DOE/OE Transmission Reliability Program

Operationalizing Synchrophasors for Enhanced Electric Grid Reliability and Asset Utilization

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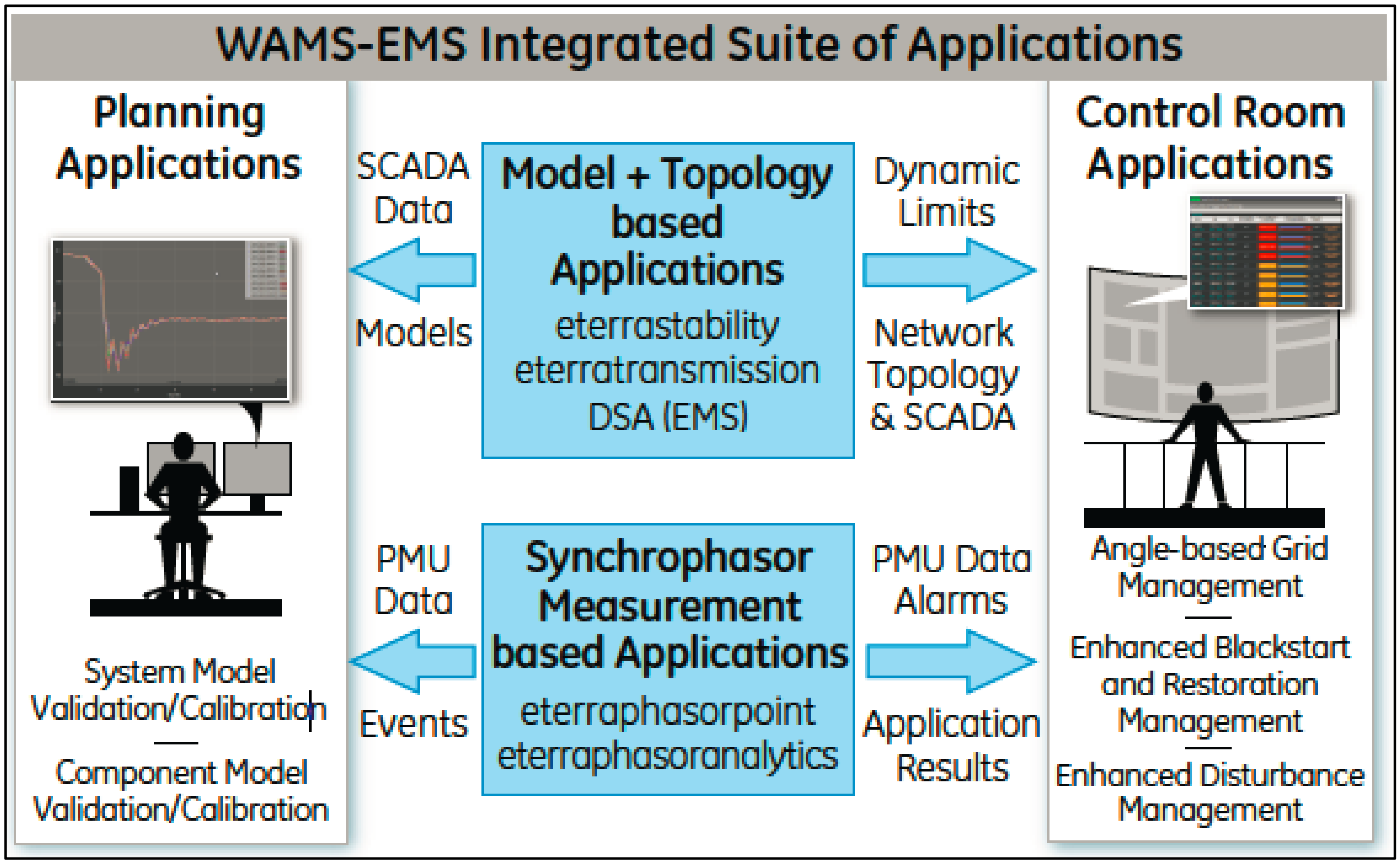
Overall Project Objectives

- Develop and demonstrate multiple ***production-grade*** synchrophasor applications to enhance system planning and operations
- Designed to enhance grid reliability and asset utilization through utilization of existing WAMS infrastructure along with EMS network applications available at control rooms
- Project includes field demonstrations at multiple utility locations

GE Global Research
GE Grid Software Solutions
GE Energy Consulting
Powertech
The Power of Trust. The Future of Energy.
MISO Midcontinent ISO
ISO new england
Peak Reliability
Pacific Gas & Electric

Project Overview



Project Overview

- Develop and demonstrate three Synchrophasor Applications:
    1. Model Validation/Calibration tool for improving models to meet emerging NERC requirements
    2. Angle-based grid management (AGM) tool for improved transmission asset utilization in voltage stability limited systems
    3. Operator guidance tool for enhanced blackstart/restoration and disturbance management
- Two phases: Phase I – R&D, Phase II – Factory Acceptance Testing and Field Demonstration
- Project duration: March, 2017 – March, 2019

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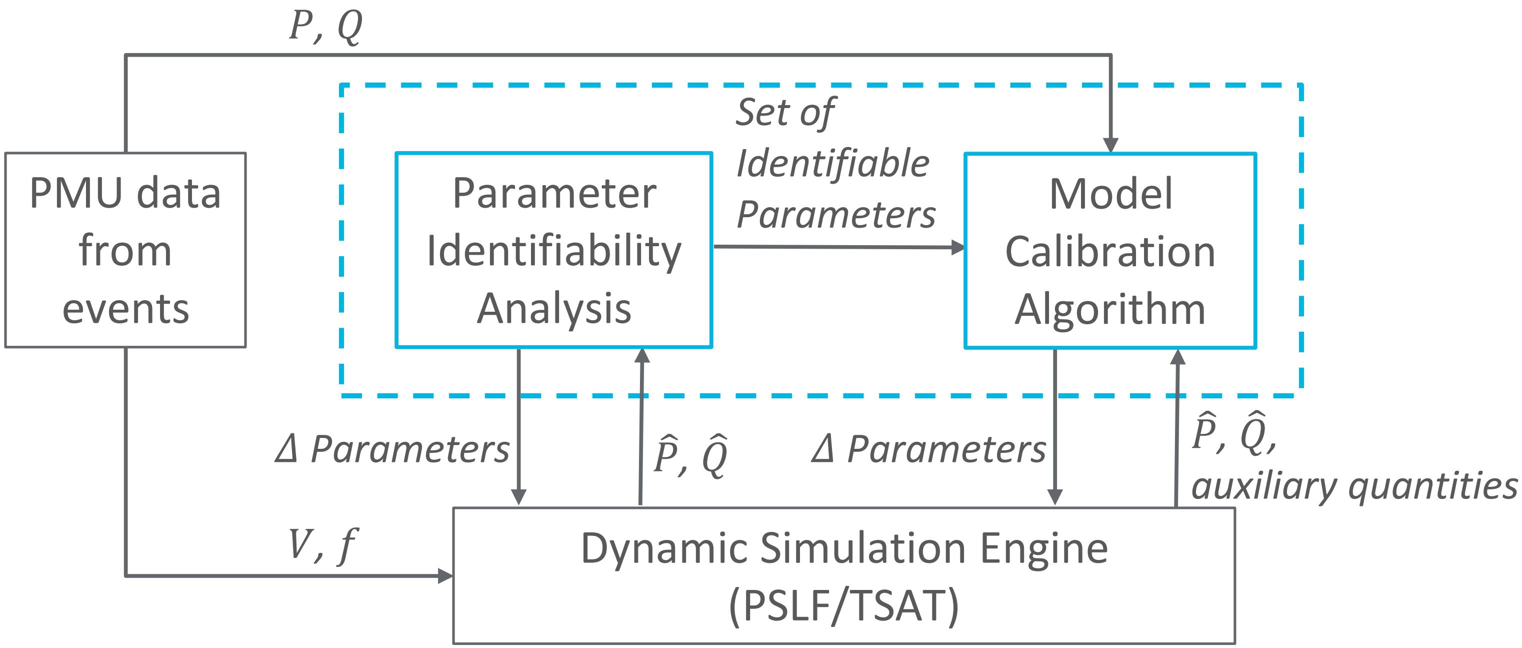
Disturbance based Model Validation/Calibration

- Production-grade software tool for disturbance based model validation/calibration
- Design approach driven by industry challenges associated with model validation/calibration
- Leverage GE's engineering analysis WAMS software platform to build this application
- Software application will have API's to interface with GE PSLF, Powertech TSAT simulation tools
- Solution generic enough to be applicable to wide variety of models (traditional generating plant, wind, solar, dynamic load, etc.)

Disturbance based Model Validation/Calibration

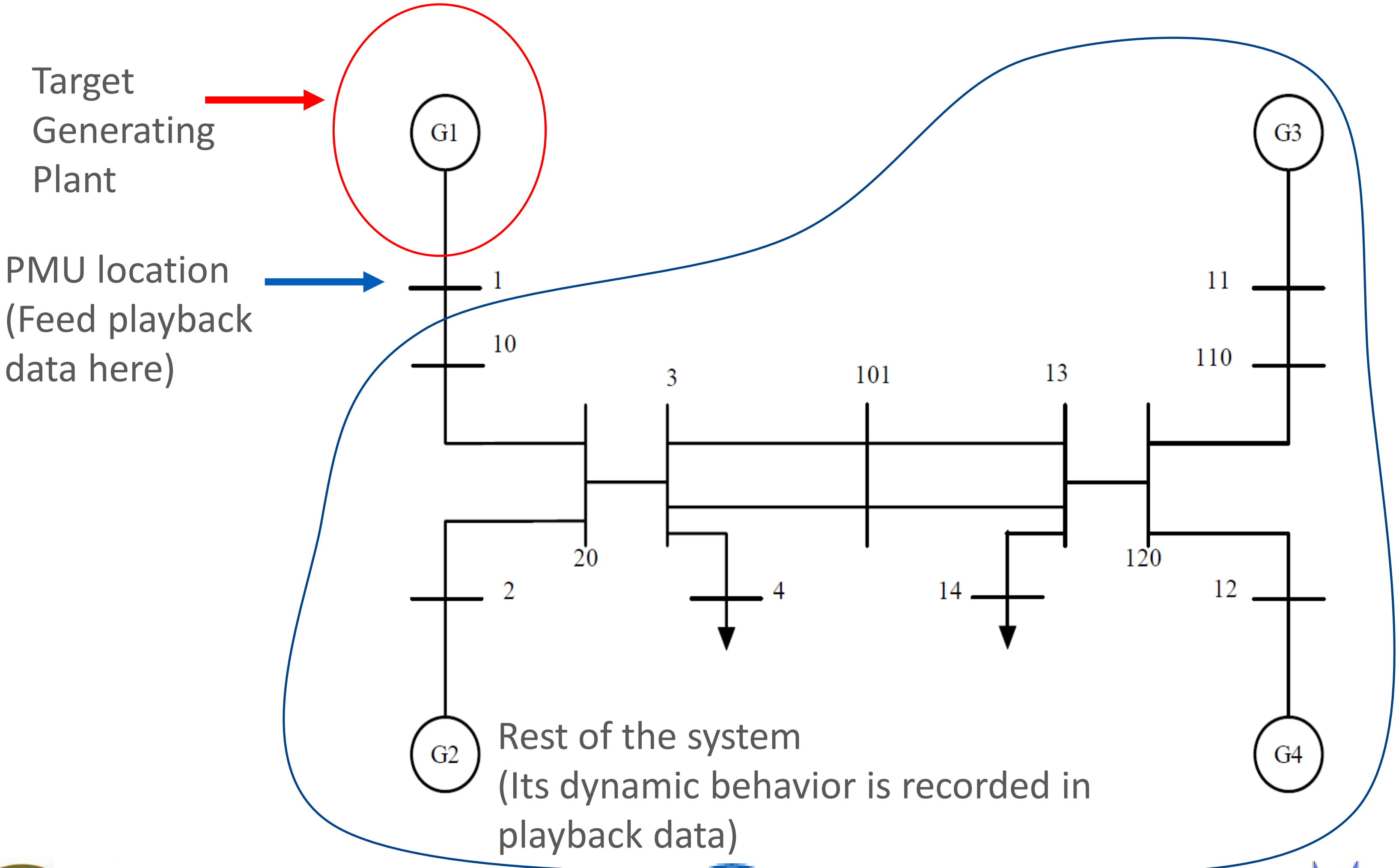
- Key considerations to ensure successful model validation/calibration:
  1. Account for non-linearity in models
  2. Account for multiple different events
  3. Physical constraints of parameters need to be enforced during model calibration
  4. Calibration results may be strongly dependent on assumed default parameter values
  5. Avoid tuning parameters that may already be at their true values

Disturbance based Model Validation/Calibration



- Parameter identifiability analysis to determine the set of identifiable parameters across a range of events and default values
- Candidate calibration algorithms
  - Unscented Kalman Filter (UKF)
  - Optimization-based Calibration

Model Validation/Calibration on 2-area System



Parameters Subject to Tune (PST Model)

- Generator Parameters (6th order model):

p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	P15
x_l	r_a	x_d	x'_d	x''_d	T'_{do}	T''_{do}	x_q	x'_q	x''_q	T'_{qo}	T''_{qo}	H	D_0	D_1

- Exciter Parameters (1st order model):

p16	p17	P18
T_r	K_a	T_a

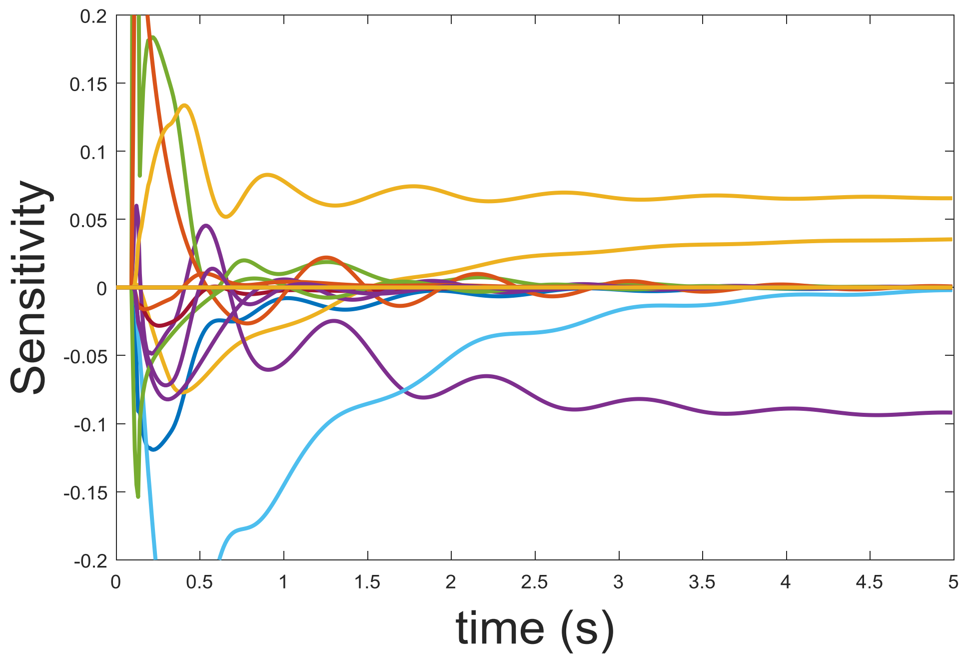
- Governor Parameters (3rd order model):

p19	p20	p21	p22	p23	p24
R	T_s	Tc	T_3	T_4	T_5

Parameter Identifiability using Sensitivity Analysis

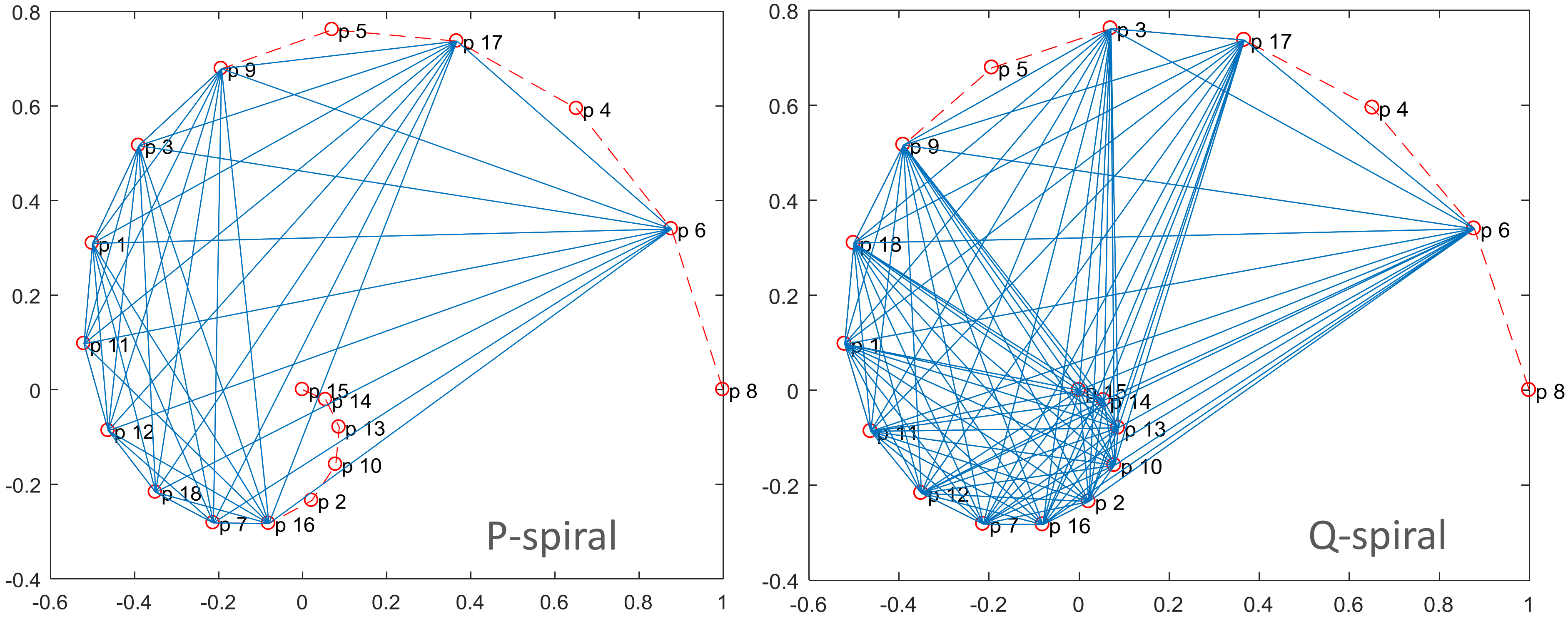
- Two aspects to be considered:
  - Magnitude of output sensitivity to parameter changes
  - Dependency among multiple parameter sensitivities

Output sensitivities to different parameters



- Difficult to recognize dependency without data analysis

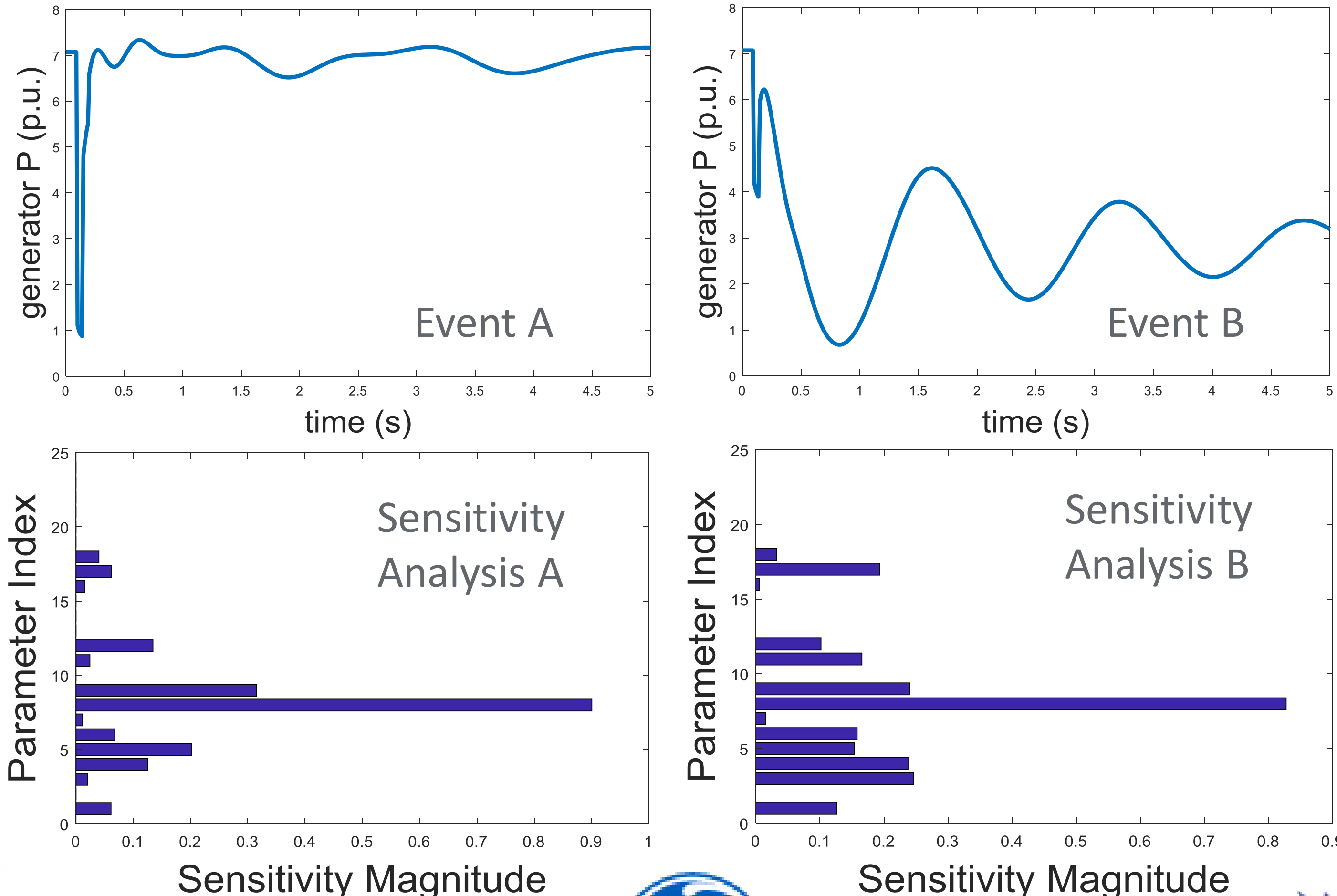
Parameter Identifiability Spiral Graph



- Sensitivity magnitude: reduces in counter-clockwise direction
- Sensitivity dependency: represented by connecting lines

Accounting for Multiple Events

- Different events may result in different parameter sensitivities

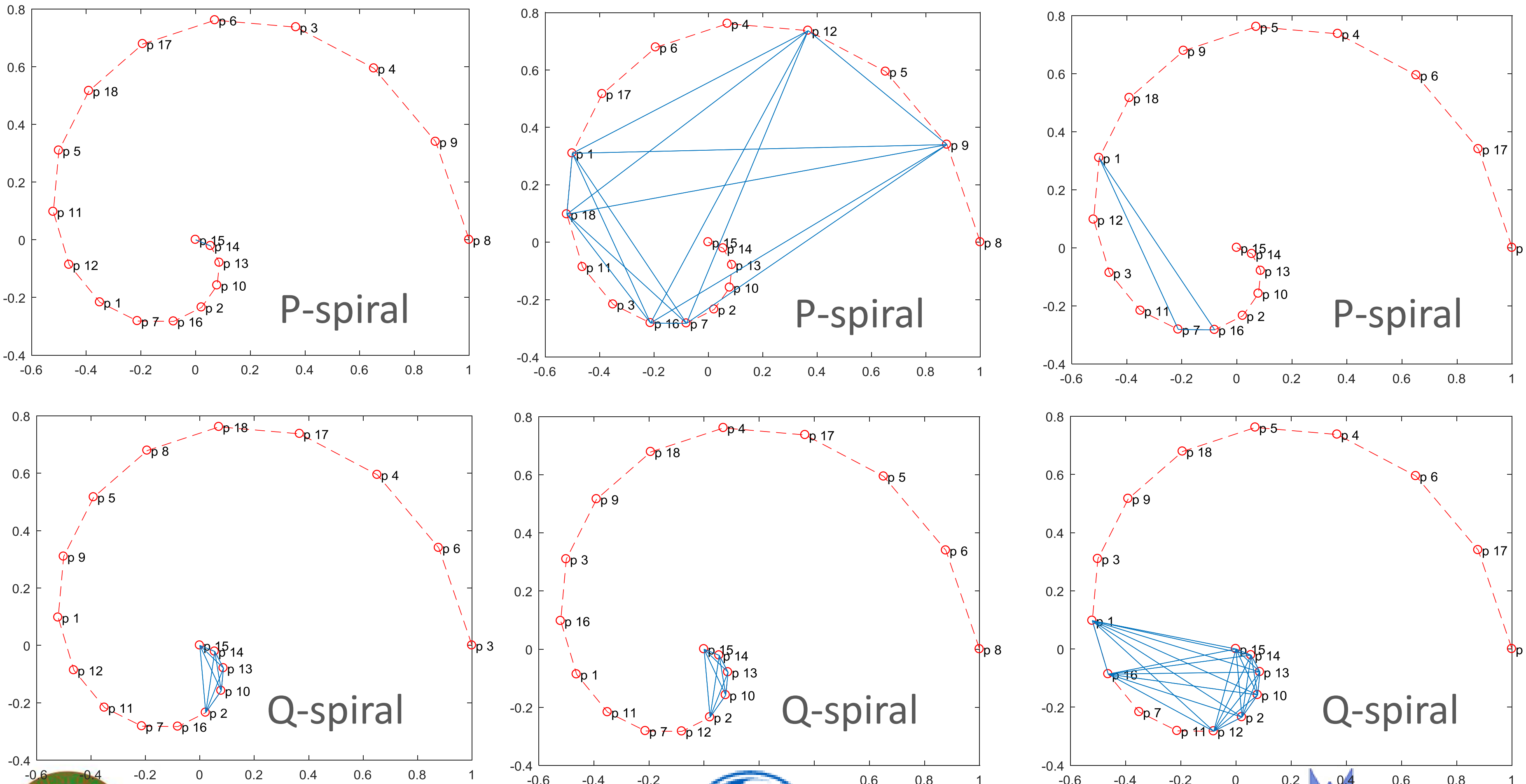


P,Q-spiral for Multiple Events

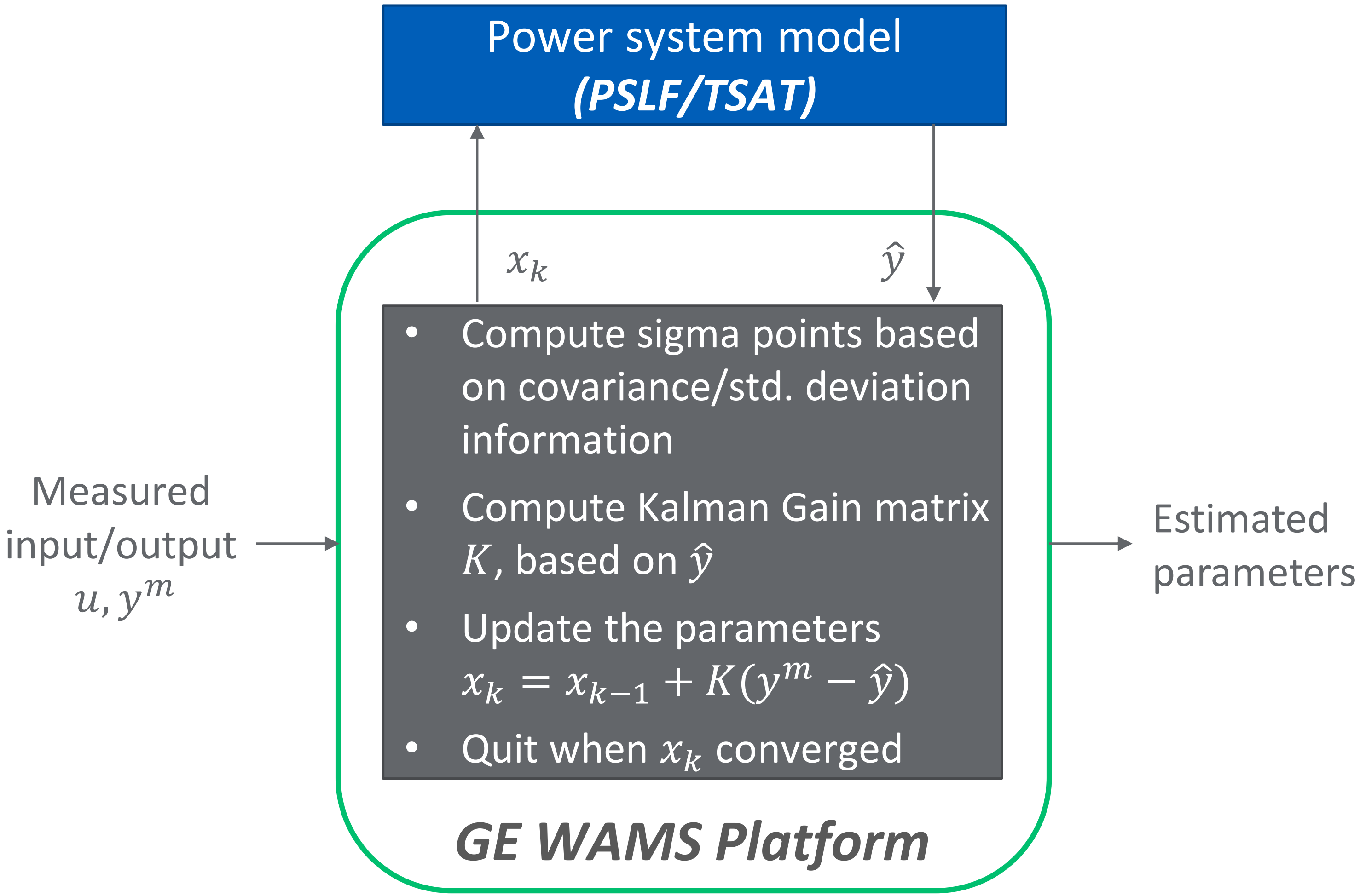
Event A

Event B

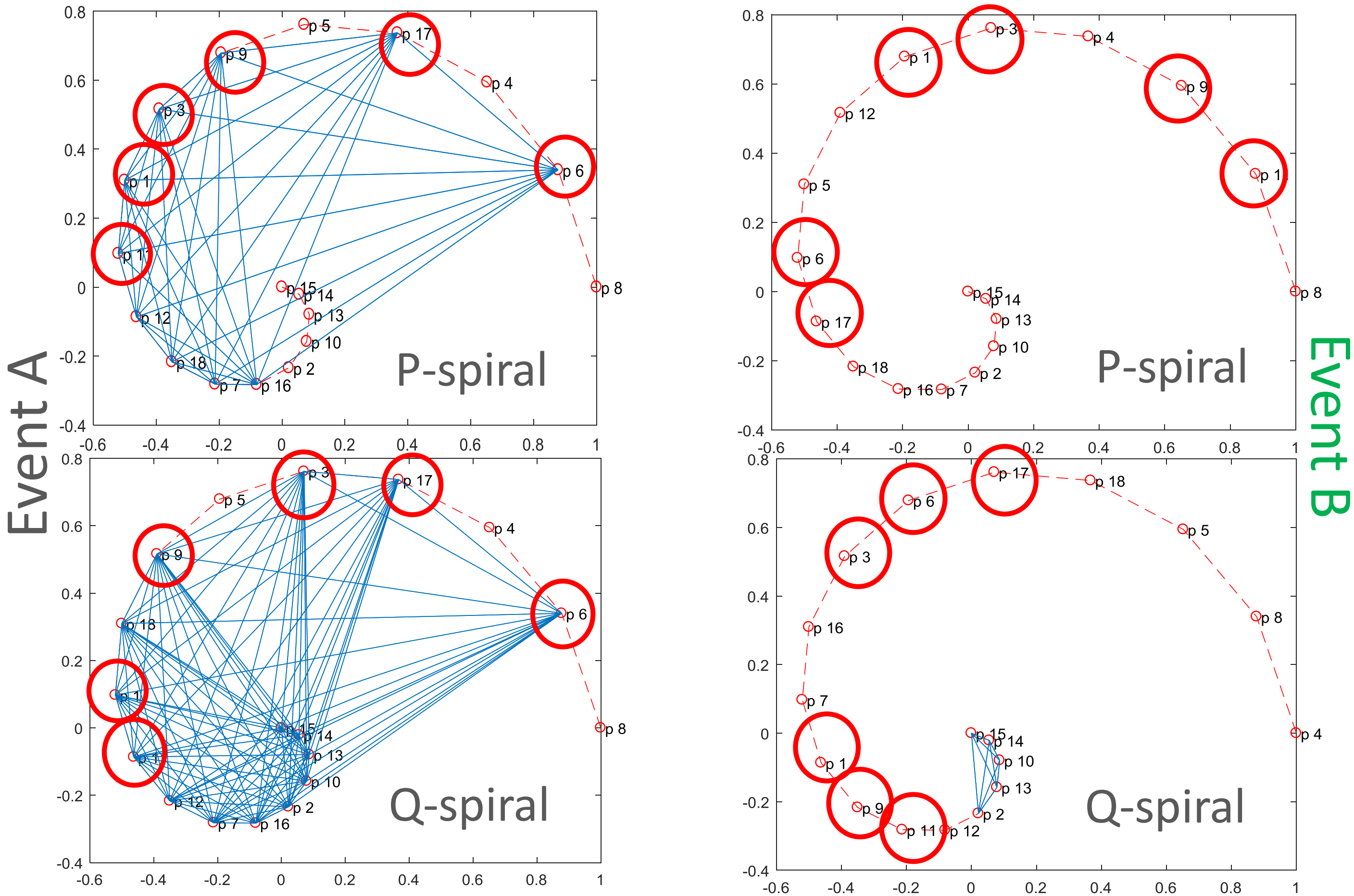
Event C



UKF based Model Calibration



Preconditioning for UKF (PST model)

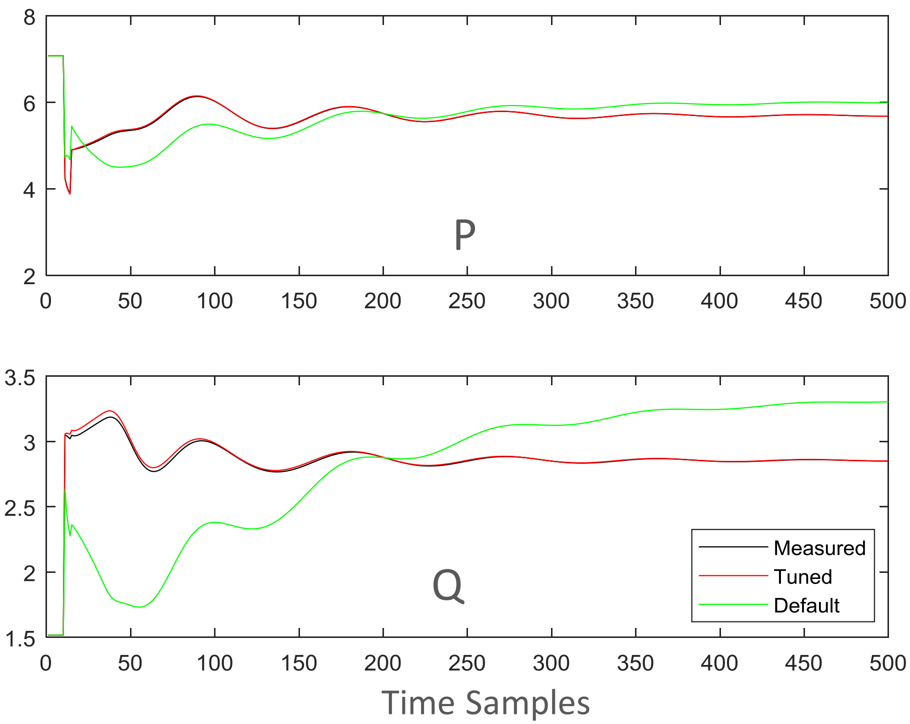


- p1, p3, p6, p9, p11, p17 are less identifiable for event A than for event B

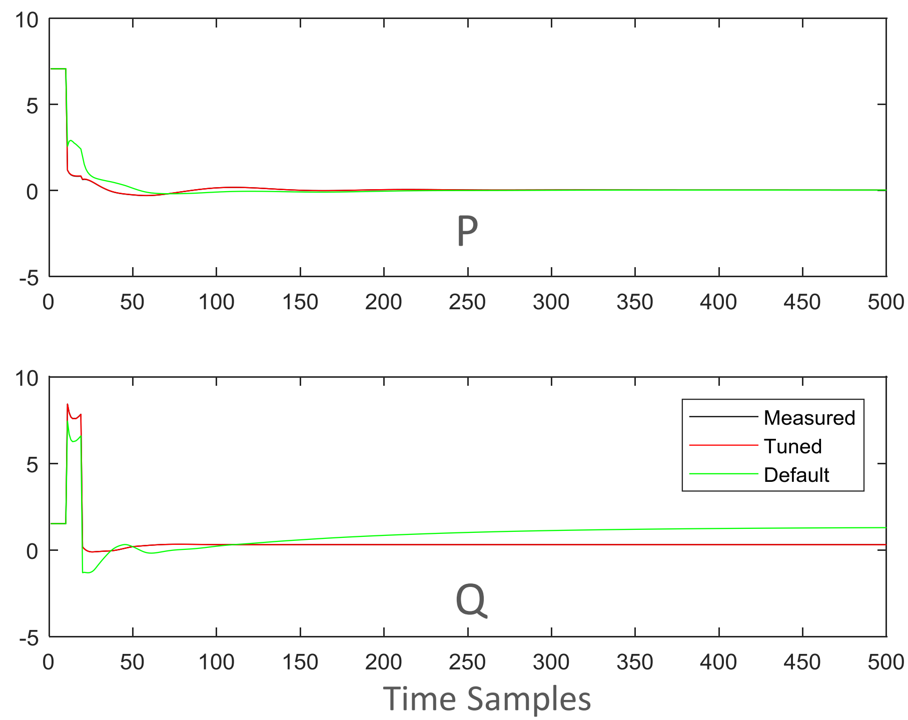
UKF based Model Calibration (PST model)

Parameters to tune: p1, p3, p6, p9, p11, p17

Event A

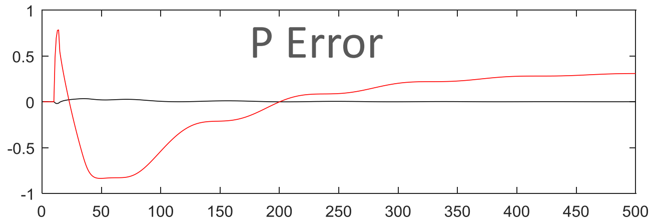


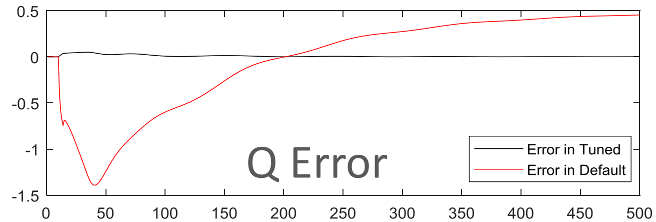
Event B



UKF based Model Calibration (PST model)

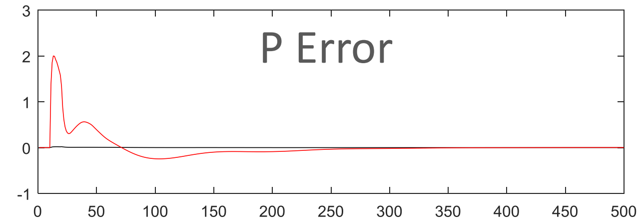
Event A

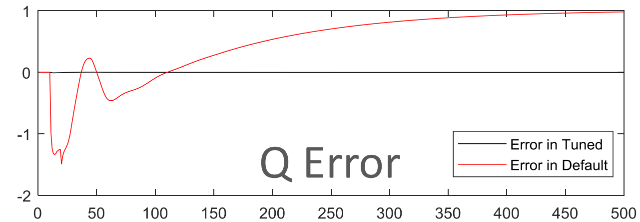




	Default	True	Tuned
P1 (X_l)	0.24	0.2	0.1847
P3 (X_d)	3.6	1.8	2.099
P6 (T'_{do})	16	8	7.332
P9 (X'_q)	1.1	0.55	0.5353
P11 (T'_{qo})	0.8	0.4	0.4058
P17 (K_a)	400	200	182.04

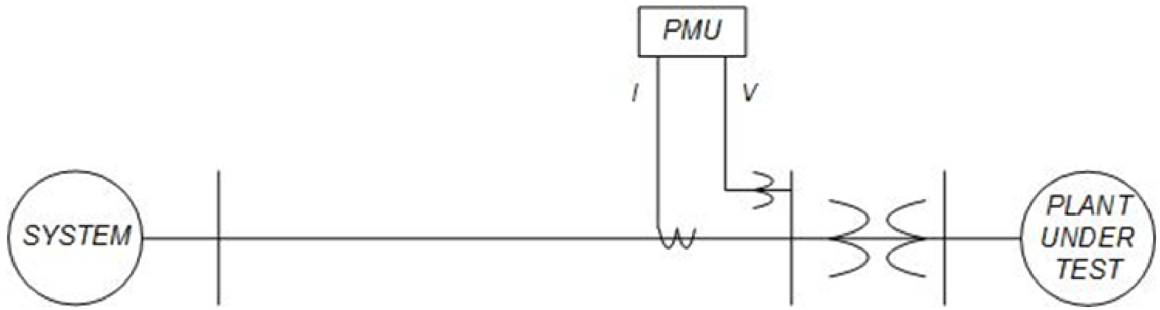
Event B

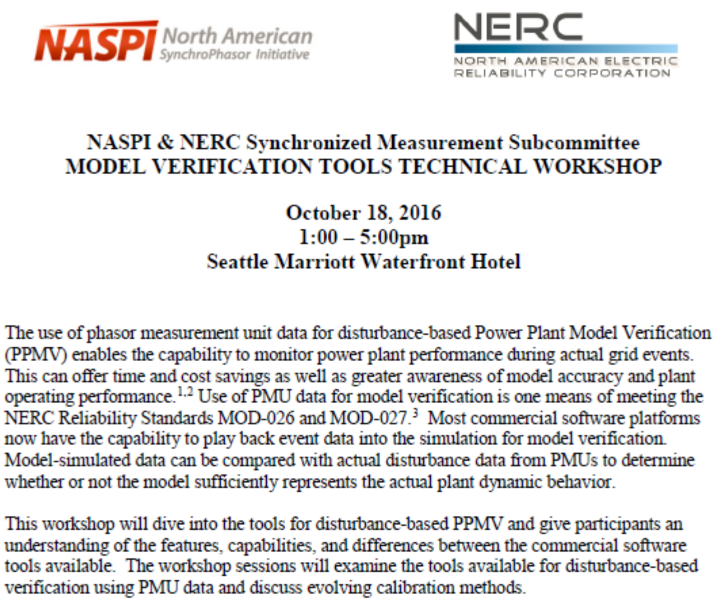




	Default	True	Tuned
P1 (X_l)	0.24	0.2	0.2001
P3 (X_d)	3.6	1.8	1.8016
P6 (T'_{do})	16	8	8.0169
P9 (X'_q)	1.1	0.55	0.5527
P11 (T'_{qo})	0.8	0.4	0.3993
P17 (K_a)	400	200	200.59

UKF based Model Calibration (PSLF model)




NASPI North American SynchroPhasor Initiative

NERC NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

NASPI & NERC Synchronized Measurement Subcommittee
MODEL VERIFICATION TOOLS TECHNICAL WORKSHOP

October 18, 2016
1:00 – 5:00pm
Seattle Marriott Waterfront Hotel

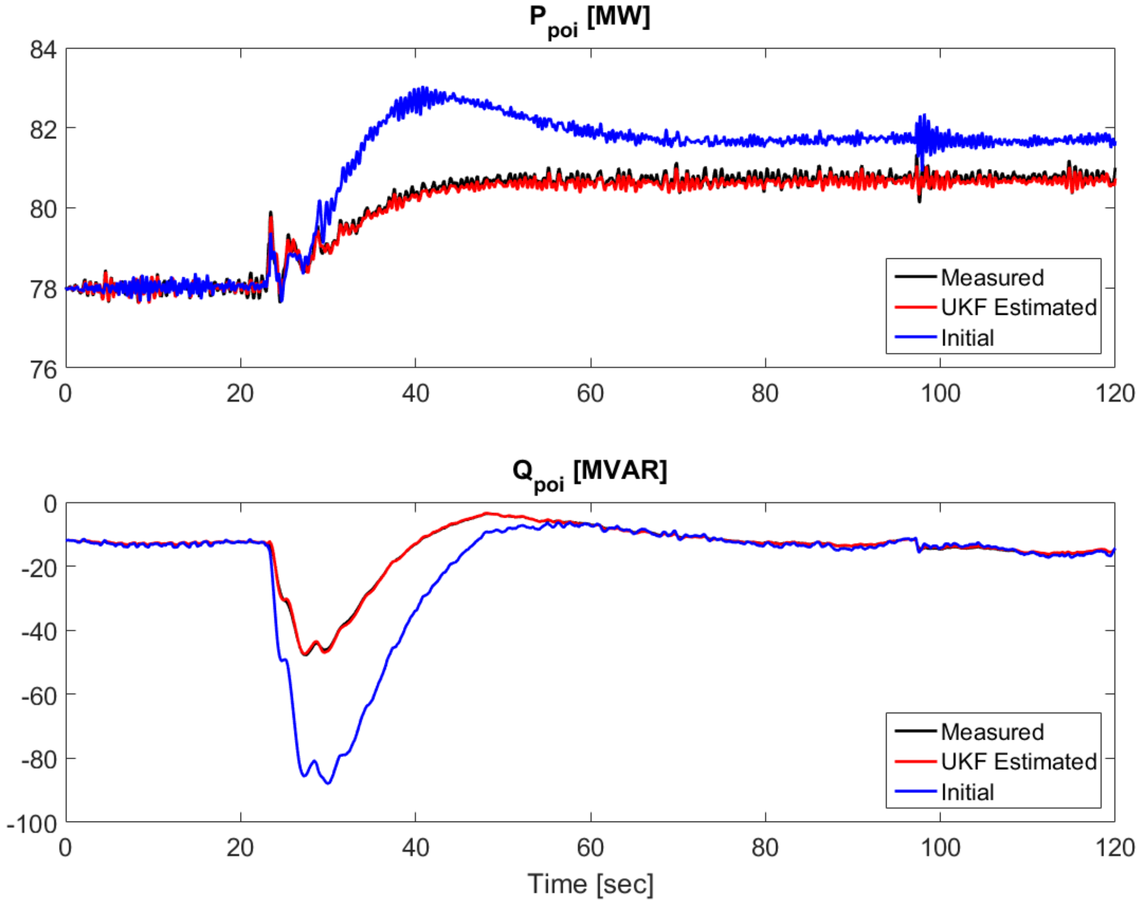
The use of phasor measurement unit data for disturbance-based Power Plant Model Verification (PPMV) enables the capability to monitor power plant performance during actual grid events. This can offer time and cost savings as well as greater awareness of model accuracy and plant operating performance.[1,2] Use of PMU data for model verification is one means of meeting the NERC Reliability Standards MOD-026 and MOD-027.[3] Most commercial software platforms now have the capability to play back event data into the simulation for model verification. Model-simulated data can be compared with actual disturbance data from PMUs to determine whether or not the model sufficiently represents the actual plant dynamic behavior.

This workshop will dive into the tools for disturbance-based PPMV and give participants an understanding of the features, capabilities, and differences between the commercial software tools available. The workshop sessions will examine the tools available for disturbance-based verification using PMU data and discuss evolving calibration methods.

- Hydro Power Plant Model*:
  - gentpj – Synchronous Generator Model
  - esst1a – Bus-fed Static Excitation System
  - ieeeg3 – IEEE Type 3 Turbine-Governor
  - pss1a – Analog Single-Input Stabilizer
- GE PSLF as the simulation tool
- Use recorded PMU data* for playback simulation

** Courtesy: BPA TIP 352 project*

UKF based Model Calibration (PSLF model)



Measured – True
UKF – Estimated
Initial – Corrupt

UKF based Model Calibration (PSLF model)

MODEL	PARAMETER NAME	DEFAULT/ CORRUPT	TRUE	UKF ESTIMATED
gentpj	tpdo	4.3	6.17	3.78
gentpj	h	4	5.5	5.31
gentpj	ld	0.55	0.67	0.28
esst1a	tc	2.1	0.9	0.84
esst1a	tb	2.5	3.85	2.67
esst1a	ka	50	125	68.5
ieeeg3	rperm	0.05	0.065	0.069
ieeeg3	rtemp	0.24	0.42	0.58
ieeeg3	tr	1.2	2.4	1.92
pss1a	a1	0.035	0.035	0.017
pss1a	t5	15	10	9.81
pss1a	t6	0.035	0.035	0.017
pss1a	ks	35	20	21.09

Initial evaluation suggests UKF performs well with respect to P, Q match as well as parameter match

Key Milestones in Phase I (R&D)

Key Milestones in Phase I	Year 1				Year 2			
	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar
Model Validation/Calibration Tool								
Model validation/calibration functional specification								
Model validation/calibration developed and tested with simulated data								
Model validation/calibration software platform integration with commercial simulation tools (PSLF, TSAT)								
Angle-based Grid Management (AGM) Tool								
AGM functional specification								
AGM algorithm developed and tested with simulated data								
AGM software platform integration								
Operator Guidance Tool								
Operator guidance tool functional specification								
Operator guidance algorithm developed and tested with simulated data								
Operator guidance software platform integration								

Project Status & Accomplishments

- Accomplishments so far:
  - Development of a parameter identifiability tool for successful model calibration
  - Evaluation of multiple candidate model calibration techniques, including successful demonstration using realistic models & data
  - Patent disclosure for novel model calibration approach
  - IEEE paper on model calibration approach in progress
  - Initial evaluation of angle-based grid management for voltage stability limited systems
- Deliverables for this year:
  - Quarterly reports, annual report describing developed algorithms and validation results with simulation data

Next Steps

Year 1:

- Finalize functional specifications for all three software applications in consultation with utility partners
- Rigorous testing and validation of developed algorithms
- Software architecture design and platform integration
- Data sharing agreements with all utility partners

Year 2:

- Field demonstration planning and preparation
- Factory acceptance testing and algorithm tuning
- Field demonstrations at utility host locations

Thank You!