PJM Use Case of Synchrophasors – Automated Generator Model Validation (AGMV)

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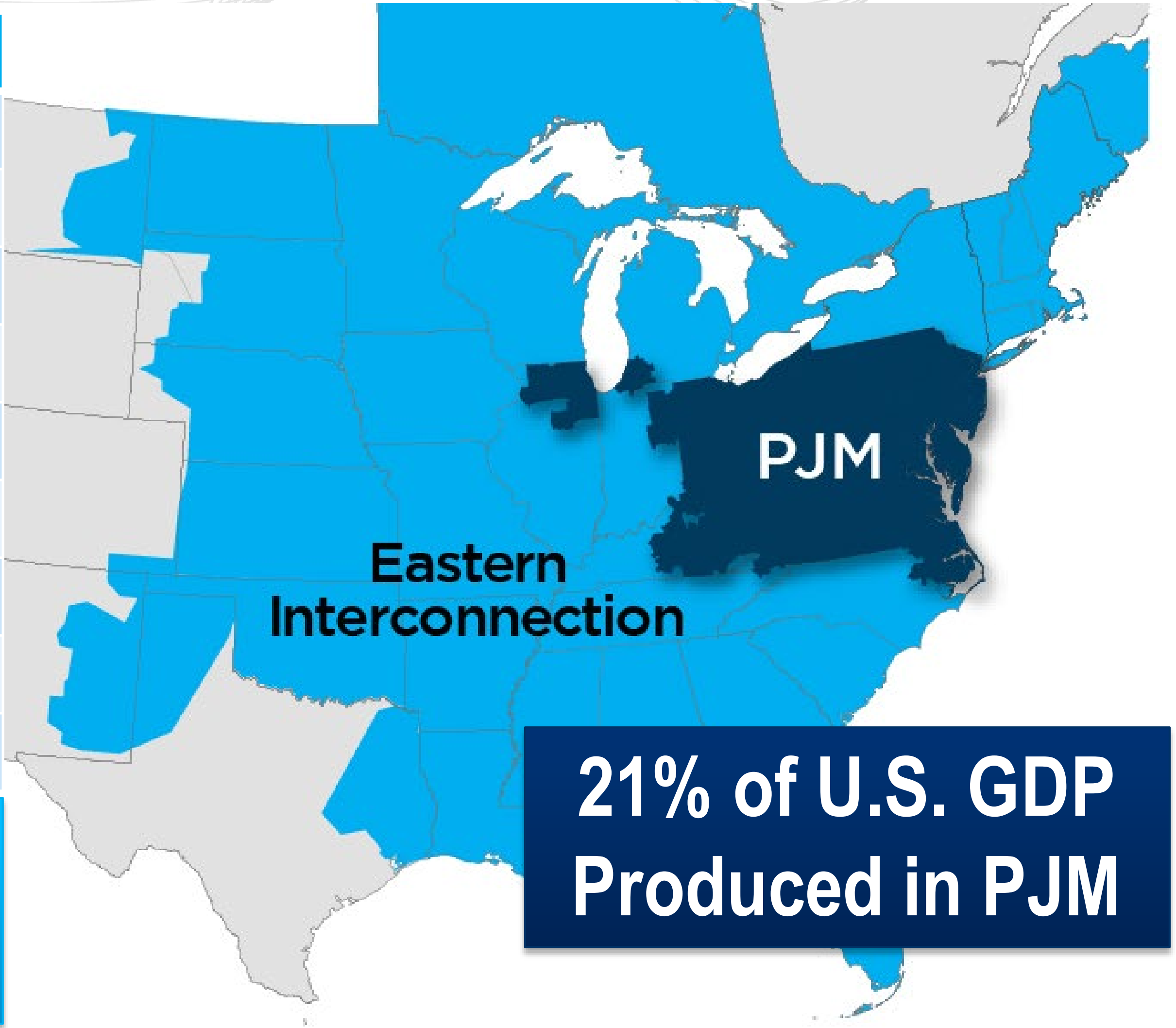
Agenda

- Introduction
- Motivation
- EPG's Tool – GMV
- PJM Deployment – AGMV
- Conclusion

PJM as Part of the Eastern Interconnection

Key Statistics	
Member companies	1,110+
Millions of people served	65+
Peak load in megawatts	165,563
Megawatts of generating capacity	183,254
Miles of transmission lines	88,115
Gigawatt hours of annual energy	795
Generation sources	1,419
Square miles of territory	368,906
States served	13 + DC

- 26% of generation in Eastern Interconnection
- 25% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection



21% of U.S. GDP Produced in PJM

As of 2/2023

PJM Phasor Measurement Unit Statistics

1,000

Total PMUs
including external companies

245

Substations with PMUs installed

~42 GB

of PMU data storage daily

(real time – 4 TB for 90 days)

----- ***Calculated Values*** -----

Real time: 7 TB for 90 days

3-Year Archive: 80 TB

750

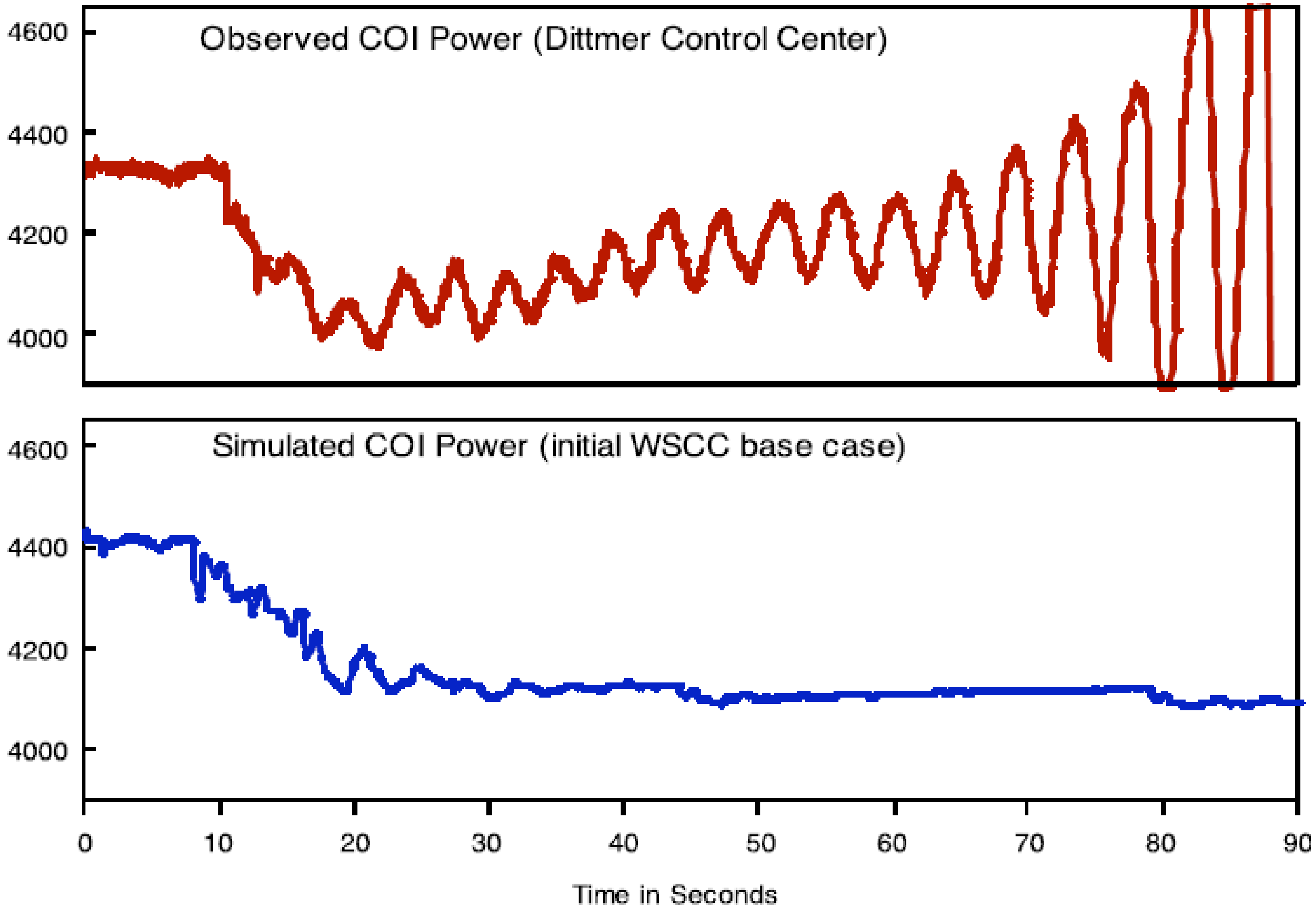
PMUs installed within PJM

30x

per second sampling rate

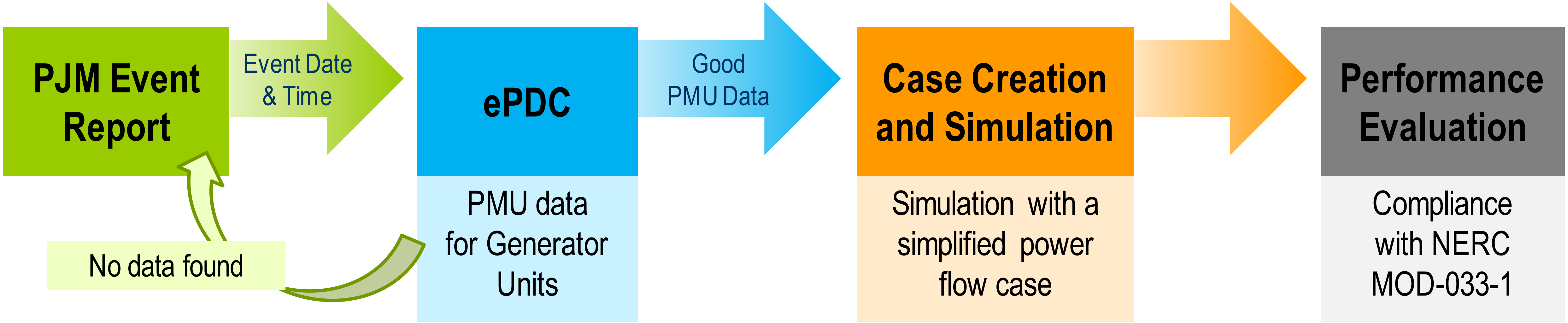
Need for Model Validation

- Dynamic models are used to represent transient behavior during grid disturbances.
- Inaccurate models can lead to incorrect assessment of system responses



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

Prior to AGMV: PJM Manual Process for GMV

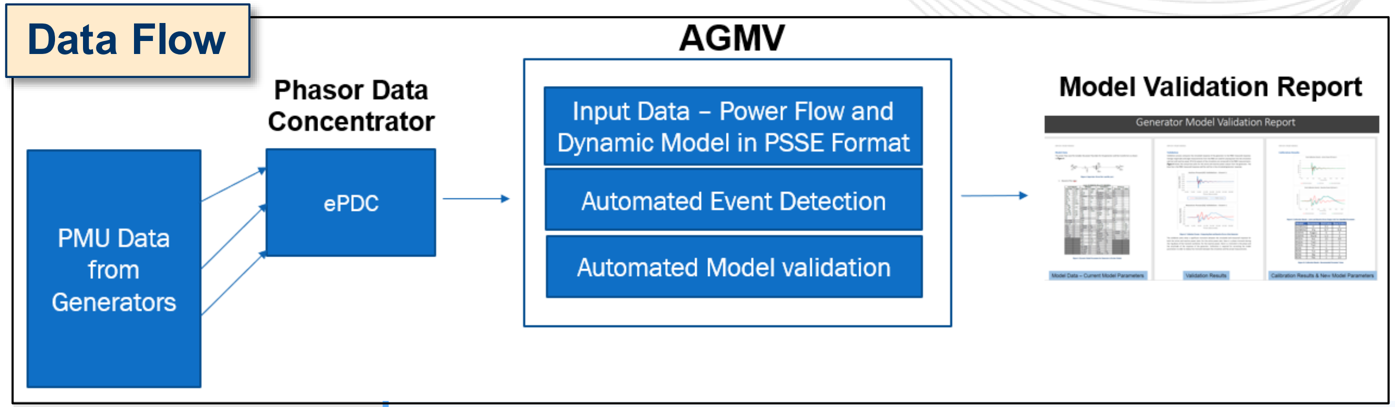


W. Qiu, T. He, B. Choi and Y. Mao, "PJM Static and Dynamic Model Validation Efforts and Experiences for MOD-033," IEEE PES General Meeting, 2017.

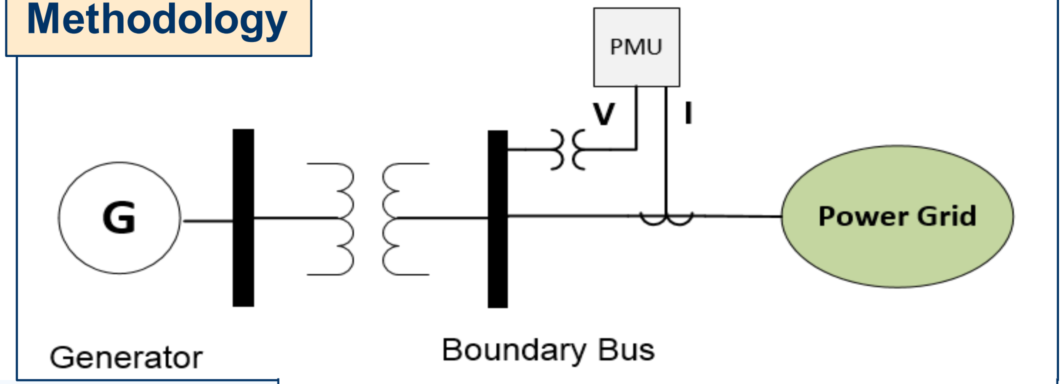
EPG's Generator Model Validation (GMV)

Use of PMU Data for Automated Validation of Generator Models

Data Flow



Methodology



- PMU records voltage and current phasors
- Playback voltage and angle
- Compare real and reactive power

Inputs	PMU C37.118 stream measuring data from generating units Model – power flow & dynamic data
PMU Location	High side or low side of generator step-up transformer
Methodology	Automatically detect significant events, perform validation – compare simulated response to PMU measurements
GMV Operation	Automated validation for events, report generation & emailing capability
Types of Models	Generator, governor, exciter, stabilizer for conventional power plants, IBRs (next release)
Deployment	Simple process, software deployed on a single server
Scalable	Single deployment can handle multiple generators

Automated Process Using GMV

Automated Generator Model Validation (AGMV) – Real-Time

- Run continuously as a service, automatically triggered after significant events
- Validate multiple events and multiple generators simultaneously
- Quantify mismatch and identify good vs. questionable (programmatic not visual)[1]
- Automated email report generation for NERC compliance

Offline Generator Model Validation and Calibration

- Perform detailed analysis offline
- Sensitivity analysis to identify key parameters
- Calibration and tuning to correct the generator model
- Generate automated report for NERC compliance

[1] W. Ju, N. Nayak et al., "Indices for Automated Identification of Questionable Generator Models Using Synchrophasors," *2020 IEEE Power & Energy Society General Meeting (PESGM)*, Montreal, QC, Canada, 2020, pp. 1–5

Example Report

Generator Validation for Event 1

Event Information

Event File Name: Load Trip Event 08-21-2023 02-45-11.412 PM.csv

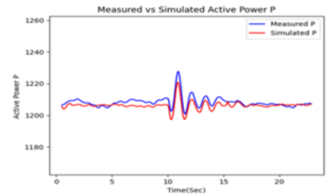
Table I: Summary of Validation Results

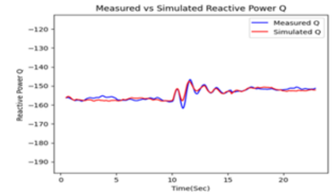
Variable	Value
Number of generator models validated	1
Number of good generator models	1
Number of questionable generator models	0

Table II: Summary of Validation Results for Individual Generators

Generator ID	Validity
GENERATOR 1	Good

Validation plots for Generator1





Validation Criteria for Generator1

Variable	P	Q	Criteria
RMSD	0.002375	0.006282	<0.2
Comprehensive Similarity	0.794	0.861	>0.5

AGMV Deployment in PJM – Data Flow

FR, VM, VA, IM, IA

Unsupervised Automation

Phasor Data Concentrator (PDC)

Phasor Data Concentration

Real-Time Dynamics Monitoring System (RTDMS)

- Real-Time Situational Awareness
- Data Storage

Enhanced Grid Event Notifications System (eGENS)

- Detect Events (Line | Gen | Load Tripping)
- Report and Email

Automated Generator Model Validation (AGMV)

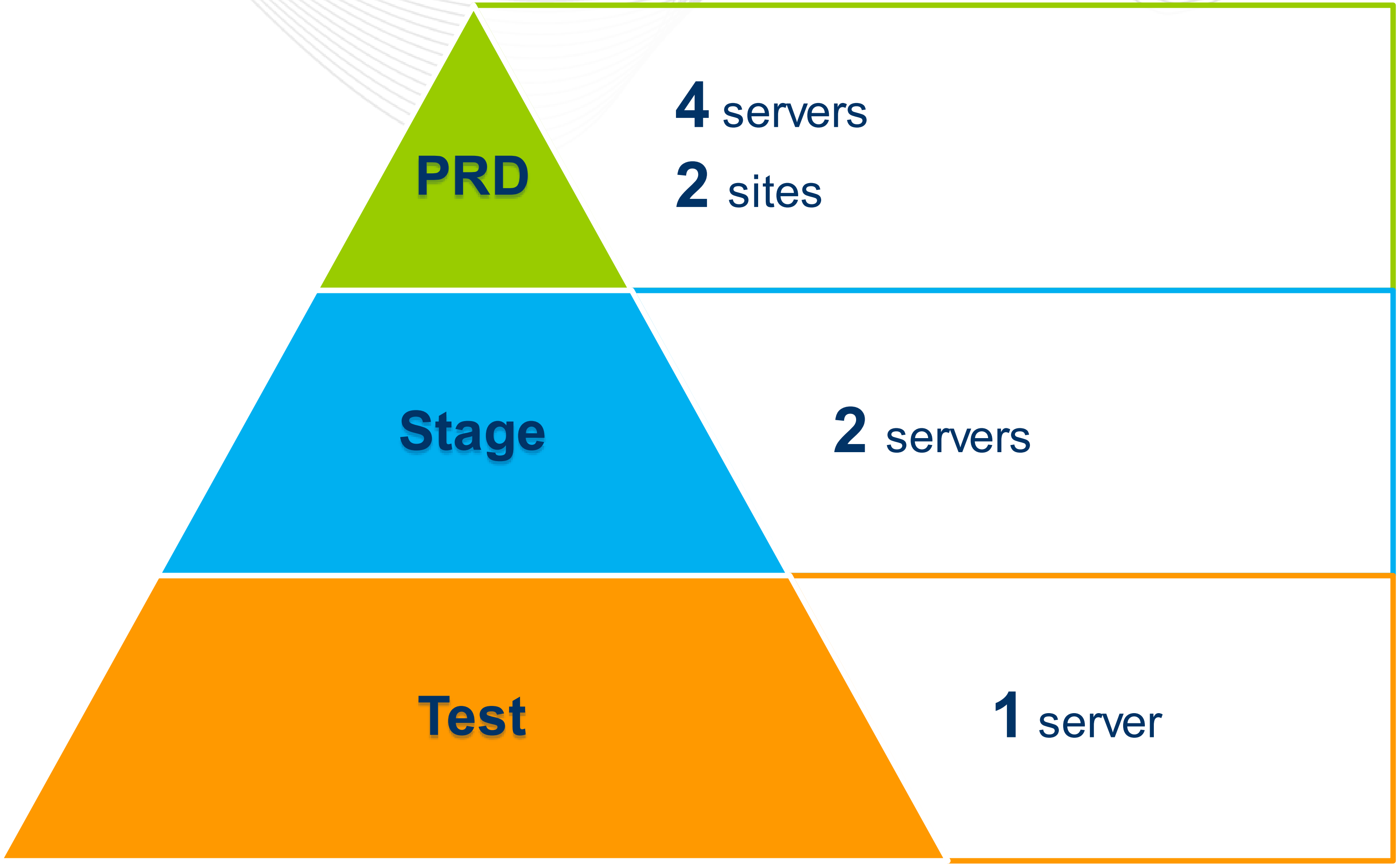
- Generator Model Validation
- Report and Email

Power Flow Data
Dynamic Model Data

Comparison: Then & Now

COMPARISONS	THEN		NOW
	Months	**Weeks**	**Minutes**
	Manual (No PMUs)	**Manual (PMUs Without Automation)**	**AGMV**
	Establish system conditions	Identify events	Unsupervised automation
		Manually draft NERC MOD-033 report	Automated report for NERC MOD-033
	Once every two years for NERC compliance		Automated for each system event

AGMV Deployment in PJM – Architecture



PRD:
Production

Example	Generator	Event
1	Unit 1	A – Line Tripping
2	Unit 1	B – Line Tripping
3	Unit 2	C – Line Tripping
4	Unit 2	D – Load Tripping

Example 1: Unit 1 With Line Tripping Event A

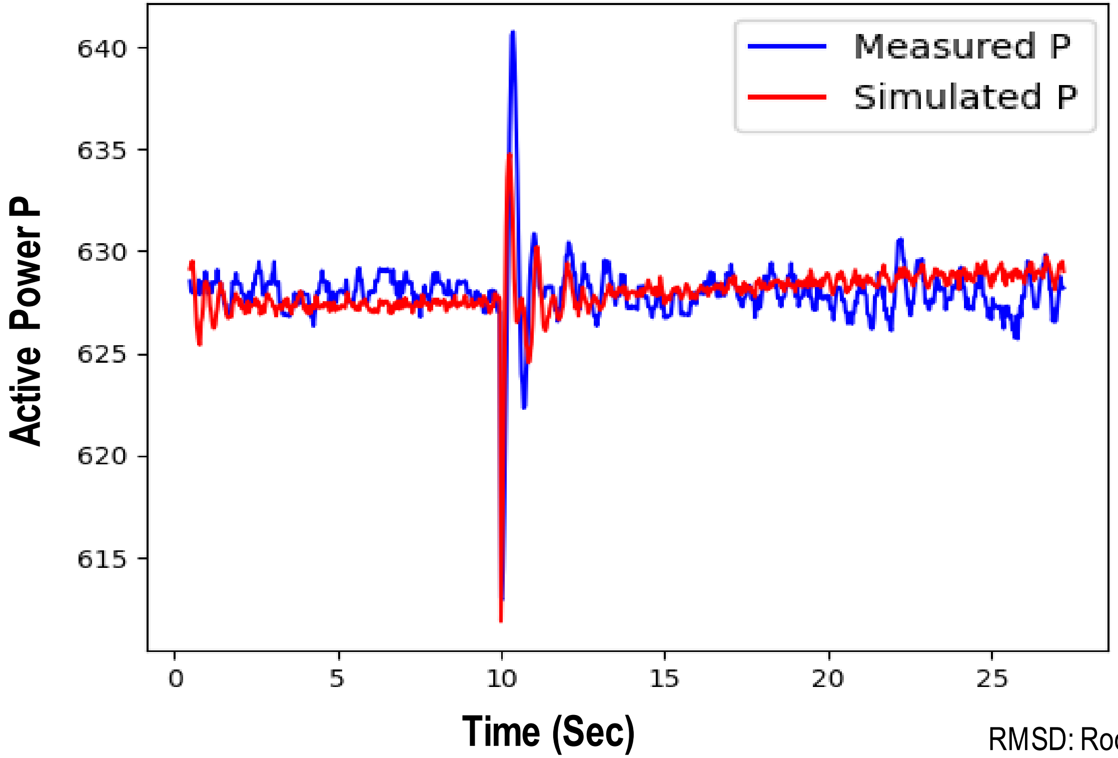
Summary of Validation Results

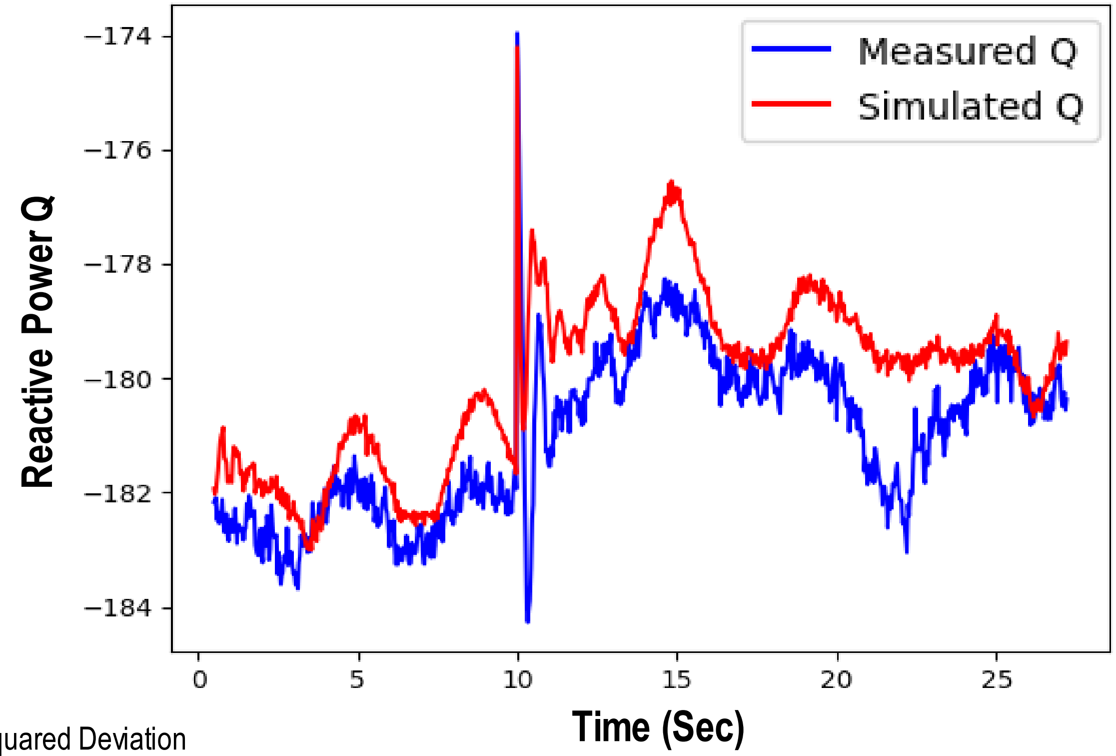
Generator ID	Validity
Unit 1	Questionable

Validation Criteria

Variable	P	Q	Criteria
RMSD	0.002398	0.00738	<0.09
Comprehensive Similarity	0.596	0.671	>0.85

Measured VS. Simulated:





RMSD: Root Mean Squared Deviation

Example 2: Unit 1 With Line Tripping Event B

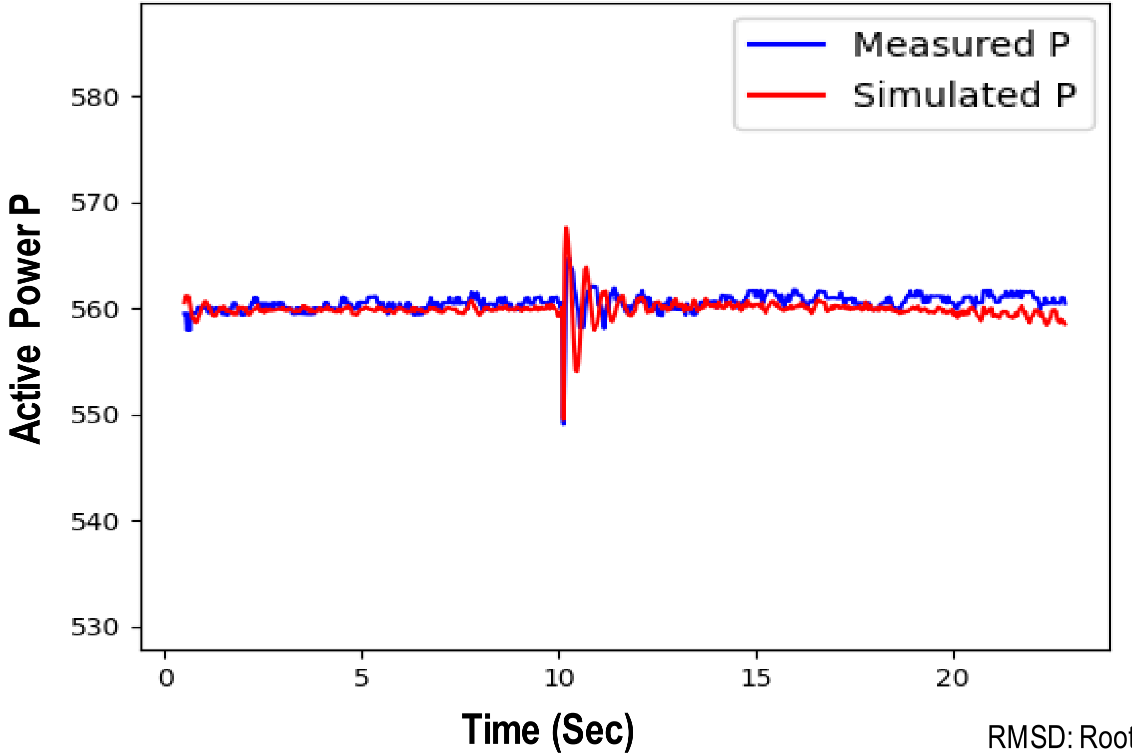
Summary of Validation Results

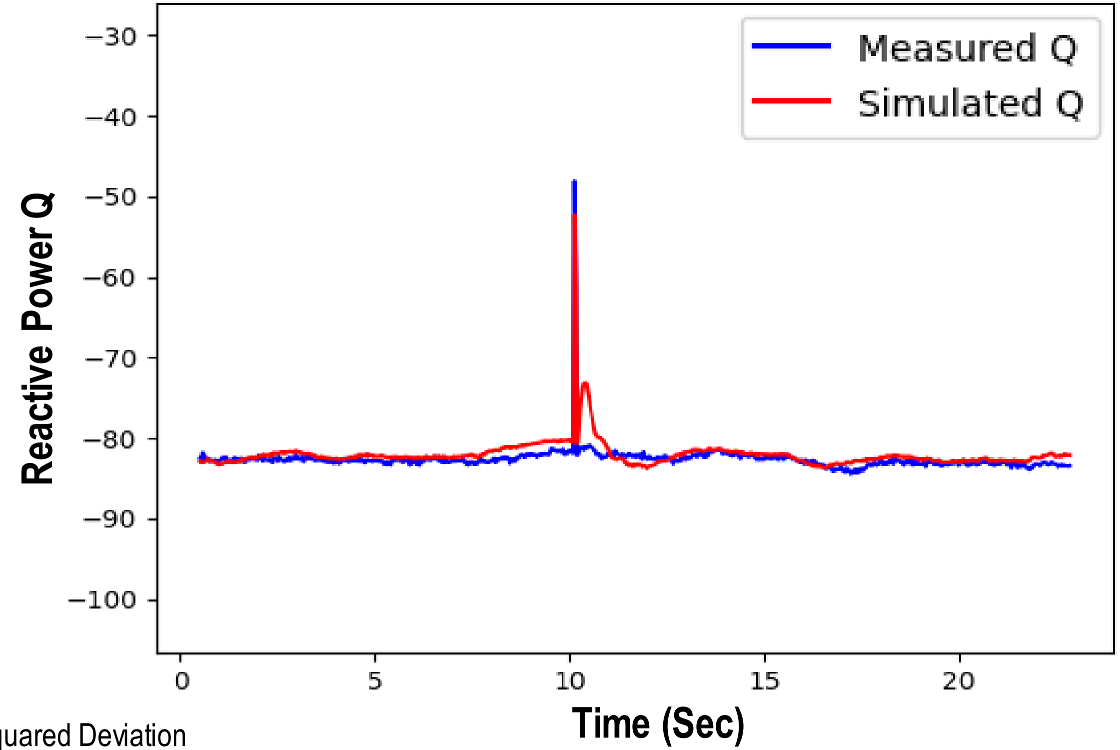
Generator ID	Validity
Unit 1	Good

Validation Criteria

Variable	P	Q	Criteria
RMSD	0.002322	0.01503	<0.1
Comprehensive Similarity	0.47	0.761	>0.4

Measured VS. Simulated:





RMSD: Root Mean Squared Deviation

Example 3: Unit 2 With Line Tripping Event C

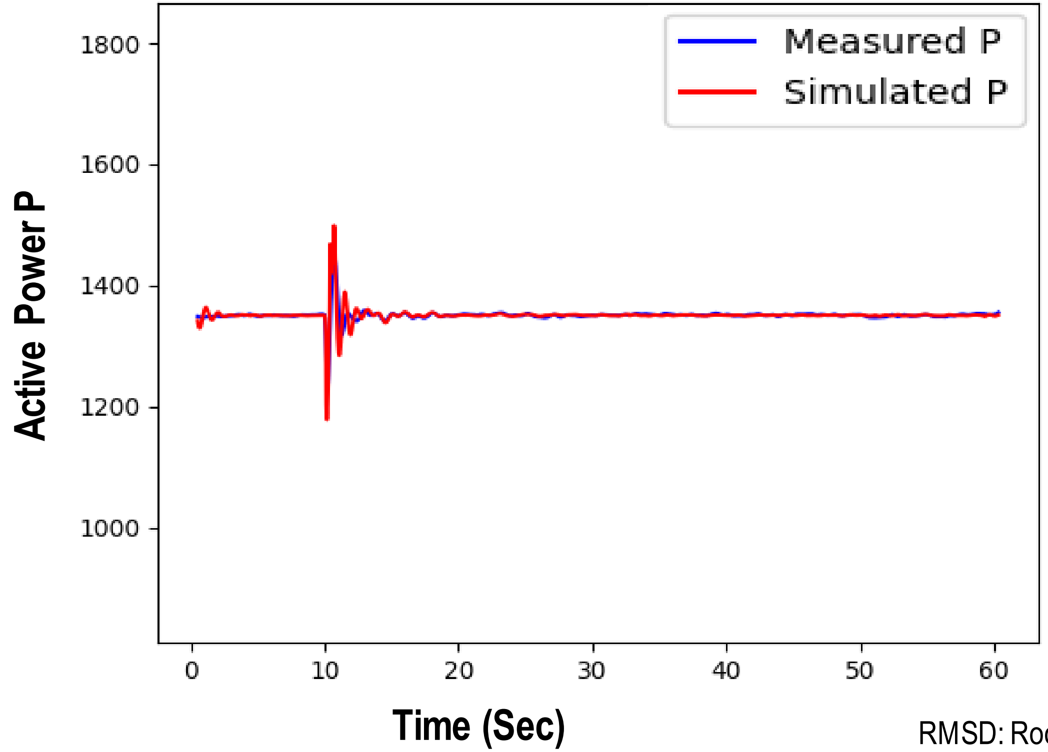
Summary of Validation Results

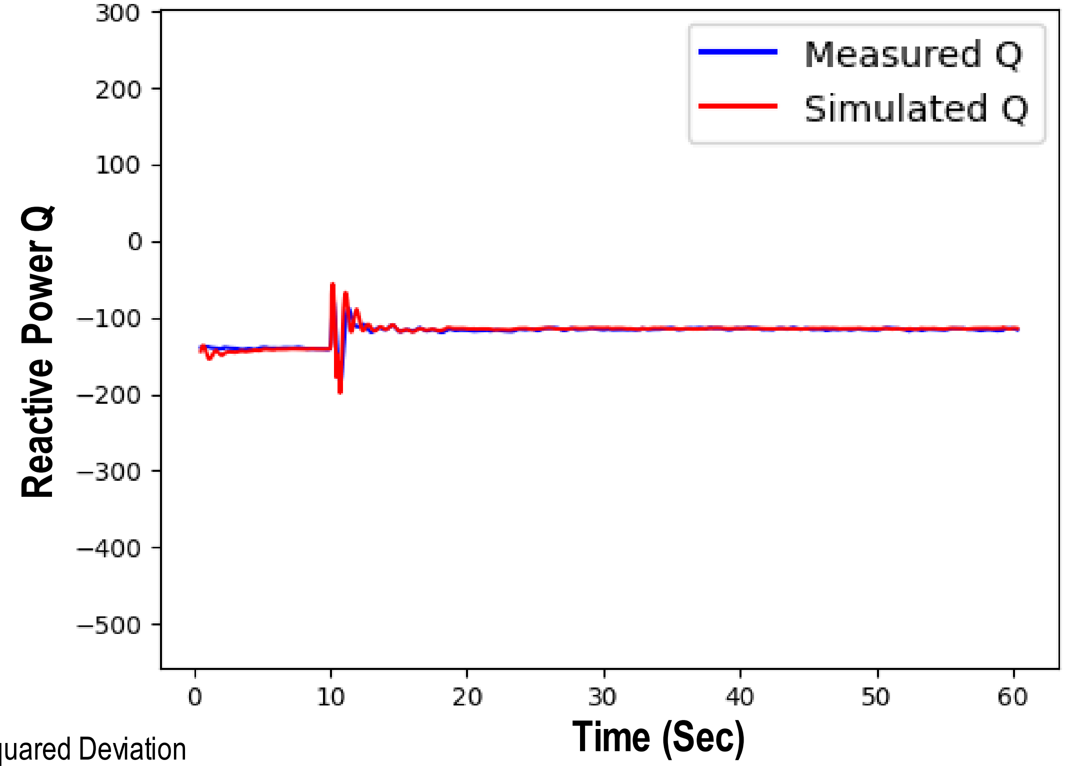
Generator ID	Validity
Unit 2	Good

Validation Criteria

Variable	P	Q	Criteria
RMSD	0.006398	0.035034	<0.2
Comprehensive Similarity	0.775	0.819	>0.5

Measured VS. Simulated:





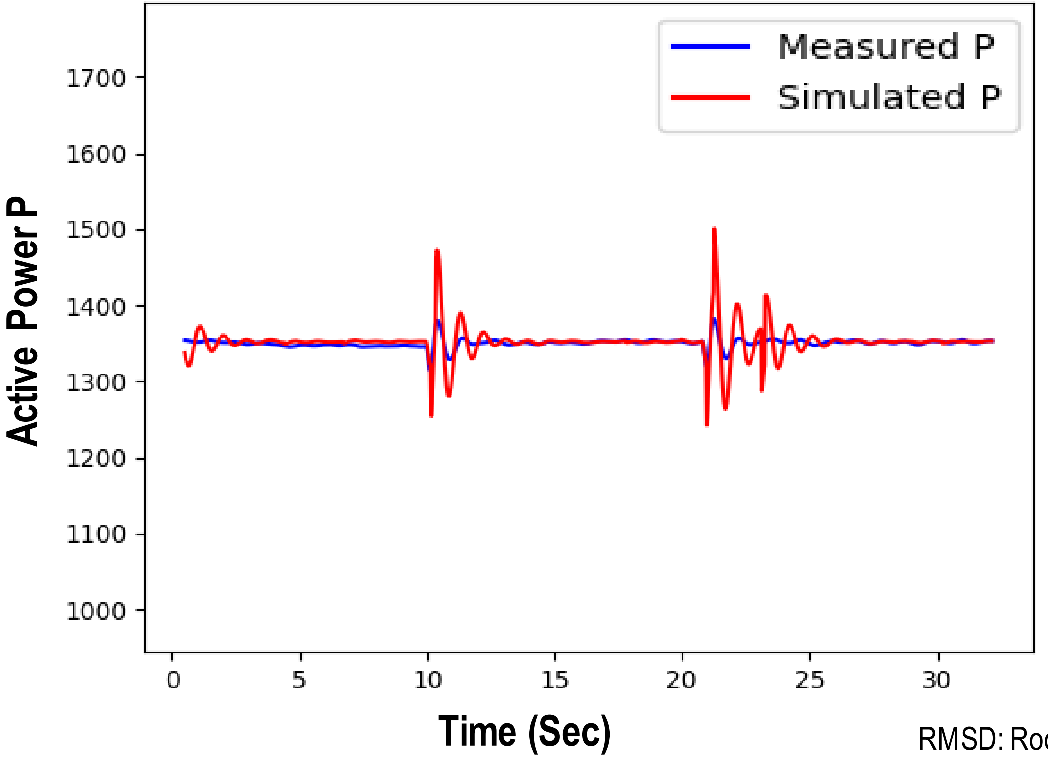
RMSD: Root Mean Squared Deviation

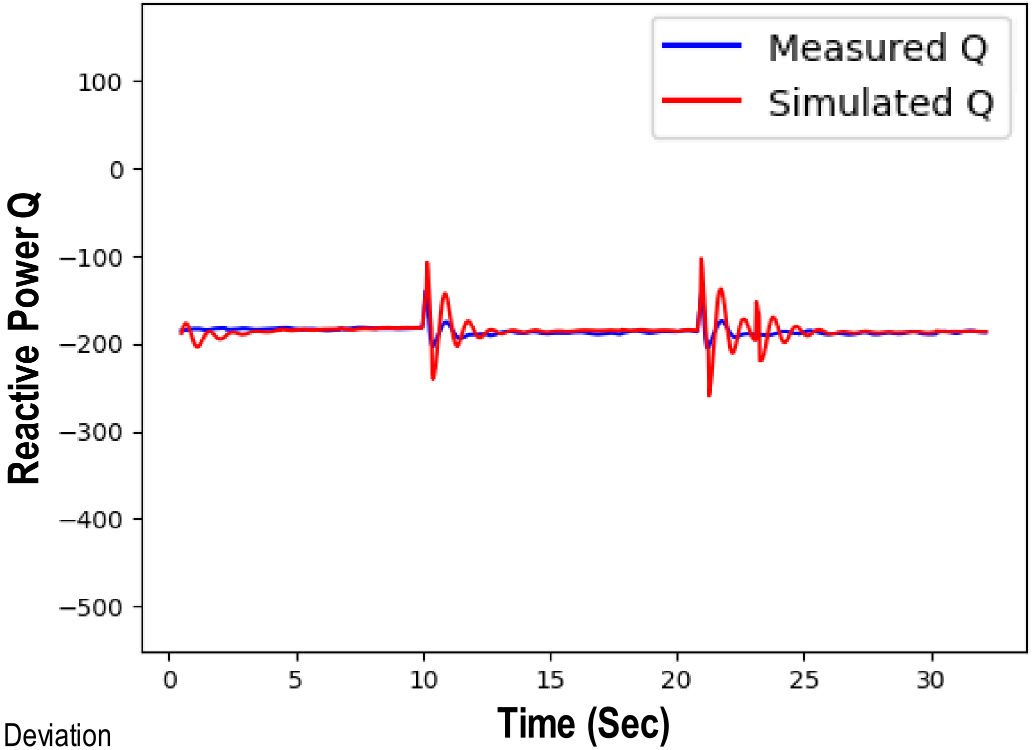
Example 4: Unit 2 With Load Tripping Event D

Summary of Validation Results	
Generator ID	Validity
Unit 2	Good

Validation Criteria			
Variable	P	Q	Criteria
RMSD	0.012649	0.049485	<0.2
Comprehensive Similarity	0.633	0.682	>0.5

Measured VS. Simulated:





RMSD: Root Mean Squared Deviation

AGMV Results Summary

	Generator	Event	Validation Result	Criteria: RMSD	Criteria: Comprehensive Similarity
1	Unit 1	A – Line Tripping	**Questionable**	< 0.09	> 0.85
2	Unit 1	B – Line Tripping	**Good**	< 0.1	> 0.4
3	Unit 2	C – Line Tripping	**Good**	< 0.2	> 0.5
4	Unit 2	D – Load Tripping	**Good**	< 0.2	> 0.5

BENEFITS TO PJM

- Greatly Reduce Workload
- Unsupervised Automation
- No Engineering Judgement Needed for Criteria Setting
- One Event to Validate Multi-Gens
- Re-run Capability

Statistical Analysis for Better Criteria Threshold Setup

Use reports from all previous events.

Model Validation for IBRs

Playback alone with PMU data may not be enough.

Other model parameters (like voltage control reference) might also be needed.