Electric Power Group Presents
Maximizing Use of Synchrophasor Technology for Everyday Tasks

Welcome!

The meeting will begin at 2:00 p.m. ET / 11:00 a.m. PT June 21, 2017

Today's Topic: Generator Model Validation using PMU data for MOD-26, MOD-27 Requirements

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Generator Model Validation using PMU data for MOD-26, MOD-27 Requirements

Webinar

June 21, 2017

Presented by
Neeraj Nayak, EPG

Outline

- **Introduction**
- **Methodology**
  > Validation Process

  > Calibration Process
- **Case Study – Gas Turbine Generator**
- **Key Takeaways**
- **Q&A, Discussion**
- **Summary**

Introduction

Challenge & Need

- Models are widely used in power system planning and operation studies
- Models are used to predict response of the grid and assess system stability during events
- Inaccurate models result in incorrect determination of system response and system stability. For e.g. August 1996 blackout – models did not represent reality
- Traditional staged tests for Generator Model Validation
  - Require units to be taken out of service
  - Expensive and Time consuming
- NERC MOD-026, MOD-027 reliability standards require verification of generator dynamic models including excitation controls, governor and turbine controls
- Synchrophasor data from PMUs provides a cost effective and efficient way to validate generator model parameters

NERC MOD-026-1 & MOD-027-1 Requirements

Standard MOD-026-1 — Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

A. Introduction

1. **Title:** Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions
2. **Number:** MOD-026-1
3. **Purpose:** To verify that the generator excitation control system or plant volt/var control function[1] model (including the power system stabilizer model and the impedance compensator model) and the model parameters used in dynamic simulations accurately represent the generator excitation control system or plant volt/var control function behavior when assessing Bulk Electric System (BES) reliability.
4. **Applicability:**

   4.1. Functional Entities:

   4.1.1 Generator Owner

   4.1.2 Transmission Planner

Standard MOD-027-1 — Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions

A. Introduction

1. **Title:** Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions
2. **Number:** MOD-027-1
3. **Purpose:** To verify that the turbine/governor and load control or active power/frequency control[1] model and the model parameters, used in dynamic simulations that assess Bulk Electric System (BES) reliability, accurately represent generator unit real power response to system frequency variations.
4. **Applicability:**

   4.1. Functional entities

   4.1.1 Generator Owner

   4.1.2 Transmission Planner

Source: NERC Reliability Standards, http://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-026-1.pdf

Source: NERC Reliability Standards, http://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-027-1.pdf

NERC MOD-026 and MOD-027 Applicability

Table 2: MOD-026 and MOD-027 Applicability		
Interconnection	"Individual generating unit"... (gross nameplate rating)	"Individual generating plant consisting of multiple generating units that are directly connected at a common BES bus with total generation"... (gross aggregate nameplate rating)
Eastern or Quebec	> 100 MVA	> 100 MVA
Western	> 75 MVA	> 75 MVA
ERCOT	> 50 MVA	> 75 MVA

Source: NERC Reliability Guideline, "Power Plant Dynamic Model Verification using PMUs", September 2016

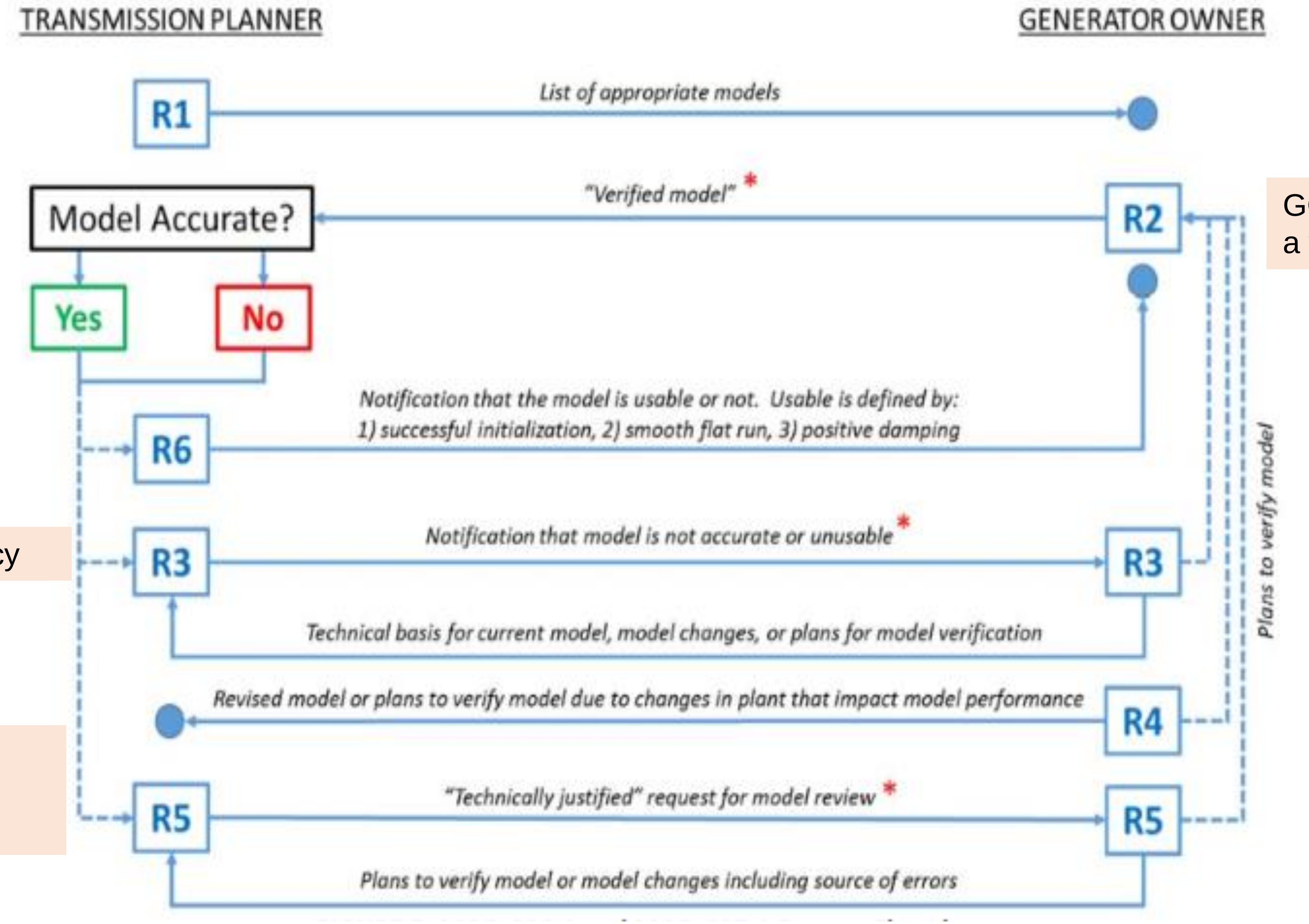
NERC MOD-027 Criteria for selecting frequency Events

Table 3: Frequency Event Criteria	
Interconnection	**Frequency Deviation from Scheduled Frequency**
Eastern	≥ 0.05 Hz
ERCOT and Western	≥ 0.10 Hz
Quebec	≥ 0.15 Hz

Source: NERC Reliability Guideline, "Power Plant Dynamic Model Verification using PMUs", September 2016

NERC Requirements (R1-R6) Flowchart

- Requirements that apply to PMU based model validation – R2, R3 & R5



GO: demonstrating a verified model

TP: verifying model accuracy

TP: providing technical justification to request for model review

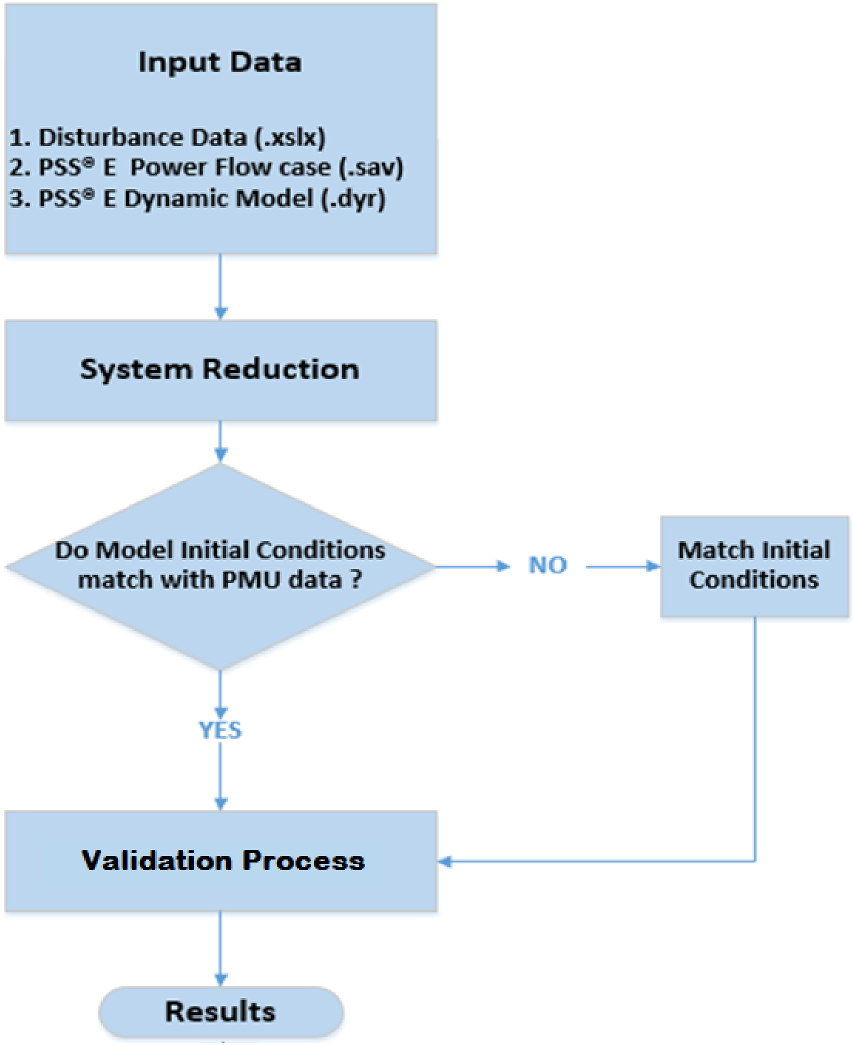
Source: NERC Reliability Guideline, "Power Plant Dynamic Model Verification using PMUs", September 2016

Generator Parameter Validation (GPV)

- EPG Developed Generator Parameter Validation (GPV) Tool & Process for Generator Model Validation
- Inputs
  - PMU Measured Event Data
  - Model – power flow & dynamic data
- Methodology
  - Automated System Reduction & Initial conditions matching
  - Validation – Comparing simulated response to PMU measurements
  - Automated Process of Identifying key Parameters using Sensitivity Analysis
  - Calibration – Allows user input & Engineering Judgement
- Types of Models that can be validated: Generator, Governor, Exciter, Stabilizer
- Tested and Validated for Steam Turbine, Gas Turbine Generator - Presented at NASPI 2016 Workshop
- Benefits
  - No need to take Units Offline - Reduces Cost Significantly
  - Can be repeated frequently

Methodology

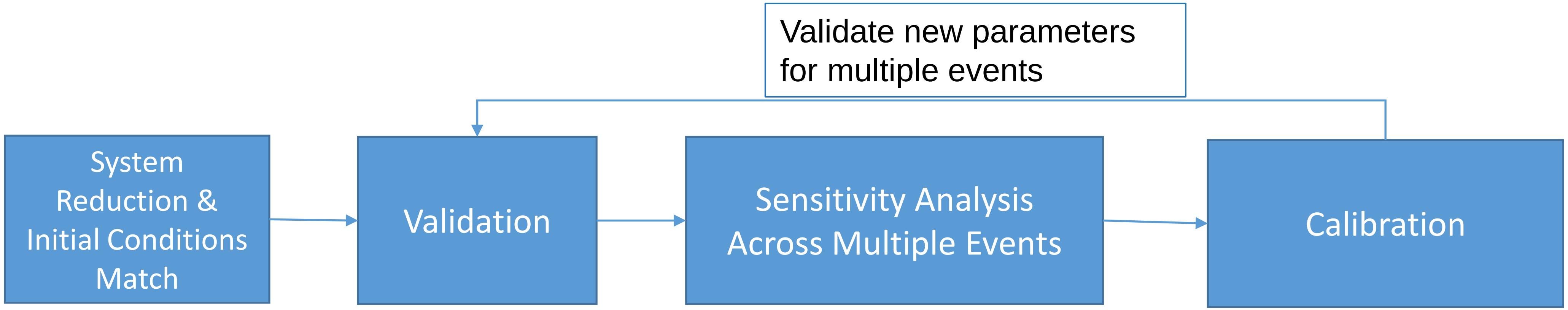
GPV Process - Validation



Steps :

1. Input Data
   a) PMU Recorded Disturbance Data at Generator terminals or POI
   b) Model Information – Power Flow and Dynamic Files
2. Automatic System Reduction
   > GPV will reduce the system beyond the boundary bus (PMU bus) keeping the Target Generator bus and the Boundary bus in the reduced system
3. Match initial conditions of the model to PMU measurements at the time of the event
4. Validation Process
   > Play in Voltage and Angle measurements from the PMU
   > Compare the measured P, Q response with model simulation

GPV Process - Calibration



Automatic

- Inject Voltage and Angle for playback
- Compare P, Q response with measurement

- Each Generator has ~ 60-70 Model Parameters
- Identifies top most sensitive parameters by computing changes in P & Q response for each parameter
- Set Bounds for individual parameters for calibration
- ➢ e.g. Gain Ks1 from PSS2B model original value was 10, new value was 50; loose bound required for gains
- ➢ Tighter Bounds for time constants & Inertia

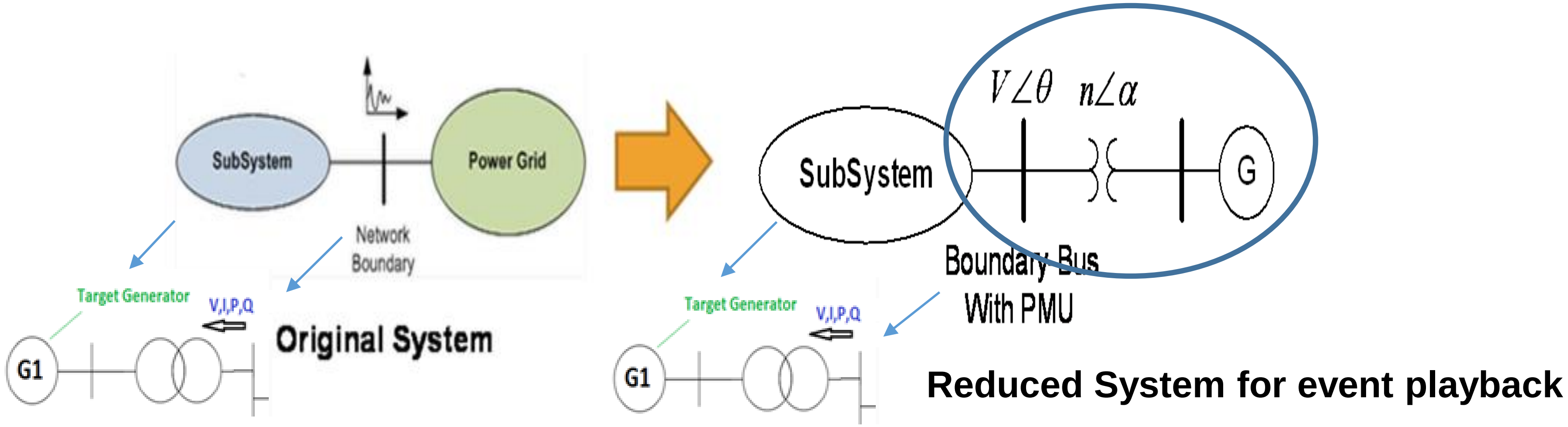
Algorithm: SPSA – PSO (Simultaneous Perturbation Stochastic Approximation – Particle Swarm Optimization)*

- ➢ Not affected by initial guess
- ➢ Multiple solutions in parallel → the best fit
- ➢ Faster convergence

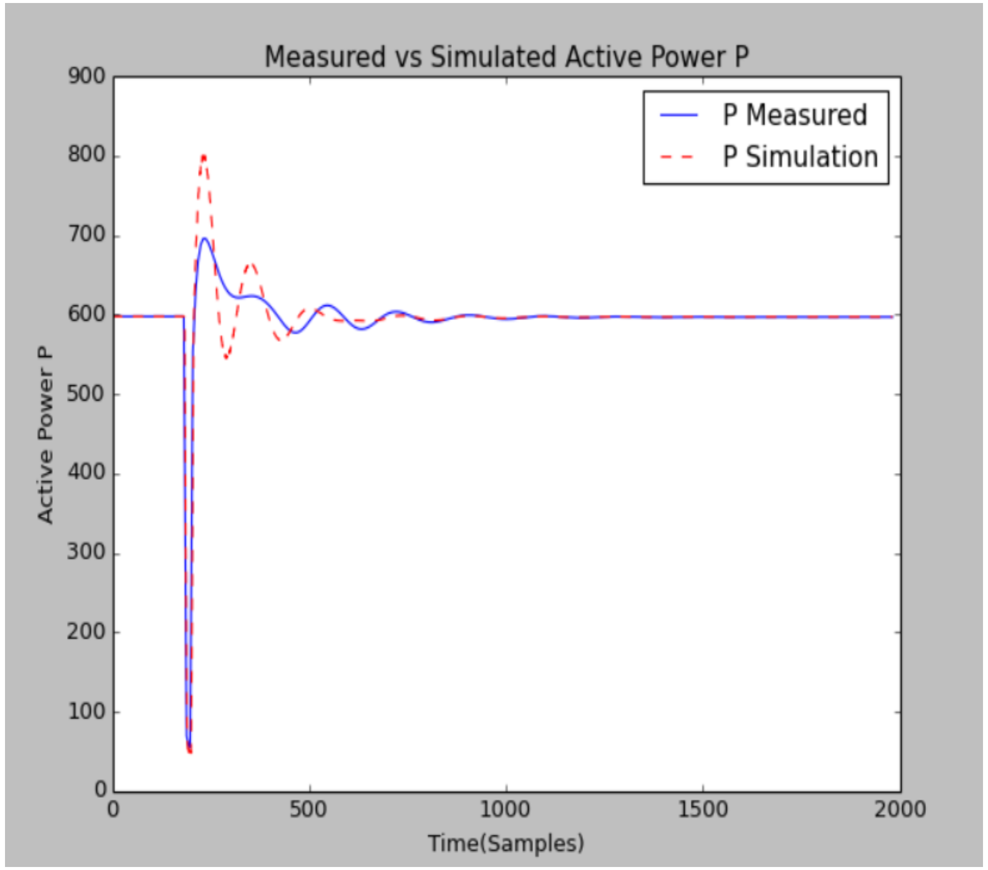
**Source*: Wei-Jen Lee et. al., "PMU based generator parameter identification to improve the system planning and operation"

Input Data & System Reduction

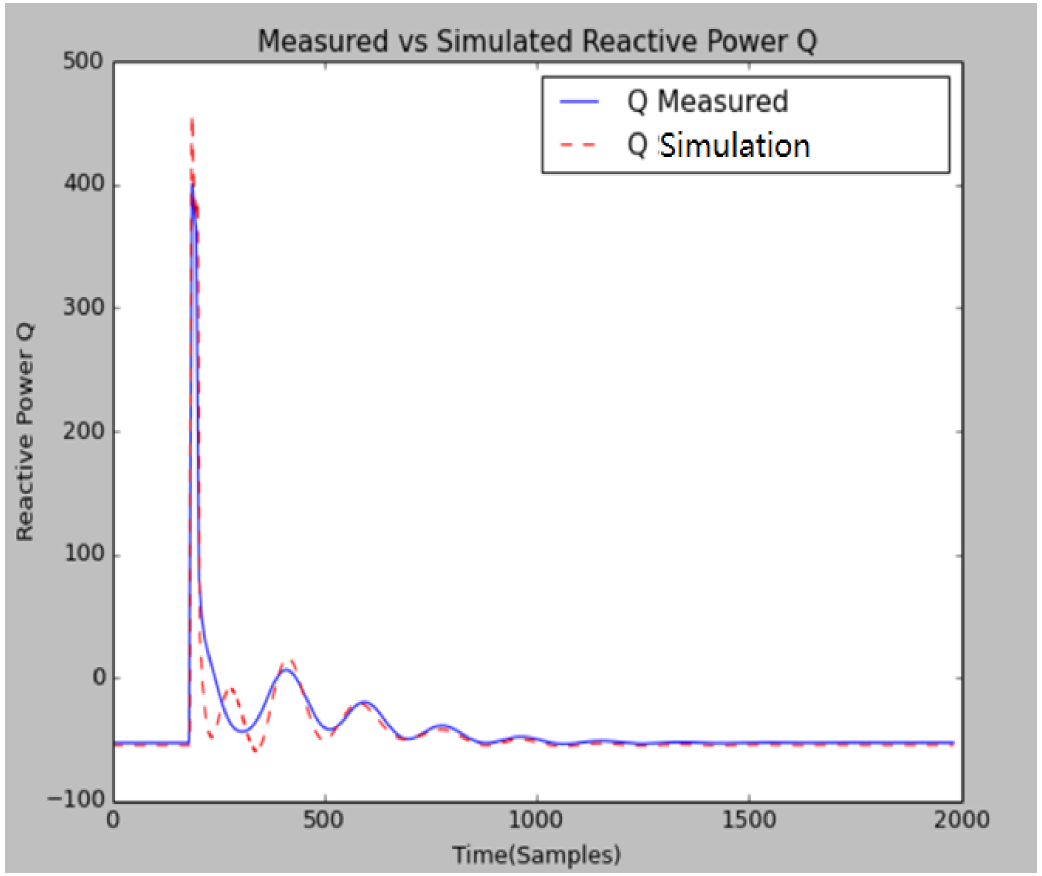
- High resolution PMU data (Voltage, Angle, P, Q) for selected grid disturbances (.xlsx);
- Network Model and Dynamic Data in PSS®E saved case format (.sav) and dynamics data format (.dyr)
- Individual generator data is required.
  For example: if Plant A has two Generators, PMU data should be taken directly from the output of the target generator
- Measurements can be on high side or low side of the Transformer
- An artificial generator and an ideal transformer are added at the boundary bus to playback PMU measurements



Example Validation Plots – Simulated vs PMU data



Active Power (P)



Reactive Power (Q)

Sensitivity Analysis- Identify Key Parameters

- Identifies Key Parameters for each model that have most effect on the P and Q response

- Ranks Parameters based on Sensitivity Values

Sensitivity Analysis/Parameter Selecti...

Parameter	MSE-P	MSE-Q	Ranks		Min	Max
GENSAL- Par 0	0.3562	1.19294	7	☐		
GENSAL- Par 1	0.05373	0.07745	14	☐		
GENSAL- Par 2	1.4388	0.39999	6	☐		
GENSAL- Par 3	19.13134	3.89948	1	☑		
GENSAL- Par 4	0.0	0.0		☐		
GENSAL- Par 5	0.02824	0.13205	12	☐		
GENSAL- Par 6	3.02644	1.10927	4	☐		
GENSAL- Par 7	1.79128	3.23443	3	☐		
GENSAL- Par 8	0.95289	4.44052	2	☐		
GENSAL- Par 9	0.00129	0.00177	22	☐		
GENSAL- Par 10	0.00028	0.00267	21	☐		
GENSAL- Par 11	0.00419	0.16833	11	☐		
HYGOV- Par 0	0.00021	3e-05	25	☐		
HYGOV- Par 1	0.01525	0.00142	17	☐		
HYGOV- Par 2	0.0012	6e-05	23	☐		
HYGOV- Par 3	0.00402	0.00028	20	☐		
HYGOV- Par 4	0.00805	0.00125	19	☐		
HYGOV- Par 5	0.01905	0.00096	16	☐		
HYGOV- Par 6	0.0	0.0		☐		
HYGOV- Par 7	0.0	0.0		☐		
HYGOV- Par 8	0.0088	0.00104	18	☐		
HYGOV- Par 9	0.02207	0.00282	15	☐		
HYGOV- Par 10	0.00074	0.00016	24	☐		
HYGOV- Par 11	0.00012	2e-05	26	☐		
SCRX- Par 0	0.11311	1.13153	8	☐		
SCRX- Par 1	0.00683	0.49723	9	☐		
SCRX- Par 2	0.12592	0.42198	10	☐		
SCRX- Par 3	0.01961	0.12695	13	☐		
SCRX- Par 4	0.0	0.0		☐		
SCRX- Par 5	0.44422	1.58719	5	☐		
SCRX- Par 6	0.0	0.0		☐		
SCRX- Par 7	0.0	0.0		☐		

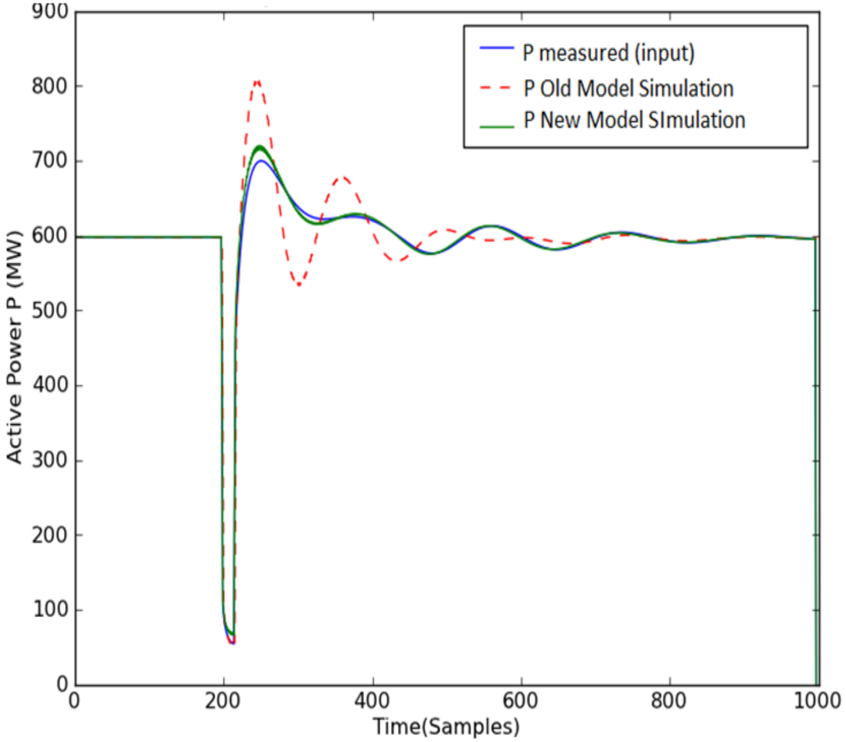
Specify Range of parameter values for Calibration Process

Red – Top 5 Most Sensitive Parameters
Yellow – Next 5 Most Sensitive
White – Remaining Parameters - 11 onwards
Green – Least Sensitive

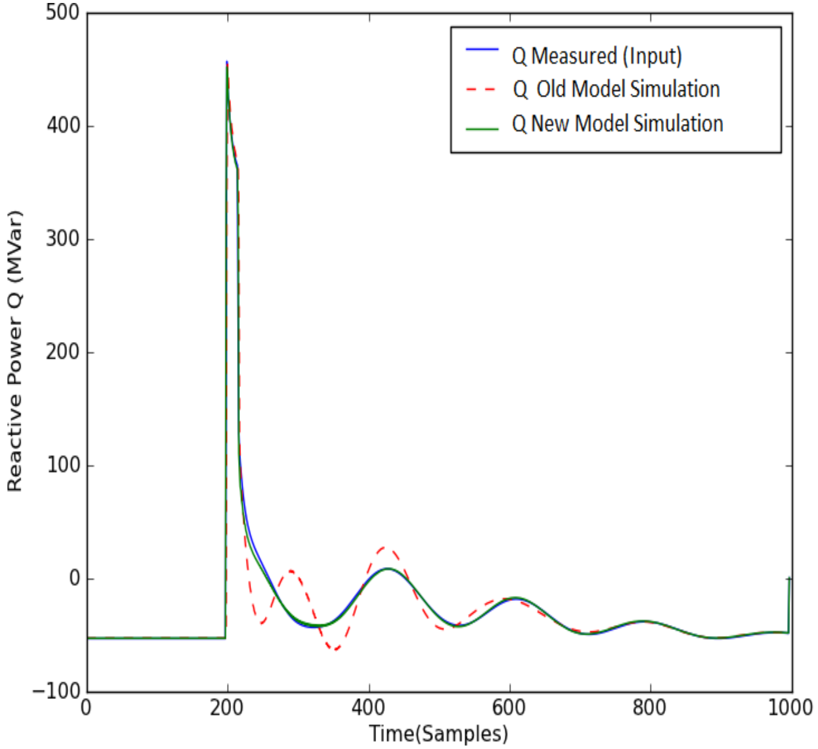
Calibration Results - Identified Parameter Values

Parameter	Description	Old Value	New Value
GENSAL Parameter 2	T''qo (sec)	0.24	0.2
GENSAL Parameter 3	H, Inertia	4.0	4.7

Active Power (Before & After Calibration)



Reactive Power (Before & After Calibration)



Case Study

- *Gas Turbine Generator - Model Validation & Calibration*

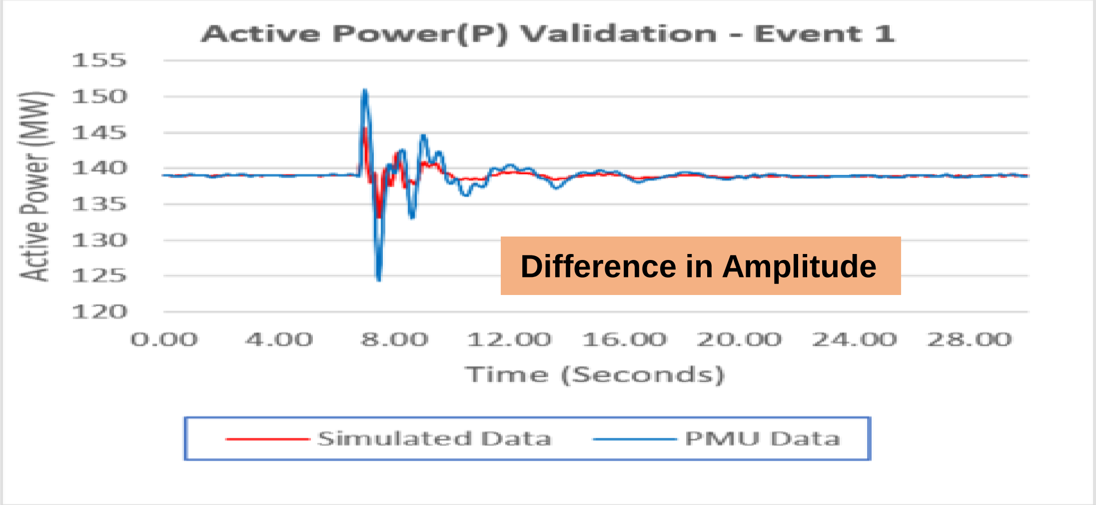
230 MVA Gas Turbine Generator

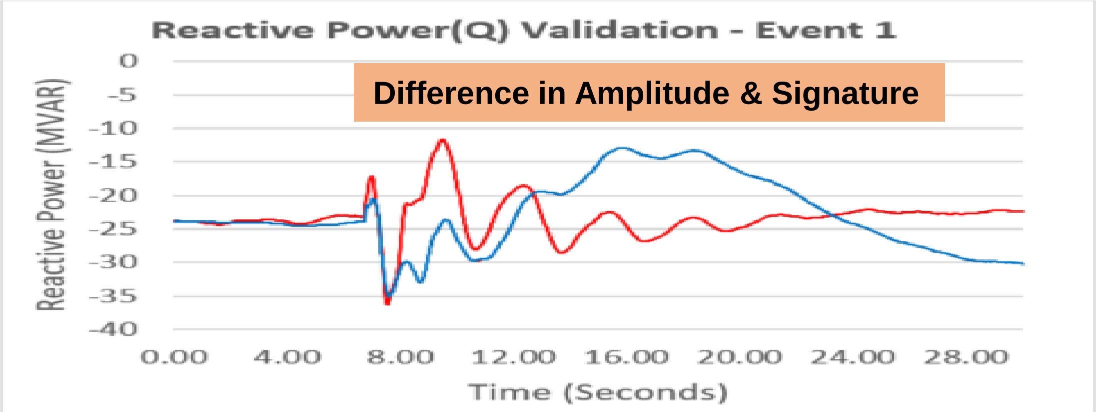
Models:
GENROU
REXS
GGOV1
PSS2A

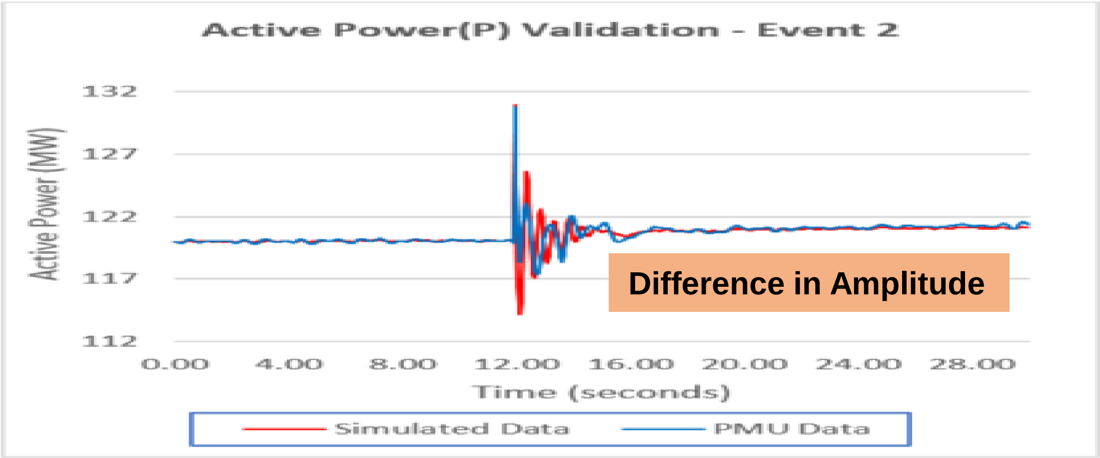
GAS TURBINE PLANT MODEL

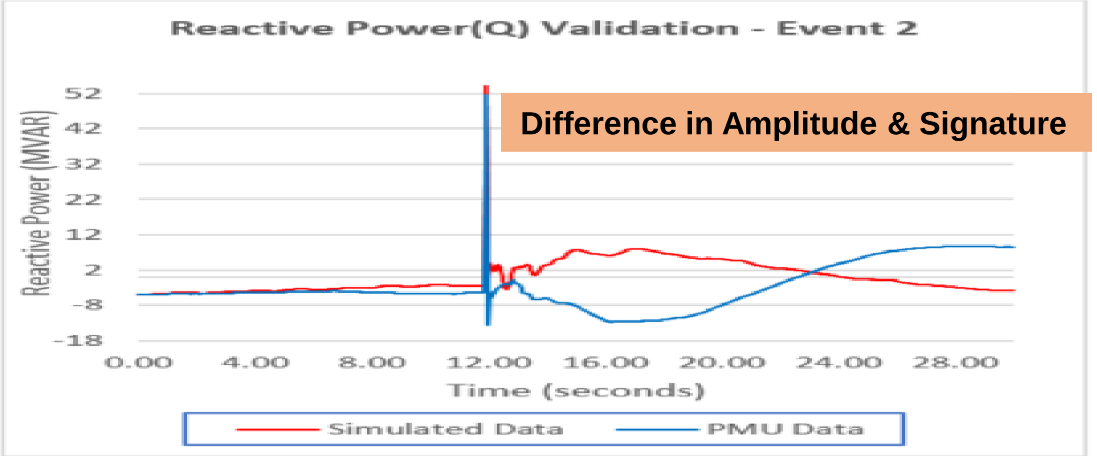
GENROU		REXS		GGOV1		PSS2A	
Param	**Value**	**Param**	**Value**	**Param**	**Value**	**Param**	**Value**
Xd	1.85	Tr	0.02	R	0.05	J1	1
X'd	0.21	Kvp	600	Rselect	1	K1	0
X''d	0.15	Kvi	0	Tpelec	0.6	J2	3
Xq	1.3	Vimax	0.2	Maxerr	0.025	K2	0
X'q	0.7	Ta	0.02	Minerr	-0.025	Tw1	1
X''q	0.15	Tb1	1	Kpgov	6	Tw2	1
Xl	0.15	Tc1	10	Kigov	0.22	Tw3	5
Ra	0.003	Tb2	1	Kdgov	0	Tw4	0
T'd0	5	Tc2	1	Tdgov	1	T6	0
T''d0	0.25	Vrmax	10	Vmax	1	T7	5
T'q0	1	Vrmin	-10	Vmin	0.24	Ks2	0.5
T''q0	0.05	Kf	0.045	Tact	0.6	Ks3	1
S(1.0)	0.12	Tf	5	Kturb	1.5	Ks4	1
S(1.2)	0.48	Tf1	1	Wfnl	0.25	T8	0.5
H	3.1	Tf2	1	Tb	1	T9	0.1
D	0	Fbf	1	Tc	1	N	1
Rcomp	0	Kip	5	Flag	1	M	5
Xcomp	0	Kii	0	Teng	0	Ks1	15
Accel	0.5	Tp	0	Tfload	0.3	T1	0.28
Kis	0	Vfmax	99	Kpload	1	T2	0.043
Pfd	0	Vfmin	-99	Kiload	3.3	T3	0.281
Pkd	0	Kh	0	Ldref	1	T4	1.16
Pfq	0	Ke	0.4	Dm	0	Vstmax	0.1
Pkq	0	Te	1.2	Ropen	99	Vstmin	-0.1
Speed	0	Kc	0	Rclose	-99	A	1
Angle	0	Kd	0.7	Kimw	0	Ta	0
		E1	2.4	Pmwset	0	Tb	0.043
		Se1	0.05	Asest	99		
		E2	3.2	Ka	10		
		Se2	0.3	Ta	1		
		Rcomp	0	Db	0		
		Xcomp	0	Tsa	1		
		Nvphz	0	Tsb	1		
		Kvphz	0	Rup	99		
		Flimf	0	Rdown	-99		

Source: NASPI PPMV Workshop October 2016









Validation Results – Event 1&2

Significant Difference in P and Q Response between Simulated & PMU data

Sensitivity Analysis for One Event

Sensitivity Analysis/Parameter Selection

Parameter	MSE-P	MSE-Q	Ranks	Min	Max
GENROU- Par 0	0.00021	0.00034	27		
GENROU- Par 1	0.00029	0.00249	21		
GENROU- Par 2	1e-05	0.00016	29		
GENROU- Par 3	0.00015	5e-05	30		
GENROU- Par 4	0.00693	0.0026	11		
GENROU- Par 5	0.0	0.0			
GENROU- Par 6	0.00015	0.00397	14		
GENROU- Par 7	0.003	0.01045	9		
GENROU- Par 8	0.00114	0.023	5		
GENROU- Par 9	0.00066	0.00153	22		
GENROU- Par 10	0.02694	0.04476	4		
GENROU- Par 11	0.0491	0.10461	2		
GENROU- Par 12	2e-05	5e-05	35		
GENROU- Par 13	1e-05	3e-05	37		
GGOV1- Par 0	2e-05	1e-05	39		
GGOV1- Par 1	1e-05	1e-05	46		
GGOV1- Par 2	0.0	0.0			
GGOV1- Par 3	0.0	0.0			
GGOV1- Par 4	0.0001	7e-05	31		
GGOV1- Par 5	0.0	0.0			
GGOV1- Par 6	0.0	0.0			
GGOV1- Par 7	0.0	0.0			
GGOV1- Par 8	0.0	0.0			
GGOV1- Par 9	0.0	0.0			
GGOV1- Par 10	4e-05	4e-05	36		
GGOV1- Par 11	0.0001	6e-05	32		
GGOV1- Par 12	1e-05	0.0			

Parameter	MSE-P	MSE-Q	Ranks	Min	Max
GGOV1- Par 13	5e-05	4e-05	34		
GGOV1- Par 14	6e-05	4e-05	33		
GGOV1- Par 15	0.0	0.0			
GGOV1- Par 16	0.0	0.0			
GGOV1- Par 17	0.0	0.0			
GGOV1- Par 18	0.0	0.0			
GGOV1- Par 19	0.0	0.0			
GGOV1- Par 20	0.0	0.0			
GGOV1- Par 21	0.0	0.0			
GGOV1- Par 22	0.0	0.0			
GGOV1- Par 23	0.0	0.0			
GGOV1- Par 24	0.0	0.0			
GGOV1- Par 25	0.0	0.0			
GGOV1- Par 26	0.0	0.0			
GGOV1- Par 27	0.0	0.0			
GGOV1- Par 28	0.0	0.0			
GGOV1- Par 29	0.0	0.0			
GGOV1- Par 30	0.0	0.0			
GGOV1- Par 31	0.0	0.0			
GGOV1- Par 32	0.0	0.0			
REXSYS- Par 0	1e-05	2e-05	38		
REXSYS- Par 1	1e-05	0.0			
REXSYS- Par 2	0.0	0.0			
REXSYS- Par 3	0.0	0.0			
REXSYS- Par 4	0.0	0.0			
REXSYS- Par 5	1e-05	0.0	41		
REXSYS- Par 6	1e-05	0.0	44		

Parameter	MSE-P	MSE-Q	Ranks	Min	Max
REXSYS- Par 7	1e-05	0.0	40		
REXSYS- Par 8	1e-05	0.0	43		
REXSYS- Par 9	0.0	0.0			
REXSYS- Par 10	0.0	0.0			
REXSYS- Par 11	0.00047	0.00479	12		
REXSYS- Par 12	0.00056	0.00469	13		
REXSYS- Par 13	0.00046	0.0034	18		
REXSYS- Par 14	0.00055	0.00344	17		
REXSYS- Par 15	0.03888	0.1535	1		
REXSYS- Par 16	1e-05	0.0	45		
REXSYS- Par 17	0.0	0.0			
REXSYS- Par 18	0.0	0.0			
REXSYS- Par 19	0.0	0.0			
REXSYS- Par 20	0.0	0.0			
REXSYS- Par 21	0.0	0.0			
REXSYS- Par 22	0.00027	0.00125	24		
REXSYS- Par 23	1e-05	1e-05	42		
REXSYS- Par 24	0.0	0.0			
REXSYS- Par 25	9e-05	0.00135	23		
REXSYS- Par 26	0.0	0.0			
REXSYS- Par 27	0.0	0.0			
REXSYS- Par 28	1e-05	0.0			
REXSYS- Par 29	0.0	0.0			
REXSYS- Par 30	0.0	0.0			
PSS2A- Par 0	1e-05	0.00277	20		
PSS2A- Par 1	1e-05	0.00277	19		
PSS2A- Par 2	0.0	0.0			

Parameter	MSE-P	MSE-Q	Ranks	Min	Max
PSS2A- Par 3	1e-05	1e-05			
PSS2A- Par 4	0.0	0.0			
PSS2A- Par 5	0.00069	0.00109	26		
PSS2A- Par 6	0.00079	0.00123	25		
PSS2A- Par 7	0.00013	0.07901	3		
PSS2A- Par 8	7e-05	0.00703	10		
PSS2A- Par 9	0.00058	0.01232	7		
PSS2A- Par 10	0.00031	0.0138	6		
PSS2A- Par 11	0.00025	0.00388	16		
PSS2A- Par 12	6e-05	0.00017	28		
PSS2A- Par 13	0.00025	0.0039	15		
PSS2A- Par 14	0.00027	0.0105	8		
PSS2A- Par 15	0.0	0.0			
PSS2A- Par 16	0.0	0.0			

Sensitivity Analysis Results Across Multiple Events

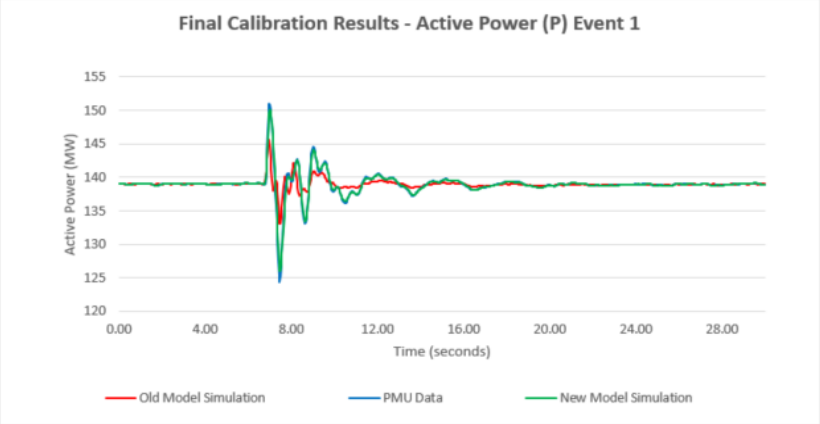
Top 15 Parameters

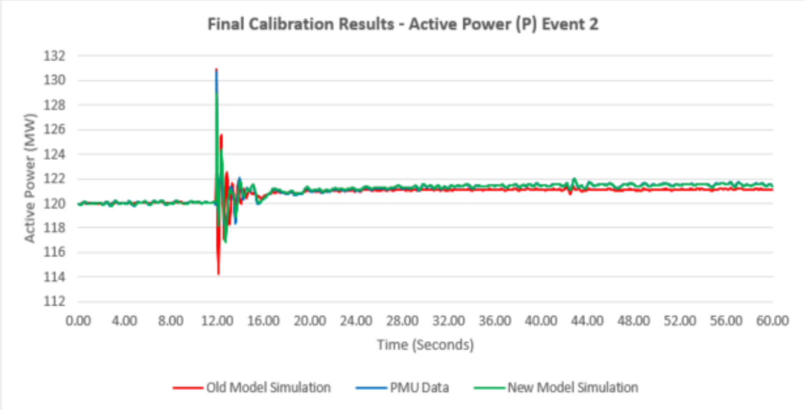
Rank	Model	Parameter
1	GENROU	Xl
2	PSS2A	Ks1
3	REXS	Tf
4	PSS2A	T9
5	GENROU	H
6	GENROU	Xq
7	REXS	Tc1
8	PSS2A	T8
9	PSS2A	Tw2
10	PSS2A	Tw1
11	GGOV1	Kpgov
12	GGOV1	Kturb
13	REXS	Kip
14	REXS	Tb1
15	GENROU	X'q

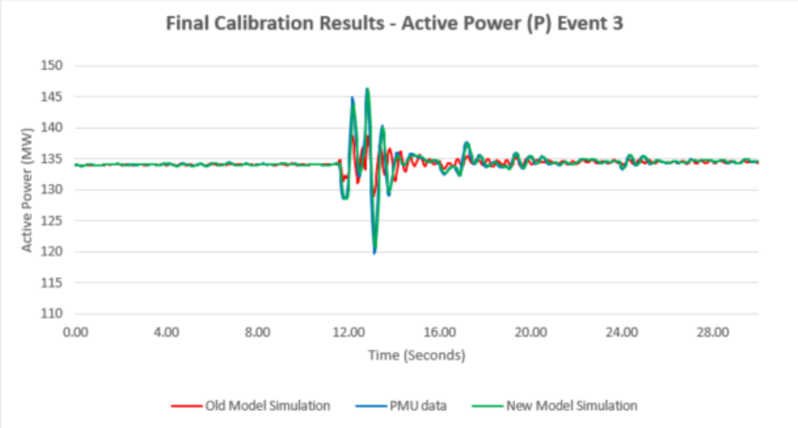
Range of Parameters for Calibration

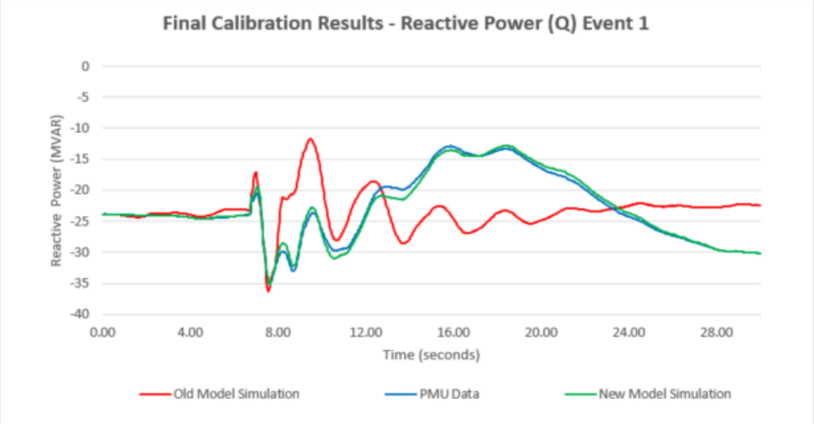
Rank	Model	Parameter	Old Value	Minimum	Maximum
1	GENROU	Xl	0.15	0.01	0.5
2	PSS2A	Ks1	15	1	50
3	REXS	Tf	5	1	10
4	PSS2A	T9	0.1	0.01	1
5	GENROU	H	3.1	0.5	10
6	GENROU	Xq	1.3	0.1	4
7	REXS	Tc1	10	1	20
8	PSS2A	T8	0.5	0.1	3
9	PSS2A	Tw2	1	0.1	10
10	PSS2A	Tw1	1	0.1	10
11	GGOV1	Kpgov	6	0.5	15
12	GGOV1	Kturb	1.5	0.1	10
13	REXS	Kip	5	0.5	15
14	REXS	Tb1	1	0.1	10
15	GENROU	X'q	0.7	0.1	3

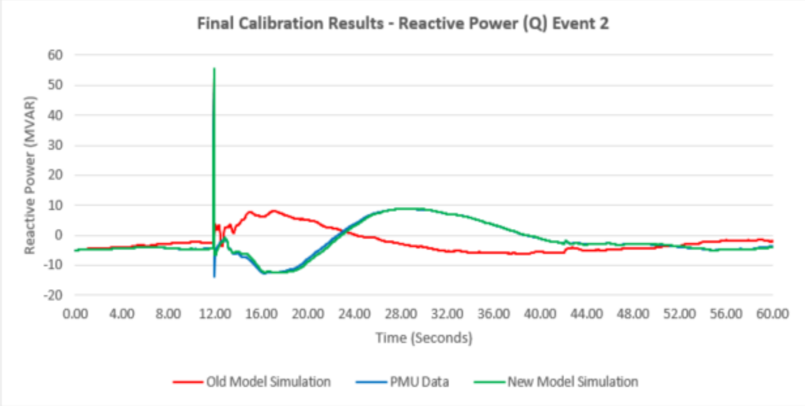
P & Q Simulated Response Compared to PMU data - Before & After Calibration

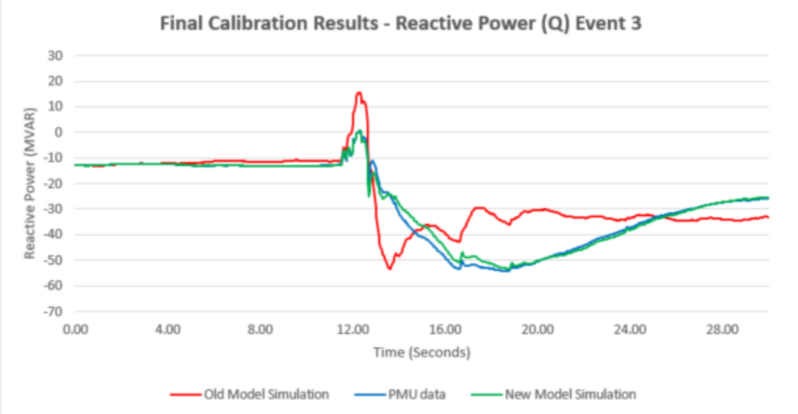












Calibration Results - Event 1, 2 & 3

After Calibration, Simulated P and Q Response Matches PMU data for All Events

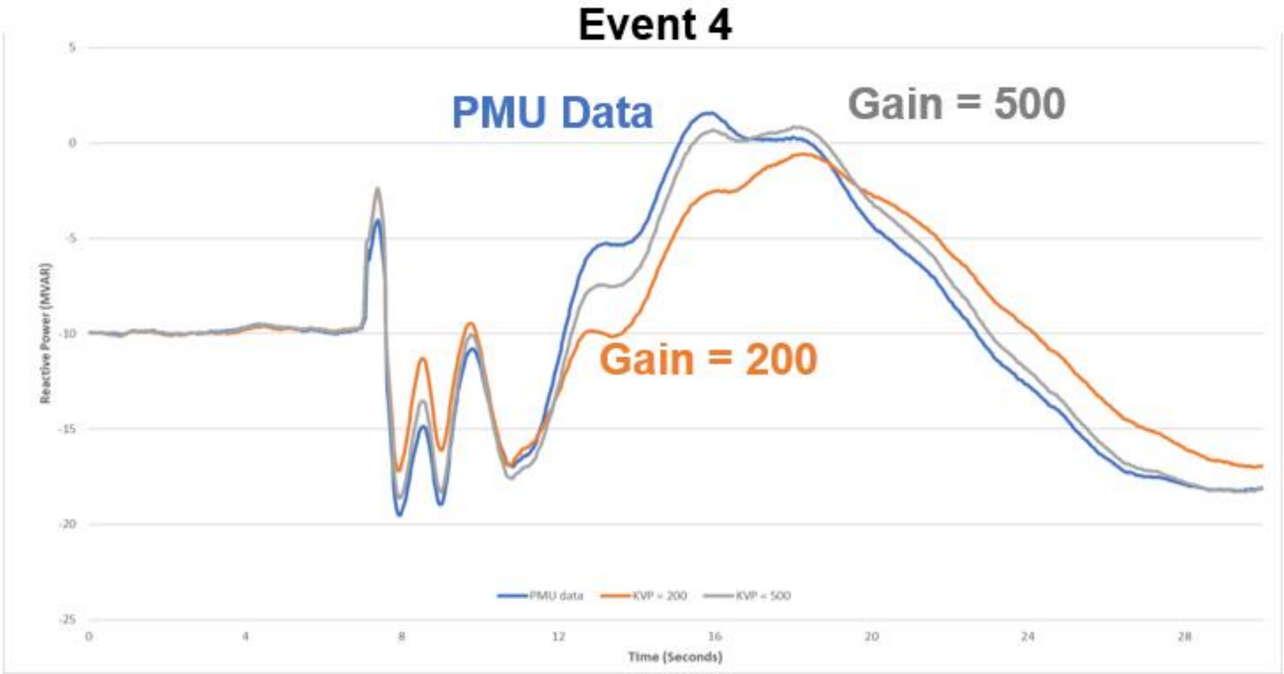
New Identified Model Parameters

Final 11 Parameters

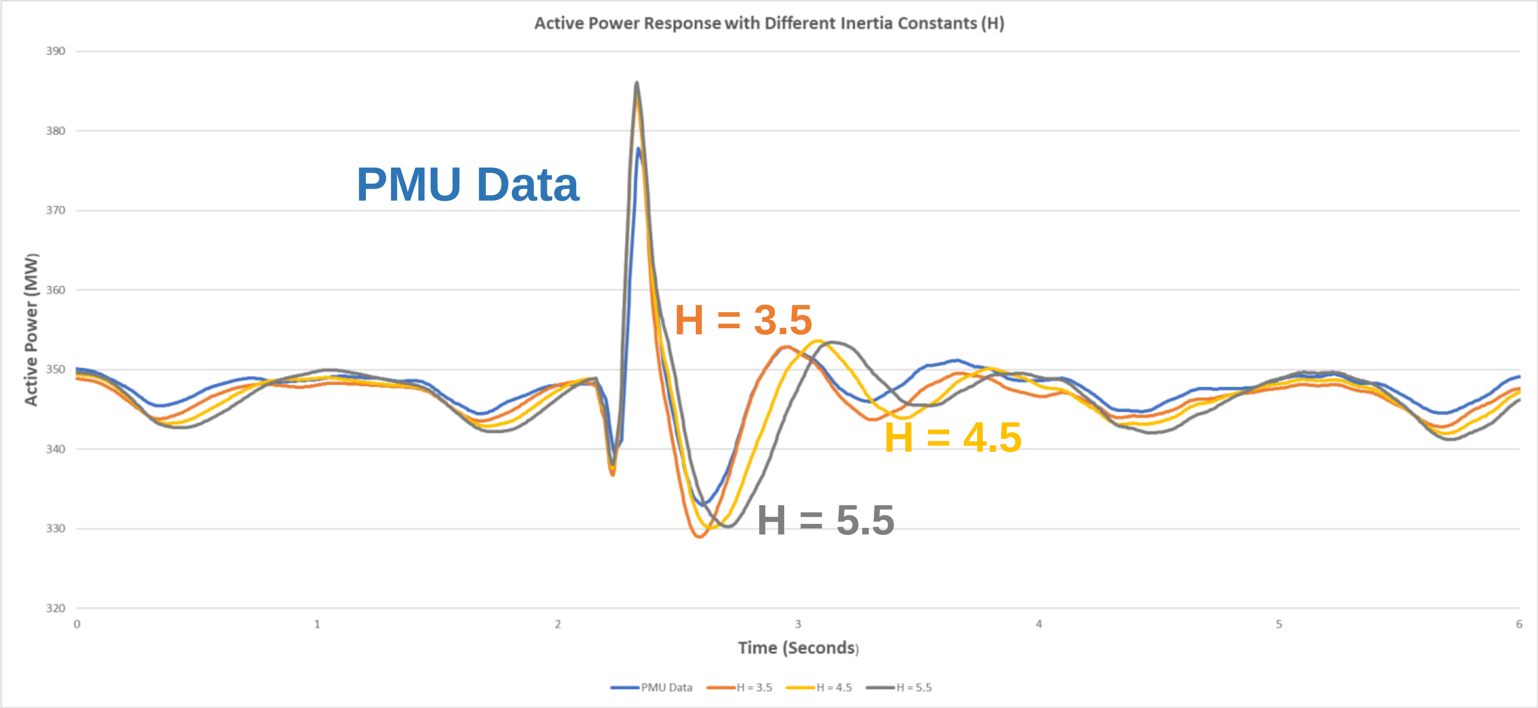
Model	Parameter	Old Value	New Value
GENROU	H	3.1	6
GENROU	X'q	0.7	0.4
GGOV1	Kpgov	6	3
GGOV1	Kturb	1.5	3
PSS2A	Ks1	15	30
PSS2A	Tw2	1	5
PSS2A	Tw1	1	5
REXS	Tf	5	1
REXS	Tc1	10	1
REXS	Kip	5	1
REXS	Tb1	1	10

Effect of Incorrect AVR gain on Reactive Power Response

Similar Signature but Offset During the Event



Effect of Incorrect Inertia(H) on Active Power Response of a Coal Fired Plant



Higher Inertia Constant – Takes More Time to Settle

Key Takeaways

- Select only the key parameters for Calibration Process
  - If all parameters are selected, Optimization algorithm tends to change parameters that do not affect the response significantly
- Use Engineering Judgment to Narrow Down on Correct Parameter Values
  - Tighten range for narrowing down on correct parameter values
  - Different Bounds for Different Parameters
- Validating Calibration Results with Multiple Events
  - Identify most sensitive parameters across all events
  - Use few events to calibrate and all events to validate

Sensitivity Analysis/Parameter Selection

Parameter	MSE-P	MSE-Q	Ranks		Min	Max
GENROU- Par 0	0.00328	0.00607	16			
GENROU- Par 1	8e-05	6e-05	38			
GENROU- Par 2	3e-05	0.00081	31			
GENROU- Par 3	0.00019	0.00074	32			
GENROU- Par 4	0.00461	0.01474	5			
GENROU- Par 5	0.0	0.0				
GENROU- Par 6	4e-05	0.00015	36			
GENROU- Par 7	0.00054	0.01912	3			
GENROU- Par 8	0.0111	0.00359	7			
GENROU- Par 9	0.001	0.00574	17			
GENROU- Par 10	0.0127	0.00996	6			
GENROU- Par 11	0.00091	0.00032	30			
GENROU- Par 12	0.0	4e-05	39			
GENROU- Par 13	0.0	1e-05				
IEEEG1- Par 0	0.05401	0.00168	2	✓		
IEEEG1- Par 1	0.0	0.0				
IEEEG1- Par 2	0.0	0.0				
IEEEG1- Par 3	1e-05	1e-05	40			
IEEEG1- Par 4	0.0	0.0				
IEEEG1- Par 5	0.0	0.0				
IEEEG1- Par 6	0.0	0.0				
IEEEG1- Par 7	0.0	0.0				
IEEEG1- Par 8	6e-05	0.00012	37			
IEEEG1- Par 9	0.00985	0.00081	9			
IEEEG1- Par 10	0.0	0.0				
IEEEG1- Par 11	0.00444	0.00015	18			
IEEEG1- Par 12	0.00268	7e-05	21			
IEEEG1- Par 13	0.0	0.0				
IEEEG1- Par 14	0.0	0.0				
IEEEG1- Par 15	0.00713	0.00018	12			
IEEEG1- Par 16	0.0	0.0				
IEEEG1- Par 17	0.0	0.0				
IEEEG1- Par 18	0.0	0.0				
IEEEG1- Par 19	0.0	0.0				
ST5B- Par 0	0.00019	9e-05	35			

Parameter	MSE-P	MSE-Q	Ranks		Min	Max
ST5B- Par 1	0.00362	0.00645	15			
ST5B- Par 2	0.00354	0.00697	14			
ST5B- Par 3	0.00249	0.00144	23			
ST5B- Par 4	0.00249	0.00141	22			
ST5B- Par 5	0.00365	0.00712	13			
ST5B- Par 6	0.0	0.0				
ST5B- Par 7	0.0	0.0				
ST5B- Par 8	0.0	0.0				
ST5B- Par 9	0.0	0.0				
ST5B- Par 10	0.0	0.0				
ST5B- Par 11	0.0	0.0				
ST5B- Par 12	0.0	0.0				
ST5B- Par 13	0.0	0.0				
ST5B- Par 14	0.0	0.0				
ST5B- Par 15	0.0	0.0				
ST5B- Par 16	0.0	0.0				
ST5B- Par 17	0.0	0.0				
PSS2B- Par 0	0.0	0.00142	27			
PSS2B- Par 1	0.0	0.00142	26			
PSS2B- Par 2	0.0	0.0				
PSS2B- Par 3	1e-05	0.00047	34			
PSS2B- Par 4	0.0	0.0				
PSS2B- Par 5	0.0043	0.00982	10			
PSS2B- Par 6	0.00433	0.01089	8			
PSS2B- Par 7	0.00098	2.37367	1	✓		
PSS2B- Par 8	5e-05	0.00061	33			
PSS2B- Par 9	0.00036	0.00421	19			
PSS2B- Par 10	0.00343	0.01745	4			
PSS2B- Par 11	0.00219	0.00206	25			
PSS2B- Par 12	0.00098	0.00046	28			
PSS2B- Par 13	0.00219	0.00206	24			
PSS2B- Par 14	0.00098	0.00046	29			
PSS2B- Par 15	0.00337	0.00858	11			
PSS2B- Par 16	0.00281	0.00412	20			
PSS2B- Par 17	0.0	0.0				

Parameter	MSE-P	MSE-Q	Ranks		Min	Max
PSS2B- Par 18	0.0	0.0				
PSS2B- Par 19	0.0	0.0				
PSS2B- Par 20	0.0	0.0				
PSS2B- Par 21	0.0	0.0				
PSS2B- Par 22	0.0	0.0				

Set Bounds for Individual Parameters

Red – Top 5 Most Sensitive Parameters
Yellow – Next 5 Most Sensitive
White – Remaining Parameters - 11 onwards
Green – Least Sensitive

Generator Model Validation Report

Model Data

The power flow case file includes the power flow data for the generator and the transformer as shown in ***Figure 4***.

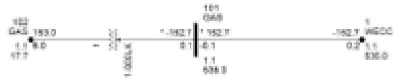


Figure 4. Input data -Power flow case file (.raw)

1. Dynamic File (.dyr)

GAS TURBINE PLANT MODEL

GENROU		REXS		GGOV1		PSS2A	
Param	Value	Param	Value	Param	Value	Param	Value
Xd	1.85	Tr	0.02	R	0.05	J1	1
X'd	0.21	Kvp	600	Rselect	1	K1	0
X''d	0.15	Kvi	0	Tpelec	0.6	J2	3
Xq	1.3	Vimax	0.2	Maxerr	0.025	K2	0
X'q	0.7	Ta	0.02	Minerr	-0.025	Tw1	1
X''q	0.15	Tb1	1	Kpgov	6	Tw2	1
Xl	0.15	Tc1	10	Kigov	0.22	Tw3	5
Ra	0.003	Tb2	1	Kdgov	0	Tw4	0
T'd0	5	Tc2	1	Tdgov	1	T6	0
T''d0	0.25	Vrmax	10	Vmax	1	T7	5
T'q0	1	Vrmin	-10	Vmin	0.24	Ks2	0.5
T''q0	0.05	Kf	0.045	Tact	0.6	Ks3	1
S(1.0)	0.12	Tf	5	Kturb	1.5	Ks4	1
S(1.2)	0.48	Tf1	1	Wfnl	0.25	T8	0.5
H	3.1	Tf2	1	Tb	1	T9	0.1
D	0	Fbf	1	Tc	1	N	1
Rcomp	0	Kip	5	Flag	1	M	5
Xcomp	0	Kii	0	Teng	0	Ks1	15
Accel	0.5	Tp	0	Tfload	0.3	T1	0.28
Kis	0	Vfmax	99	Kpload	1	T2	0.043
Pfd	0	Vfmin	-99	Kiload	3.3	T3	0.281
Pkd	0	Kh	0	Ldref	1	T4	1.16
Pfq	0	Ke	0.4	Dm	0	Vstmax	0.1
Pkq	0	Te	1.2	Ropen	99	Vstmin	-0.1
Speed	0	Kc	0	Rclose	-99	A	1
Angle	0	Kd	0.7	Kimw	0	Ta	0
		E1	2.4	Pmwset	0	Tb	0.043
		Se1	0.05	Aset	99		
		E2	3.2	Ka	10		
		Se2	0.3	Ta	1		
		Rcomp	0	Db	0		
		Xcomp	0	Tsa	1		
		Nvphz	0	Tsb	1		
		Kvphz	0	Rup	99		
		Flimf	0	Rdown	-99		

Figure 5. Dynamic Model Parameters for Generator & Exciter Models

Model Data – Current Model Parameters

Validation

Validation process compares the simulated response of the generator to the PMU measured response. Voltage magnitude and angle measurements from the PMU are used for playing back into the simulation and real and reactive power (P & Q) outputs of the simulation are compared to the PMU measurements. ***Figure 6*** shows the comparison plots for the active and reactive power output from the generator. The blue line is the PMU measured response and the red line is the simulated generator response.

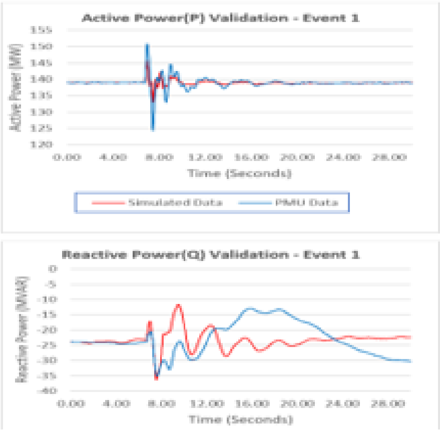


Figure 6. Validation Process - Comparing Real and Reactive Power of the Generator

The validation plots show a significant mismatch between the simulated and measured response for both the active and reactive power plots. For the active power plot, there is a phase mismatch during the ring-down of the transient oscillation. For the reactive power, there is a mismatch in the phase and the amplitude of the response of the generator. Calibration is required for correcting the model parameters in order to reduce the mismatch between the simulation and the actual measurements.

Validation Results

Calibration Results

Figure 9. Calibration Results - Active and Reactive Power Output with New Identified Parameters

Model	Parameter	Old Value	New Value
GENROU	H	3.1	6
GENROU	X'q	0.7	0.4
GGOV1	Kpgov	6	3
GGOV1	Kturb	1.5	3
PSS2A	Ks1	15	30
PSS2A	Tw2	1	5
PSS2A	Tw1	1	5
REXS	Tf	5	1
REXS	Tc1	10	1
REXS	Kip	5	1
REXS	Tb1	1	10

Figure 10. Calibration Results - Recommended Parameter Values

Calibration Results & New Model Parameters

Q&A, Discussion

Your Practice, Use Cases, Suggestions

Q&A, Discussion

- **Q&A**
- **Generator Model Validation**
  - Your Practices
  - Use Cases
  - Pain Points
  - Suggestions
- **Next Webinar Focus**
  - Priority
  - Other topics

EPG Webinar Series

- Extracting large amounts of synchrophasor data efficiently for offline analysis. (August 2016)
- Quickly creating an event report that could be distributed to operators, engineers and managers. (Sept. 2016)
- System Model Validation for MOD-33 Requirement (Oct. 12)
- Configuring alarms and validate parameters to provide meaningful results for operators. (Dec 14)
- Synchrophasor Intelligence in EMS for Use in Operations (Jan 2017)
- Use Cases of Linear State Estimator Technology for Grid Resiliency (Feb 2017)
- Delivering Reliable and Validated PMU Data for Use by Operators (April 2017)
- Generator Model Validation using PMU data for MOD-26, MOD-27 Requirements (June 2017)
- Remote/Mobile access with local host for real-time monitoring and event diagnostics during emergencies
- Data Mining for grid events of different types, e.g. oscillations, generator trips etc.
- Using composite alarms as early warning for operator action
- Addressing data issues, such as PMU timing, phase correction, etc.
- ePDC/DataNXT/RTDMS pub/sub Synchrophasor Distribution Service
- Other topics?

Summary

- Synchrophasor data from PMUs provides a cost effective and efficient way to validate generator model parameters & satisfy NERC MOD-026, MOD-027 requirements
- EPG's GPV tool & methodology
  - Inputs Required – PMU measured event data and Model data
  - Simple Validation Process
  - Automated Identification of Key Parameters through sensitivity analysis
  - Allows User Input and Engineering Judgement for Calibration
  - Results are combined into a report for documenting model validation and calibration results

Thank you for participating!

If you have any questions regarding any part of the webinar, please contact us at Contact@electricpowergroup.com

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Electric Power Group

201 S. Lake Ave., Ste. 400
Pasadena, CA 91101
626-685-2015