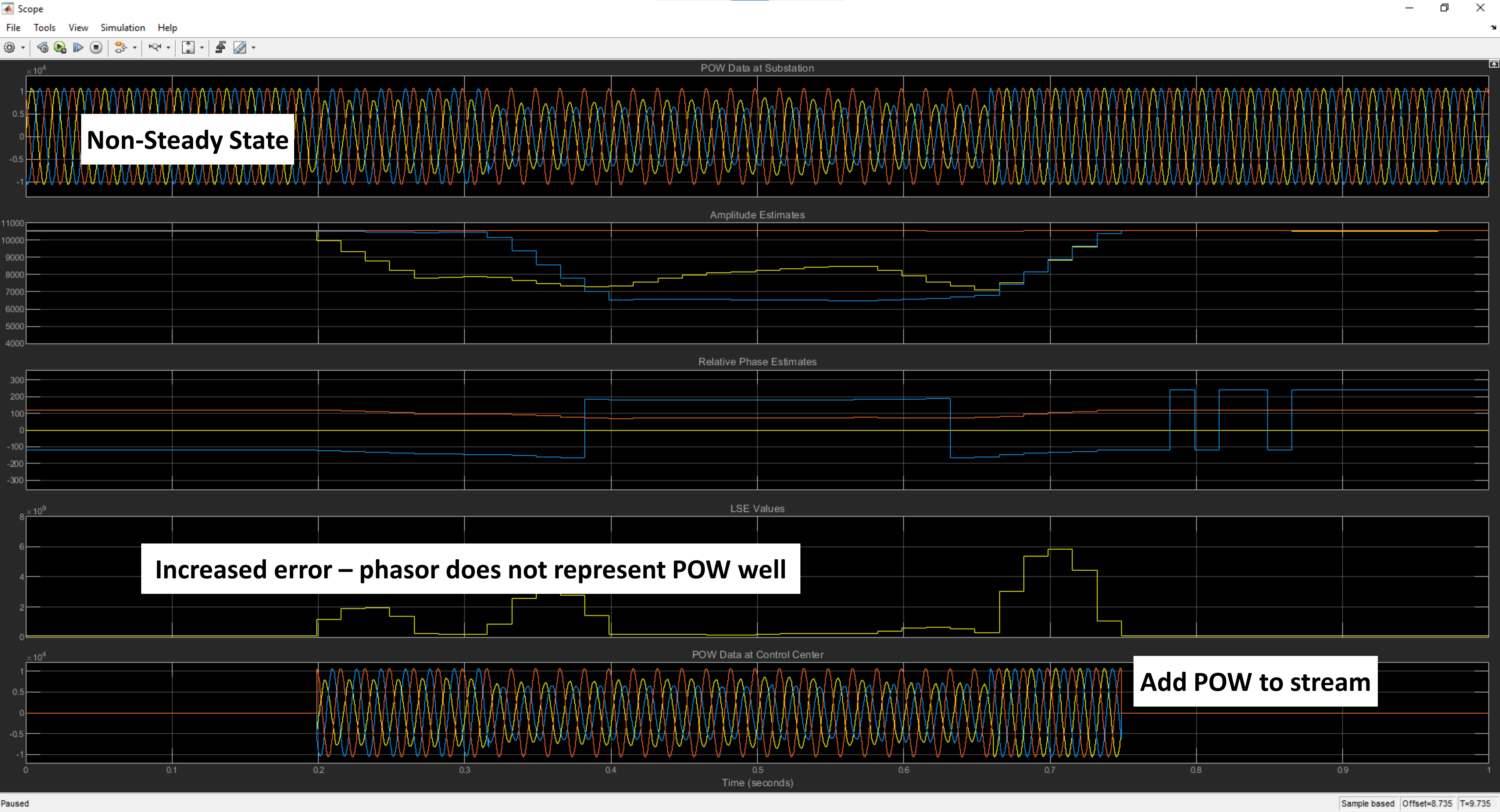
Laboratory Demonstration

Automated POW reporting



POW is spread over multiple frames to minimize communication burden

Scope
File
Tools
View
Simulation
Help
POW Data at Substation
×10^4
Steady State
Amplitude Estimates
Only report phasors
Relative Phase Estimates
LSE Values
×10^8
Low error – phasor represents POW well
POW Data at Control Center
×10^4
Time (seconds)
Ready
Sample based
Offset=9
T=10.000



Scope
File Tools View Simulation Help
POW Data at Substation
Non-Steady State
Amplitude Estimates
Relative Phase Estimates
LSE Values
Increased error – phasor does not represent POW well
POW Data at Control Center
Add POW to stream
Time (seconds)
Paused
Sample based
Offset=8.735
T=9.735

Summary

- Despite an identified need, few new POW applications have been deployed
- Value proposition for streaming POW is not strong enough to justify expenses: bandwidth, network management, security, storage
- Conventional use (trigger-based recording) will continue to dominate if streaming remains the focus
- Alternatives to streaming are needed
  - Automation to enable retrieval of gapless POW housed in substations
  - Synchrophasor-first architectures
  - Event capture with customizable triggering conditions
  - Distributed solutions