Electric Power Group

Generator
Model Validation

Automated validation of generator models using synchrophasor technology and advanced analytics

Generator
Model Validation

Introduction - Industry Need

Inaccurate models can result in incorrect assessment of system response and may result in failure to predict instability and blackouts. For. e.g. during August 1996 blackout – models did not represent reality. The measured response of Power flow on California Oregon Intertie (COI) was undamped and showed large oscillations whereas the model showed well damped response. Generators are one of the most critical components in determining power system response to events and disturbances.

NERC standards for model validation - MOD-026, MOD-027 require verification of generator dynamic models including excitation controls, governor and turbine controls. Traditional staged tests for Generator Model Validation require units to be taken out of service and is expensive and Time consuming. Testing is typically carried out when unit is offline in isolation and does not incorporate the system response and dynamics.

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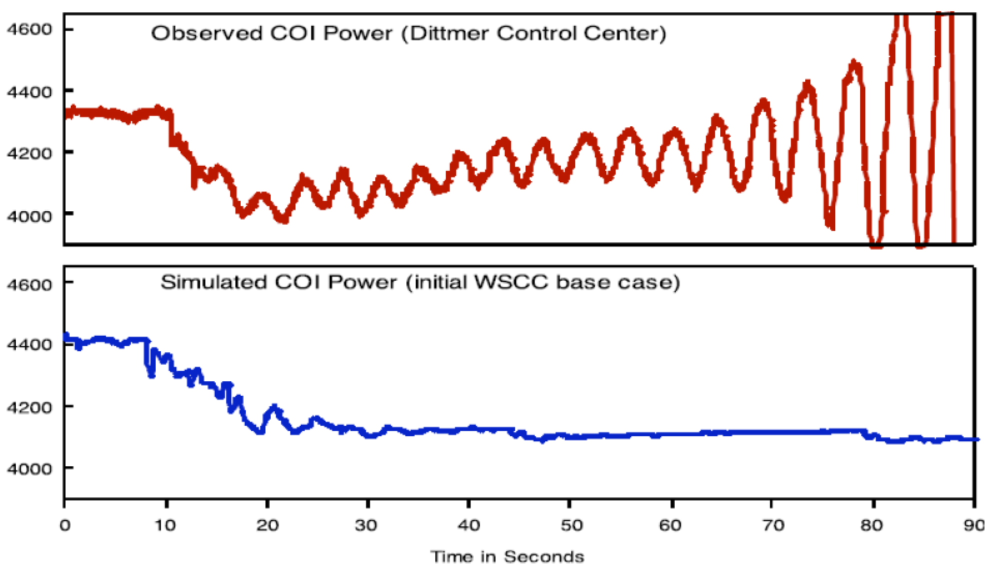


August 1996 Simulated vs. Actual System Response

Using Synchrophasors for generator model validation

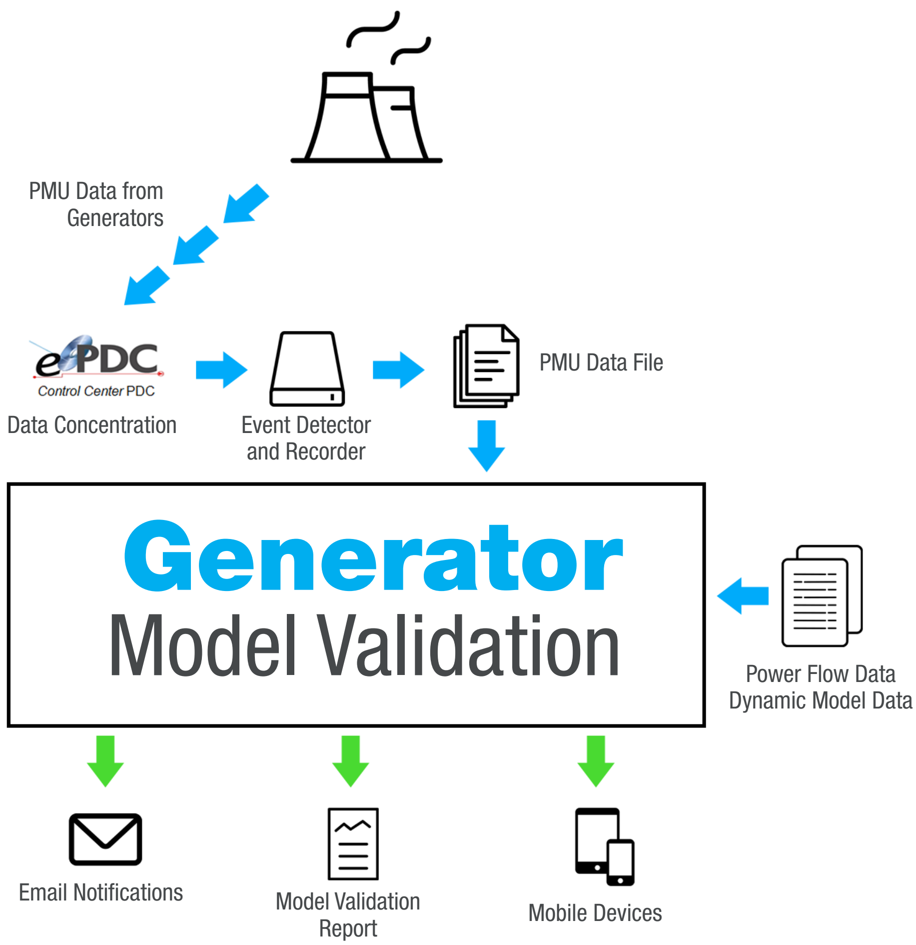
Synchrophasor data from PMUs or DFRs enable online generator model validation and provide the following benefits:

- Units do not have to be taken offline
- Reduces costs of outage and cost of experts to perform tests for validating generator models
- Generator performance is verified while accounting for system dynamics as opposed to isolated offline testing
- PMU measurement
- Can be repeated frequently for every significant event instead of performing validation every 5 to 10 years
- Can be performed for multiple events and multiple generators
- Ability to perform model calibration and identify correct model parameters
- Meet NERC MOD-26, MOD-27, MOD-33 Compliance

Overview

GMV (Generator Model Validation) uses synchrophasor data from PMUs or DFRs to validate and calibrate generator, excitation system and turbine control system models. Data from PMUs is concentrated and time-aligned by EPG's enhanced Phasor Data Concentrator (ePDC®). ePDC combines data from several generators and provides output to an event recorder. The event recorder detects an event based on defined thresholds such that events with significant frequency and/or voltage deviations are captured. Whenever a significant event is detected, PMU data is recorded for that event in COMTRADE or csv files. PMU data along with the power flow and dynamic data for the generator is then used to validate the model and generate a report that compares simulated data with PMU data.

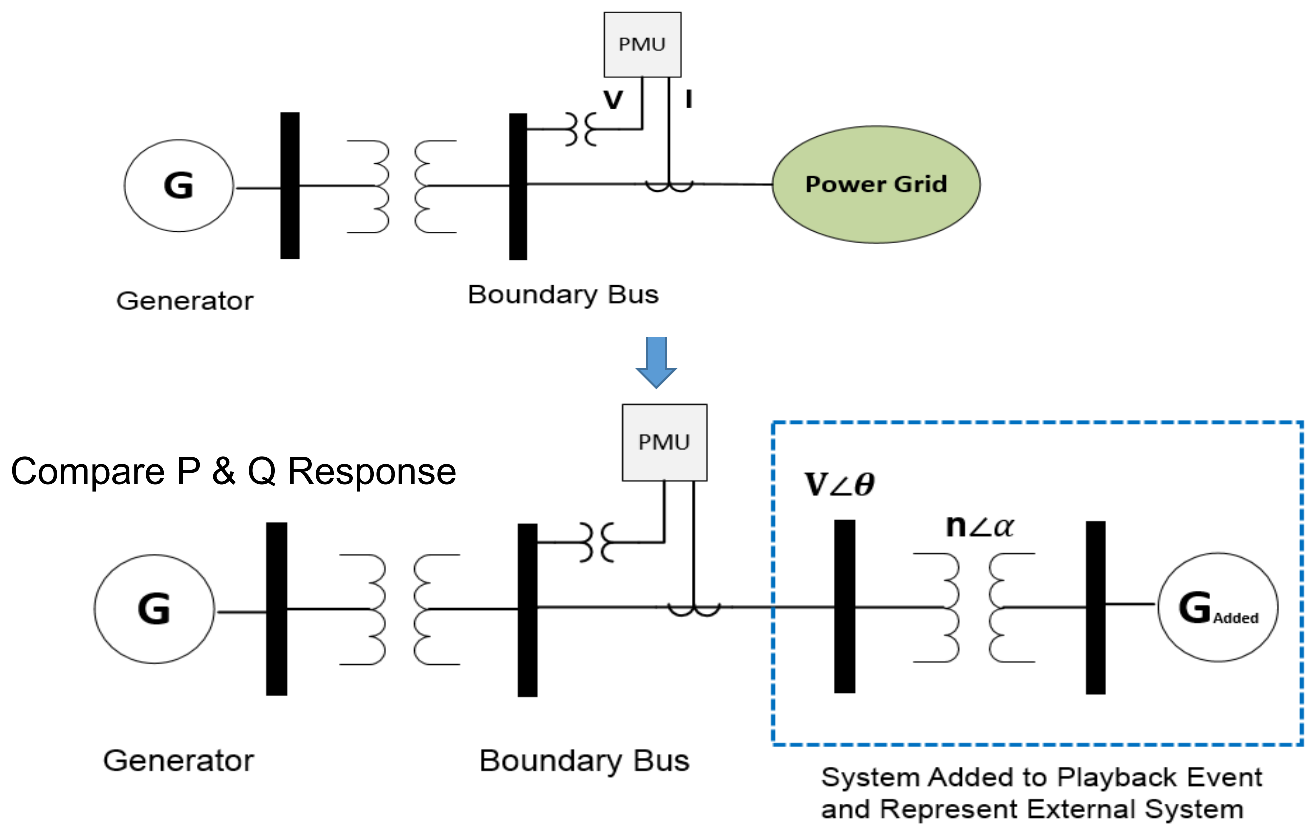
GMV provides an automated report that identifies whether the model accurately represents the response of the generator and control system to different events and disturbances. Furthermore, sensitivity analysis can be performed to identify key parameters that should be considered for tuning when the model response does not match the actual response. The sensitivity analysis results quantify the change in the generator response for change in each parameter. This helps in identifying parameters in the model that have the most impact on the generator response and narrows down from several parameters to a few for fine tuning and calibration. For each event, multiple generating units can be validated if PMU data is available from the individual generating units. This application can be installed locally at the generating station or in a central location such as control center which can collect data from multiple generators at different locations.



Methodology

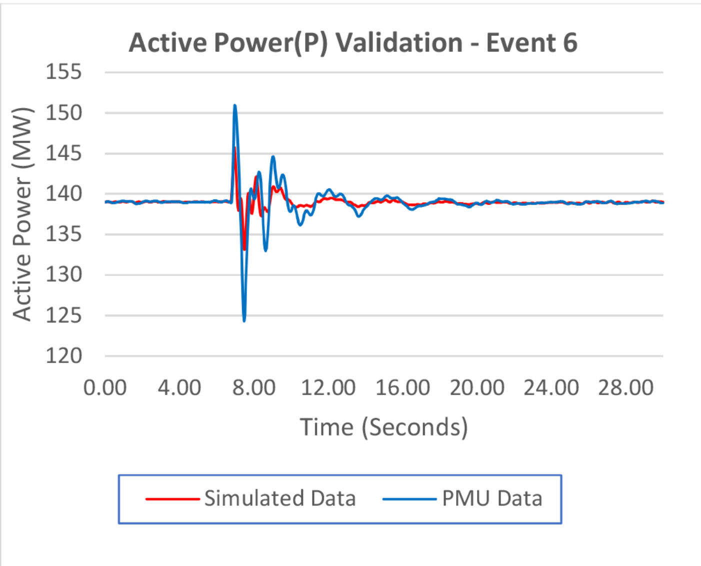
The generator model is initialized such that the generator initial conditions in the model match the actual generator conditions at the start of the event. This includes adjusting the active power and reactive power output from the generator. A hybrid dynamic simulation approach is used where PMU measurements are fed into the model to playback the event and obtain the model response. The external system beyond the boundary bus is replaced by an equivalent system added to represent the external system and replay the terminal conditions of the generator during the event.

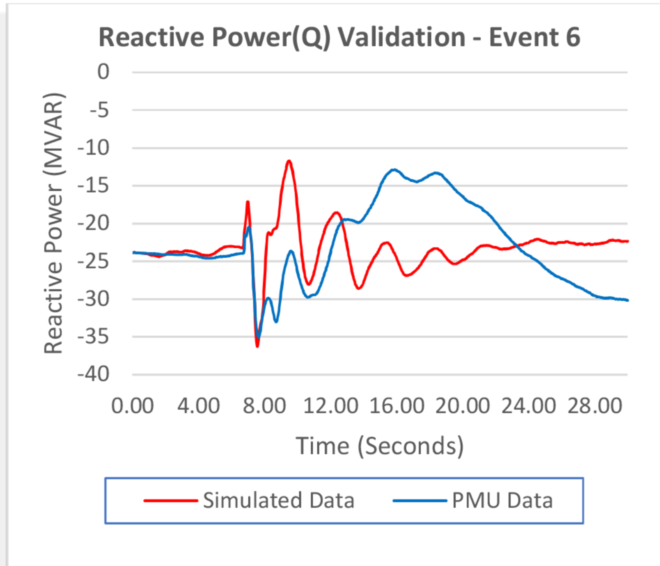
Voltage magnitude (VM) and voltage angle (VA) measurements from PMU are fed into the model using the generator and transformer added and the active power (P) and reactive power (Q) output from the simulation is compared with the actual response from the generator. The measurements could be taken on the high side of the generator step-up transformer or the low side. This approach allows the use of PMU measurements to subject the generator in the model to the same terminal conditions as in the field and then compare the response of the generator in the model with the actual response. Since PMU measurements capture the terminal conditions of the generator during event, this method does not require knowledge of the exact event or sequence of events that occurred in the system.



Validation

Results from model validation include comparison plots showing PMU measured response of the generator and the simulated response for active and reactive power output. These results help identify whether the model can be used to accurately represent the generator response for different events in the system. An example of comparison plots for validation of a gas turbine generator is shown below. It can be noted that there is a significant mismatch between the PMU measured response and the simulated response of the generator especially for the reactive power output. Typically, the validity of the model is evaluated based on visual observations and comparison of the simulated and measured response, however the mismatch can also be quantified and expressed mathematically using GMV.





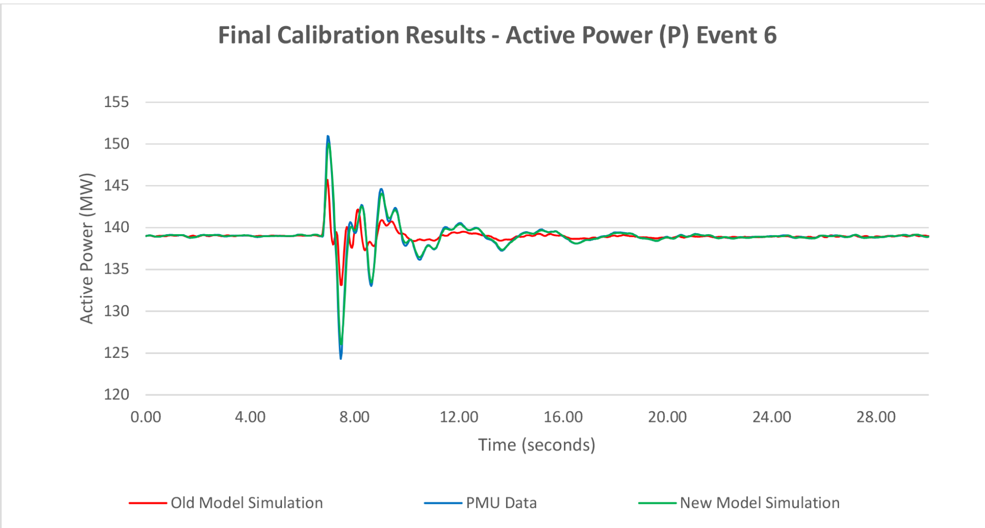
Sensitivity Analysis

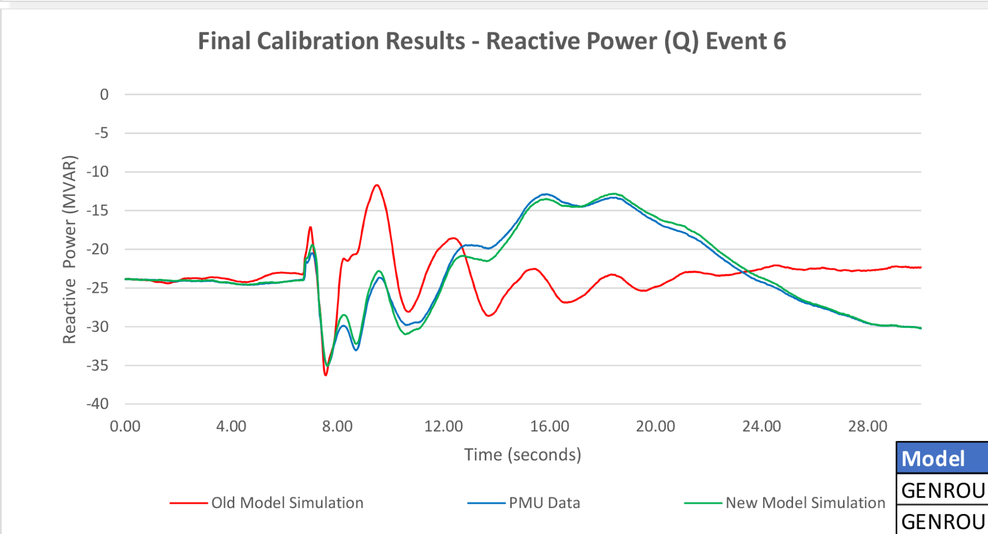
Generator dynamic models have several parameters (50 – 100). Not all parameters require tuning or calibration to improve the model response. Sensitivity Analysis helps in identifying key parameters that have a significant impact on the generator response. Sensitivity analysis calculates the change in the active and reactive power response of the generator to changes in model parameters and ranks parameters based on the Mean Square Error (MSE). This helps to narrow down from a list of several parameters to a select few parameters (~ 5-10) for the calibration process. The remaining parameters are not changed during the calibration process since they do not have a significant impact on the model response. An example of sensitivity results are shown below where top 3 key parameters are highlighted.

	Models	Model Parameters	Current Value	Calibrated Value	MSE-P	MSE-Q	Rank	Minimum	Maximum
1	☐ Select All								
2	☐ GENROU	T'do(>0)(sec)	5.85		0.0154	0.24384	13		
3	☐ GENROU	T"do(>0)(sec)	0.044		0.17222	0.09429	16		
4	☐ GENROU	T'qo(>0)(sec)	0.65		0.00656	0.01027	21		
5	☐ GENROU	T"qo(>0)(sec)	0.062		0.00993	0.0234	19		
6	☐ GENROU	H- Inertia	3.223		30.33625	15.14905	1		
7	☐ GENROU	D-Speed damping	0.0		0.0	0.0	NaN		
8	☐ GENROU	Xd	1.73		0.11781	0.17748	15		
9	☐ GENROU	Xq	1.682		0.07249	0.14803	17		
10	☐ GENROU	X'd	0.457		19.74647	11.75749	2		
11	☐ GENROU	X'q	0.573		0.13598	0.28038	11		
12	☐ GENROU	X"d=X"q	0.351		14.6057	7.94303	3		
13	☐ GENROU	Xl	0.258		0.02276	0.01871	20		
14	☐ GENROU	S(1.0)	0.028		9e-05	0.00031	24		
15	☐ GENROU	S(1.2)	0.273		0.00022	0.00778	22		
16	☐ ESAC6A	Tr(sec)	0.02		0.00933	0.26141	12		
17	☐ ESAC6A	Ka	500.0		0.0355	1.51837	8		
18	☐ ESAC6A	Ta(sec)	49.9		0.03255	1.54982	7		
19	☐ ESAC6A	Tk(sec)	4.0		0.03812	1.88223	5		
20	☐ ESAC6A	Tb(sec)	0.04		0.01477	0.37737	10		
21	☐ ESAC6A	Tc(sec)	0.2		0.04604	1.86142	6		
22	☐ ESAC6A	Vamax	13.6		0.07254	2.20297	4		
23	☐ ESAC6A	Vamin	-12.6		0.0	0.0	NaN		
24	☐ ESAC6A	Vrmax	999.0		0.0	0.0	NaN		
25	☐ ESAC6A	Vrmin	-999.0		0.0	0.0	NaN		
26	☐ ESAC6A	Te(>0)(sec)	0.67		0.06902	0.19416	14		

Calibration

If there is a mismatch in the simulated results from the model and the PMU measurements, it is important to identify and correct the model parameters that influence the mismatch The process of identifying and correcting dynamic model parameters is referred to as model calibration. Calibration is performed on the basis of results from sensitivity analysis and uses key parameters identified in sensitivity analysis. Calibration process involves the use of optimization algorithms to find the set of parameters that best matches the simulated response. It is important to note that calibration of dynamic models requires the use of engineering judgement and knowledge of generator and control system. Calibration results show the newly identified parameter values and comparison plots showing PMU measured response with the actual model and the new model with identified parameter values. Figure below shows comparison plots and new identified parameters after model calibration. It can be noted that the simulation response (green) for the new identified parameters matches closely with the PMU measurements (blue) as compared to the old model simulation (red).





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

Automated Report

GMV provides capability to generate automated reports after significant events. GMV reporting capability includes:

- Summary of model validation results
- Identification of questionable models
- Plots for individual generators
- Validation for multiple events
- Validation for multiple generators
- Reporting and notifications - email, PDF, mobile devices
- Compliance with NERC MOD 26-27, MOD 33

Generator Model Validation Report

Event 1: March 23rd, 2019 3:15:22 PM

Number of Generators

Number of generator models validated	15
Number of good generator models	13
Number of questionable generator models	2

Summary of Validation Results

Generator	Result
G1	Questionable
G2	Questionable
G3	Good
G4	Good
G5	Good
G6	Good
G7	Good
G8	Good
G9	Good
G10	Good
G11	Good
G12	Good
G13	Good
G14	Good
G15	Good

Parameter Used for Quantifying Mismatch

Criteria	Threshold
Accumulated Error Ratio	0.025
First Swing Peak Value	0.1
First Swing Peak Time(s)	0.5
Settling Time(s)	0.5

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Validation Results for G1

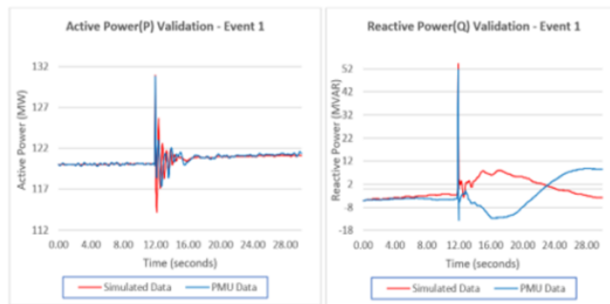

Figure 1. Active power & Reactive Power Comparison

Active Power Comparison

Criteria	PMU measurement	Simulated data	Difference
Accumulated Error	0.098927913	0.098927913	0
First Swing Peak Value	695.7307436	800.7687378	105.038
First Swing Peak Time	0.245	0.3	0.055
Settling Time	7.44499399	7.50499399	0.05

Reactive Power Comparison

Criteria	PMU measurement	Simulated data	Difference
Accumulated Error	0.144973111	0.144973111	0
First Swing Peak Value	399.3055053	459.6365356	60.325
First Swing Peak Time	0.035	0.085	0.05
Settling Time	8.64499399	1.52499399	-7.12

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Key **Features**

- Validate generator models for multiple events
- Validate all types of conventional generating units - Hydro, Nuclear, Combined Cycle, Other Steam & Gas Turbine Generators
- Validate renewable energy generators - Solar, Wind etc
- Validate multiple generators
- Quantify mismatch and identify good vs questionable models
- Platform detailed analysis offline
- Sensitivity analysis
- Perform calibration and tuning
- Automated report generation and email notification
- Meet NERC MOD-26, MOD-27 Compliance
- Comprehensive input commnuication modes
    - *TCP*
    - *UDP/UDP*
    - *TCP/Broadcast*
    - *TCP/Multicast*
    - *TCP/Unicast*
    - *Spontaneous Broadcast*
    - *Spontaneous Multicast*
    - *Spontaneous Unicast*
    - *Serial through ethernet converter*
    - *Variable input data rate (up to 100 sample/sec or 120 samples/sec)*

- Input data formats
    - *C37.118*
    - *C37.118.2*
    - *PDC Stream*
    - *COMTRADE*
    - *CSV Files*

System Requirements

Operating System:	Windows 7 or later, Windows 2008 R2 or later (64bit)
Processor Speed:	2.8 GHz or higher
Processor Cores:	Intel Core i5 or higher
Memory:	8 Gigabytes or higher
Hard Disk Storage:	50 GB Minimum
Prerequisites:	Siemens PTI PSS\E, Python 2.7

About **EPG**

Electric Power Group (EPG) was established on June 24, 1999 and began operations in 2000. EPG is led by technical, management, and executive level personnel with extensive utility power systems experience in planning, operations, transmission, protection with specialization in use of synchrophasor technologies and advanced applications for analytics, real-time operations and grid monitoring technologies. EPG's research in the use of synchrophasor measurements led to the development of the first of its kind wide-area real-time performance monitoring system for electric grids, referred to as Real Time Dynamics Monitoring System (RTDMS®); the first prototype was installed at California ISO in 2003. EPG's RTDMS® application for Wide Area Situational Awareness and other synchrophasor applications are in use at many of the leading ISOs and utilities in North America for real time and off-line analytics as well as real time wide area situational awareness and monitoring in control centers. EPG applications using SCADA data are installed at North American Electric Reliability Corporation (NERC) for reliability monitoring.

EPG is a leading provider of synchrophasor technology solutions with more than 32 customers in USA, Canada, Middle East, India and Dominican Republic. EPG specializes in working with transmission companies, utilities and ISOs in the areas of power systems planning, analysis, reliability technologies, control center operations, research and development, and development and implementation of synchrophasor technology applications. EPG has been working with synchrophasor technology since 2001 and has extensive first-hand knowledge and experience with addressing the challenges that ISOs and utilities face in making use of synchrophasor applications by operators, reliability coordinators, operating engineers, and planners.

EPG experience covers all components of synchrophasor technology networks and use of synchrophasor technology data for reliability management including – data collection, synchronization, data validation and conditioning, data archiving, linear state estimation, real-time streaming to applications, real-time monitoring and offline analysis applications for use in control room, engineering environments, substations, universities and technology centers.

EPG WAMS and Substation Applications

PHASOR DATA MANAGEMENT

Collection and Synchronization

eSPDC
Substation PDC

ePDC
Control Center PDC

Storage

PHASOR ARCHIVER

Integration

ICCP DNP-3

Validation and Conditioning

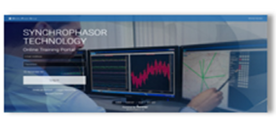
DATA NXT
Algorithms / Models

GRID RESILIENCY

PhasorNxt

TRAINING

PSOT
Phasor Simulator
for Operator Training



Synchrophasor
Training Courses

REAL-TIME ANALYTICS, MONITORING, NOTIFICATIONS & REPORTS

PHASOR RTDMS®
Analytics and Monitoring

eGENS
enhanced
Grid Events
Notification System

GridSmarts
Reports

OFFLINE ANALYTICS PLATFORM

Phasor Grid Dynamics Analyzer

ePDE
Phasor Data Extractor

AUTOMATED Event Miner
Big Data Analytics

LINEAR STATE ESTIMATION

eLSE
enhanced Linear State Estimation

GRID PERFORMANCE

GRID PERFORMANCE
ASSESSMENT SERVICE

SUBSTATION APPLICATIONS

iTAM
Intelligent
Transmission Alert
Monitor

eGENS
enhanced
Grid Events
Notification System

GMV
Generator Model
Validation

PhasorSmart
WAMS Package for Substations

for further information on all EPG products and services please visit us at www.electricpowergroup.com

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