PhasorSmart

WAMS Package for Substations, Utilities
Universities and Reseachers
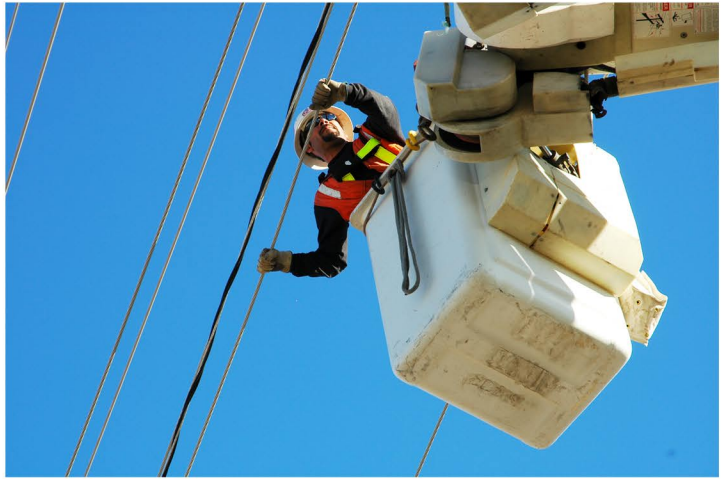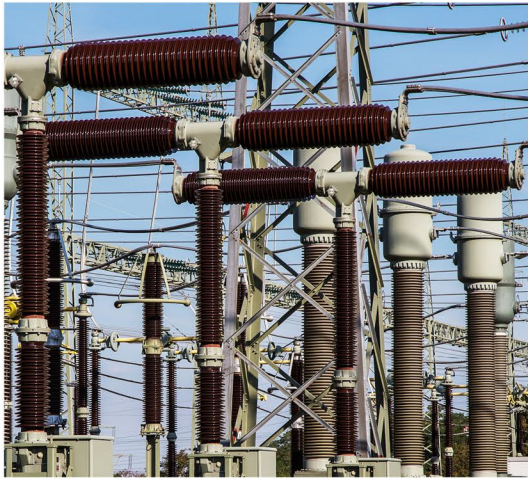
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Introduction

The electric power industry has been using EMS-SCADA technology for over 50 years. The industry is rapidly adopting the next generation technology for wide area measurement systems using Phasor Measurement Units (PMUs) which provide high-resolution and time-synchronized data typically at 25 or 50 frames/second for 50 Hz systems and 30 or 60 frames/second for 60 Hz system. This high resolution and time synchronized data provides grid managers, control center operators, engineers with capability to monitor grid performance and reliability at transmission level, distribution level and micro-grids by monitoring, visualizing and analyzing power system dynamics that cannot be obtained from the traditional SCADA/EMS system. PMU technology use is growing worldwide and provides applications and use cases, including:

PhasorSmart provides a simple, easy to use package enabling data visualization as well as simulated results and test algorithms with real or simulated data

- Oscillation Monitoring, Detection & Root Cause Diagnostics
- Grid Stress – Phase Angle Monitoring for Wide Area Situational Awareness and Grid Stability
- Event Root Cause Analysis for Real Time System Vulnerability Assessment
- Islanding Detection and Resynchronization
- Model Validation
- Event Mining to identify events by type, location, severity to guide planning and operations
- Frequency Response Analysis
- Renewables Integration
- Distribution and Micro-grid performance and analysis
- Fault Analysis

The applications can be used by utility transmission and distribution engineers and operators, advanced technology groups, smart grid centers or in substations. Substation use cases include asset health monitoring for transformers, generators, instrument transformers (CT, PT, CCVT), local generator oscillations, generator performance analysis etc.

Universities have a need to develop curricula and support research on new algorithms and analytic methods to take advantage of this data to address industry need for trained engineers.

Electric Power Group (EPG) has developed a software package called PhasorSmart to address this need by providing a simple and easy to use package that will enable visualization of data as well as simulated results and test algorithms with real or simulated synchrophasor data. PhasorSmart specifically addresses substation needs for asset health monitoring and performance monitoring of key substation equipment using data from PMUs, DFRs and other IEDs in the substation.

Introducing **Phasor**Smart

PhasorSmart is a software platform that is designed for substations, utilities, universities and technology centers to perform real-time substation monitoring, user defined algorithm for research and validation, grid performance analysis, applications development, and training on use of synchrophasor technology.

- Concentrate and Time Align Data from multiple devices in substations (PMUs, DFRs, PDCs)
- Visualize Real-time Data and Results on a web user-interface
- Replay historical PMU Data
- Visualize simulated data from
  - 3rd Party Simulation Tools (PSSE, PSLF, TSAT, PowerWorld, PSCAD, Mi Power etc.)
  - 3rd Party Real-time simulators (RTDS, ePHASORSIM, TSAT-ePMU, PowerWorld Dynamic Studio)
- Test User-defined Algorithms and visualize results
- Monitor key substation equipment health and performance
  - Generator
  - Transformers
  - Instrument Transformers (CT, PT, CCVT)
- Generate Visual Alerts and Alarms to test algorithms and threshold settings for operations
- Assess renewable integration impacts
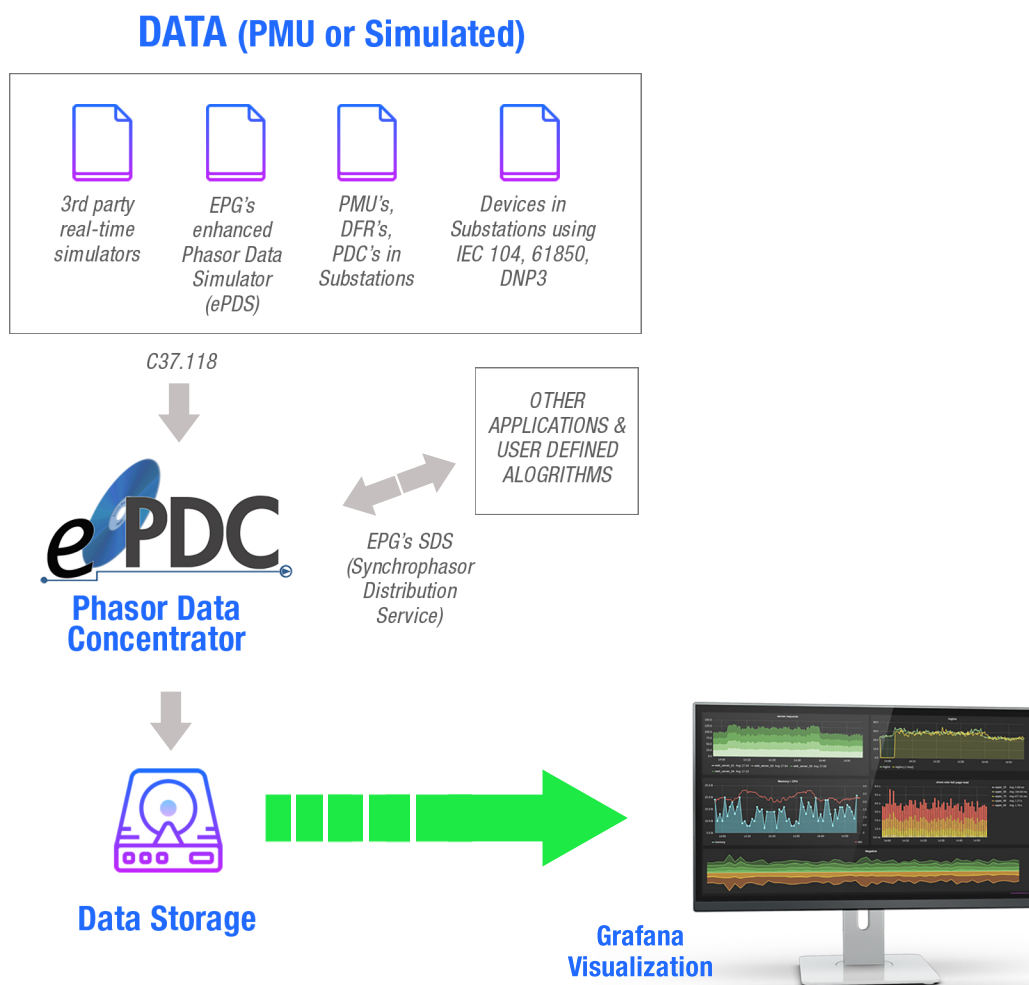
**Grafana
Visualization**

Architecture & Data Flow

Electric Power Group (EPG)'s enhanced Phasor Data Concentrator (ePDC) is a feature-rich high-performance PDC to receive, time-align, concentrate, and distribute synchrophasor data in different formats with different communication methods. The time aligned synchrophasor data can be sent to downstream applications for further data processing and storage. ePDC uses EPG's Synchrophasor Distribution Service (SDS) for sending data to user defined algorithms and applications as well as retrieving and storing data and results from them. This allows users to develop their own algorithms in C++, C# or Python and easily use data as input or send results for visualization.

PhasorSmart uses an open-source time-series database. In PhasorSmart, it is used as the visualization database for real-time displays and historical playback. Grafana is an open source visualization platform allowing users to query, visualize, and alert on synchrophasor metrics and user-defined algorithm results.

In addition to the PMU data stream, PhasorSmart also includes EPG's enhanced Phasor Data Simulator (ePDS) that provides users the capability to visualize historical PMU data or simulated data from 3rd party simulators such as PSS\E, PSLF, TSAT, PowerWorld, PSCAD, MiPower etc. Users can perform simulations, visualize results, test algorithms etc. using ePDS. Additionally, PhasorSmart also integrated real-time data from simulators such as RTDS, ePHASORSIM, TSAT – ePMU, Power World Dynamics Studio etc. such that users can test simulation scenarios and contingencies as well as corrective actions in real-time.

DATA (PMU or Simulated)

| 3rd party real-time simulators | EPG's enhanced Phasor Data Simulator (ePDS) | PMU's, DFR's, PDC's in Substations | Devices in Substations using IEC 104, 61850, DNP3 |

C37.118

ePDC
Phasor Data Concentrator

OTHER APPLICATIONS & USER DEFINED ALOGRITHMS

EPG's SDS (Synchrophasor Distribution Service)

**Data Storage**

Grafana Visualization

PhasorSmart Use Case Examples

PhasorSmart in Substations

PhasorSmart is designed for use in substations for monitoring key substation equipment using data from PMUs, DFRs and other IEDs to achieve the following use cases

- Provide primary protection relay information to quickly identify the type of fault, and also to find the root cause of loss of critical equipment within substations

- Real time supervision of CTs/CVTs/PTs within substations

- In generating substations to monitor real time generator flows (real & reactive power limits), local oscillations to quickly identify the root cause

- Generator and/or substation transformer parameter monitoring such as loss of life, through fault , and over load, tap positions etc.

- Wind & Solar generator performance analysis within local substation

PhasorSmart has add-on modules for IEC 104, IEC 61850 and DNP3 that allows users to receive data from substation devices that support protocols other than C37.118.
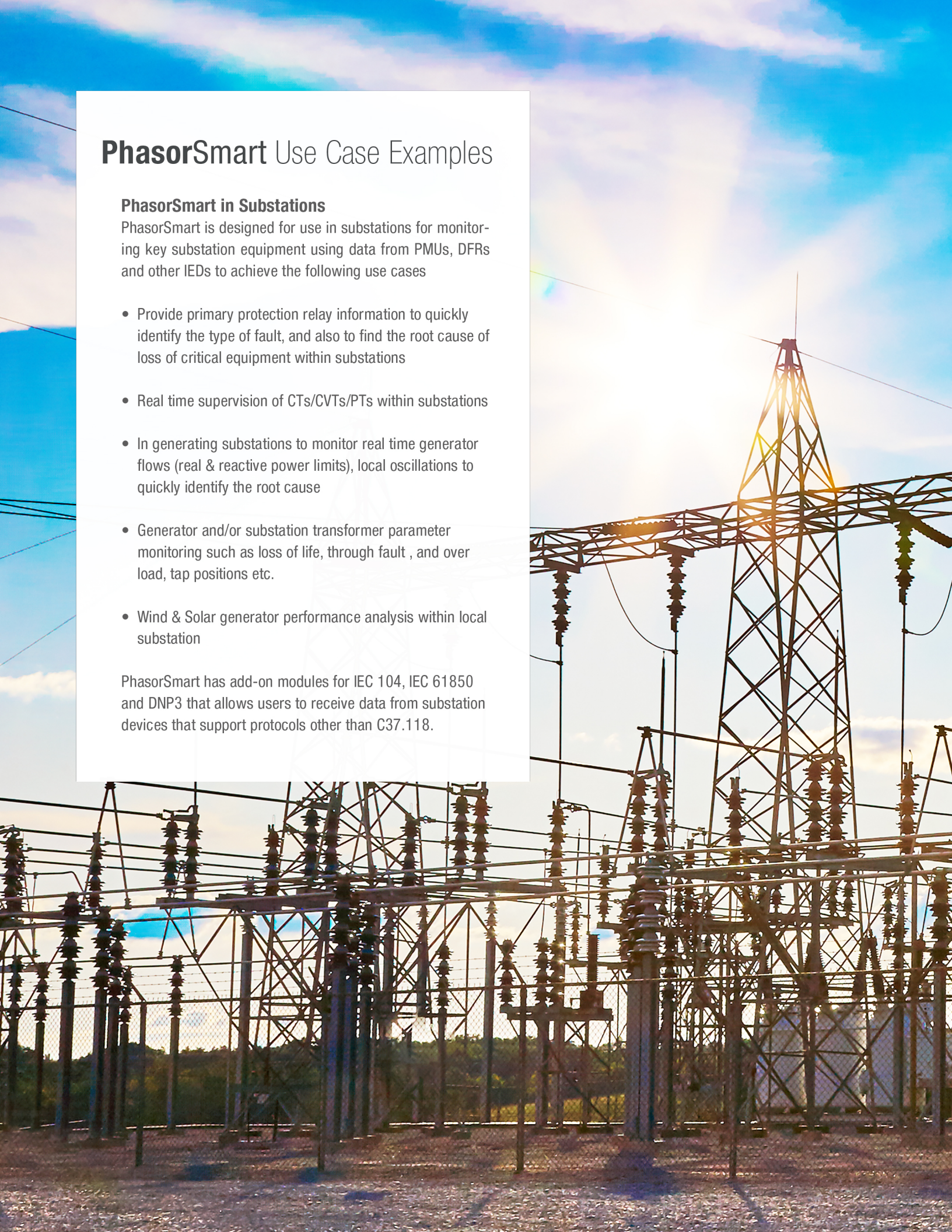
PhasorSmart Use Case Examples

PhasorSmart at Utilities

PhasorSmart is designed for use in utility technology and research centers for developing, testing and validating applications. PhasorSmart allows users to develop algorithms using synchrophasor data from PMUs or simulated data, perform testing and validation and visualize results on graphical displays. Key uses of synchrophasor data include:

- Event Detection
- Oscillations Monitoring and Detection
- Islanding
- Anomaly Detection
- Voltage Stability
- Fault Analysis
- Distribution System Monitoring and Applications Research using Synchrophasor Data – MicroGrids, Fault Location, Load Modelling etc.

PhasorSmart can also be used by utilities as a starter synchrophasor system for visualizing synchrophasor data, historical events, simulated data etc.

PhasorSmart Use Case Examples

PhasorSmart at Universities & Research Centers

PhasorSmart is designed for use in Universities and Research Centers to create a synchrophasor technology laboratory, Research new Algorithms, Perform Testing, Validation and Results Visualization.

PhasorSmart is also designed for use in training by Professors and Trainers to use synchrophasor data and simulation tools to educate students on the following synchrophasor technology topics:

- Synchrophasor Fundamentals

- Simulation of Events Using Offline or Real-time Simulators – Event Detection, Diagnosis, Corrective Action

- Event Signatures – Classification and Study of Different Event Types based on Signatures

- Oscillations – Fundamentals, Mode Metering, Oscillation Detection, Corrective Actions

- Phase Angle Differences – Grid Stress, Line Reclosing, Island detection and Resynchronization

PhasorSmart includes 5 starter test cases inbuilt for utilizing the above use cases.

Features and Functionalities

OVERALL
- Test User-defined algorithms using Synchrophasor Distribution Service (SDS) SDK in C#, C++ or Python
- Visualize results from offline and real-time simulations using ePDS
- Create custom dashboards
- Generate alerts, alarms and email notifications
- Visualize data on variety of charts and displays – trends, bar charts, histograms, dial charts etc.
- Receive, time-align, concentrate, and distribute synchrophasor data using ePDC
- Replay recorded data
- Inject measurement errors as C37.118/C37.118.2 stream to downstream applications

ePDC

INPUT

Input Communication Modes
- TCP
- UDP/UDP
- TCP/Broadcast
- TCP/Multicast
- TCP/Unicast
- Spontaneous Broadcast
- Spontaneous Multicast
- Spontaneous Unicast
- Serial through Ethernet Converter

Comprehensive Input Configurations
- accepts all phasor data including C37.118, C37.118.1, and 60255-118-1
- Variable Buffer Size
- Variable Input Data Rate (up to 100 samples/sec or 120 samples/sec)
- Late PMU Limit
- "Future" PMU Limit
- Multiple Time Zones
- Enable/Disable Input option
- Configuration of multiple inputs
- Copy input configurations
- Portable configuration format (for duplication, replication)
- User definable input naming
- PMU ID Code matching
- Stream Sorting
- Sort by Arrival
- Sort by Time
- Auto switch to Sort by Arrival
- Auto switch to Sort by Time
- Auto Configuration
- User settable Time Offsets
- Supports enhanced PMU Characteristics
- Manually send testing commands to PMU
- Auto ping remote PMU
- PMU failover from one to another
- Manual and Automatic PMU Characteristics configuration:
  (PMU Name; ID Code; # of Phasors; # of Analogs; # of Digitals; Phasor Formats; Frequency Formats; Analog Formats)
- Input PMU configuration change logging/tracking

INPUT DATA FORMATS

- C37.118
- C37.118 B
- C37.118 Draft 6
- Macrodyne 1 (M)
- Macrodyne 2 (G)
- PDC Stream
- FNet
- C37.118.2
- ICCP
- Optional Add On Modules
  - DNP3
  - IEC 104
  - IEC 61850

OUTPUT

Output Comm. Modes

- TCP
- UDP/UDP
- TCP/Broadcast
- TCP/Multicast
- TCP/Unicast
- Spontaneous Broadcast
- Spontaneous Multicast
- Spontaneous Unicast

Comprehensive Output Configurations

- Unique Output stream naming
- Outputs configurable at PMU and channel levels
- Multiple output streams with custom/unique configurations
- Auto inclusion/exclusion of new PMUs
- Auto inclusion/exclusion of new measurements
- Multiple/Individual Communication modes
- Definable output addresses/ports for clients
- Up/Down sample output data rates
- User definable latency allowed
- Output scaling
- Config frame sending on/off; interval user definable
- Output Scaling & Offsets – PHUNIT, Magnitude and Angle scaling and offsets
- Configurable phasor channels – name, type, scaling factor, offset parameters
- PMU/channel configuration tracking according to name of receiving sequence
- User definable Phasor, Analog and Frequency formats (Floating, Integer, Polar, Floating Rectangle etc.)
- Missing sample padding
- Output individually configurable
- Support referenced phasor angle output
- Support angle reference auto failover based on PMU data quality and associated voltage magnitude data quality
- Support redundant source selection
- PMUs vs Outputs Cross-checking/tracking

Output Formats
- C37.118
- C37.118.2
- OPC Data Access 3.0 standard
- Disk efficient, high performance, full resolution Relational Database (SQL Server, Oracle, MySQL)
- COMTRADE standard
- SDS

MONITORING AND REPORTING

Monitoring - Inputs
- Overall Input Monitoring
- Individual Input Monitoring
- Individual Input PMU Monitoring
    - Channel name
    - Channel type
    - Channel value
- Input PMU Data date/time latency monitoring
- PMU availability/dropout monitoring
- Input measurement trending
- Latency monitoring
- Late PMU/Future Timestamped PMU detection
- Monitored Parameters, Status and Metrics:
    - Active, Inactive, Disabled
    - Data Status (good, bad, time error, no data)
    - Expected samples, Received samples, Missing samples
    - Availability %, Last received
    - Received packets
- Communication Status Monitoring (by period and cumulative)
    - Missing Data
    - Checkword Error
    - Time Error
    - GPS Unsync
    - Format Error

Monitoring - Outputs
- All configured output activities are monitored
- Monitored Characteristics - Output name, Station ID, Status(active, inactive, disabled), Destination
- Data Frames sent, Last sent, availability monitoring
- Auto-refresh Output Status
- Configurable auto-refresh rate
- Individual Output Monitoring:
    - PMU Status
    - PMU ID, Station ID
    - Input Code, Output Code
    - PMU Status Flag
- Individual Output PMU Monitoring
    - Channel name (input)
    - Channel name (output)
    - Channel type
    - Channel value

Monitoring – Data Manager

- Time Alignment Status Monitoring
- PMU relative latency monitoring
- Maximum output wait time tuning

Monitoring - Error and Status Messages

- Input System messages
- Data Manager messages
- Output System messages
- Watchdog messages
- Message Filtering and sorting (critical, normal, all)
- Logging to text file as default
- email notification
- Logging to SNMP supported
    - Selectable message type
    - Selectable message priority
- Logging to Syslog supported
    - Selectable message type
    - Selectable message priority
    - Configurable target IP/port
    - Configurable OID structure

Reporting - PMU Input Performance Statistics

- Hourly log for every input PMU
- Checkword Error, Format Error, Time Error, GPS UnSync, Good, Received, Missing

SYSTEM WATCHDOG

- Monitors system services
- Auto-Restart
- Redundancy features

SECURITY (NERC CIP Compliance)

- Role based access control (admin definable roles)
- Settable Timeout
- Screen Lock
- Definable password characteristics (Caps, Numbers, Special Chars, Length etc.)
- Password expiration
- User management utility
- Active Directory integration

SYSTEM

- Support Windows and Linux
- High performance (tested over 400 PMUs)
- Low latency at 1-2 ms
- Fail-over friendly

GRAFANA VISUALIZATION

- Query, visualize, alert on and understand metrics
- Panels
  - Graphs/Trends
  - Single Statistics Dial/Panel
  - Tables
  - Heatmaps
  - Alert List
  - Dashboard List
  - Text Panels
- User-Defined Dashboards
  - Variables
  - Annotations
  - Folders
  - Playlist
  - Search
  - Sharing
  - Synchronized Time Range
  - Export & Import

SYSTEM REQUIREMENTS

Grafana executables are used for ePDC integration. 64-bit version of Windows OS is required to install and run ePDC with Grafana.

Operating System:	64bit Microsoft Windows 2008 R2 or later 64bit Microsoft Windows 7 or later
Processor Speed:	2.8 GHz or higher
Processor Cores:	Dual Intel Processors (8 cores total or more)
Memory:	8 Gigabyes or more
I/O Ports:	1 Network Interface Card (NIC) Supporting 1Gbps
Hard Disk Storage:	100GB minimum

Substation Deployment can be on a PC or a hardened PC.

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 – phasor data concentrators for data collection, synchronization, archiving, real-time streaming to applications, real-time monitoring and offline analysis applications for use in control room, engineering environments, universities and technology centers.

EPG Products

EPG has a suite of 15 Wide-Area Real-Time Monitoring and Visualization Systems (WAMS) products/solutions covering all end-to-end process of data collection, processing, visualization and analysis of phasor data. Brief description of the products and their categories:

Phasor Data Collection and Synchronization

a) enhanced Phasor Data Concentrator (ePDC®) – The enhanced PDC (ePDC®) developed by Electric Power Group (EPG) is the next generation technology for Phasor Data Concentrators (PDCs) to time synchronize high resolution phasor data for use by synchrophasor applications. ePDC® is designed to accept phasor data input from Phasor Measurement Units (PMUs) or other Phasor Data Concentrators (PDC) using C37.118 data format. The ePDC® concentrates all the data by aligning the data by timestamps for output to downstream applications using the C37.118 data format.

b) enhanced Substation Phasor Data Concentrator (eSPDC®) – eSPDC® supports all ePDC® features but limited to 10 PMUs. eSPDC® is optimized for substation environment where computer resources (CPU, memory, network bandwidth) might be limited.

Phasor Data Storage

a) Phasor Archiver – Phasor Archiver is a data store that stores the raw phasor data from ePDC® and/or processed data from Real Time Dynamics Monitoring System (RTDMS®) Server at full resolution. This is a relational database hosted in SQL Server or MySQL.

Phasor Data Integration

a) ICCP – EPG's ICCP adapter is developed to integrate Synchrophasor data with EMS using Field-Proven SISCO ICCP Stack. This enables data exchange with ISO's and Utilities including raw PMU Measurements (voltages, currents, frequency, etc.), calculated values (angle difference, real/reactive power, mode, sensitivity, oscillation, etc.), and alarms/events (threshold violation, rate of change violation).

b) DNP-3 – EPG's DNP3 add-on module sends Synchrophasor data and alarms to EMS/SCADA through DNP3 standard.

c) PI Gateway – EPG's PI Gateway has two components PI Gateway Service and PI Web App. PI Gateway Service, a Windows Service, implements archiving functions to send data to PI Server for data storage. PI Web App implements functions to configure and monitor PI Gateway Service.
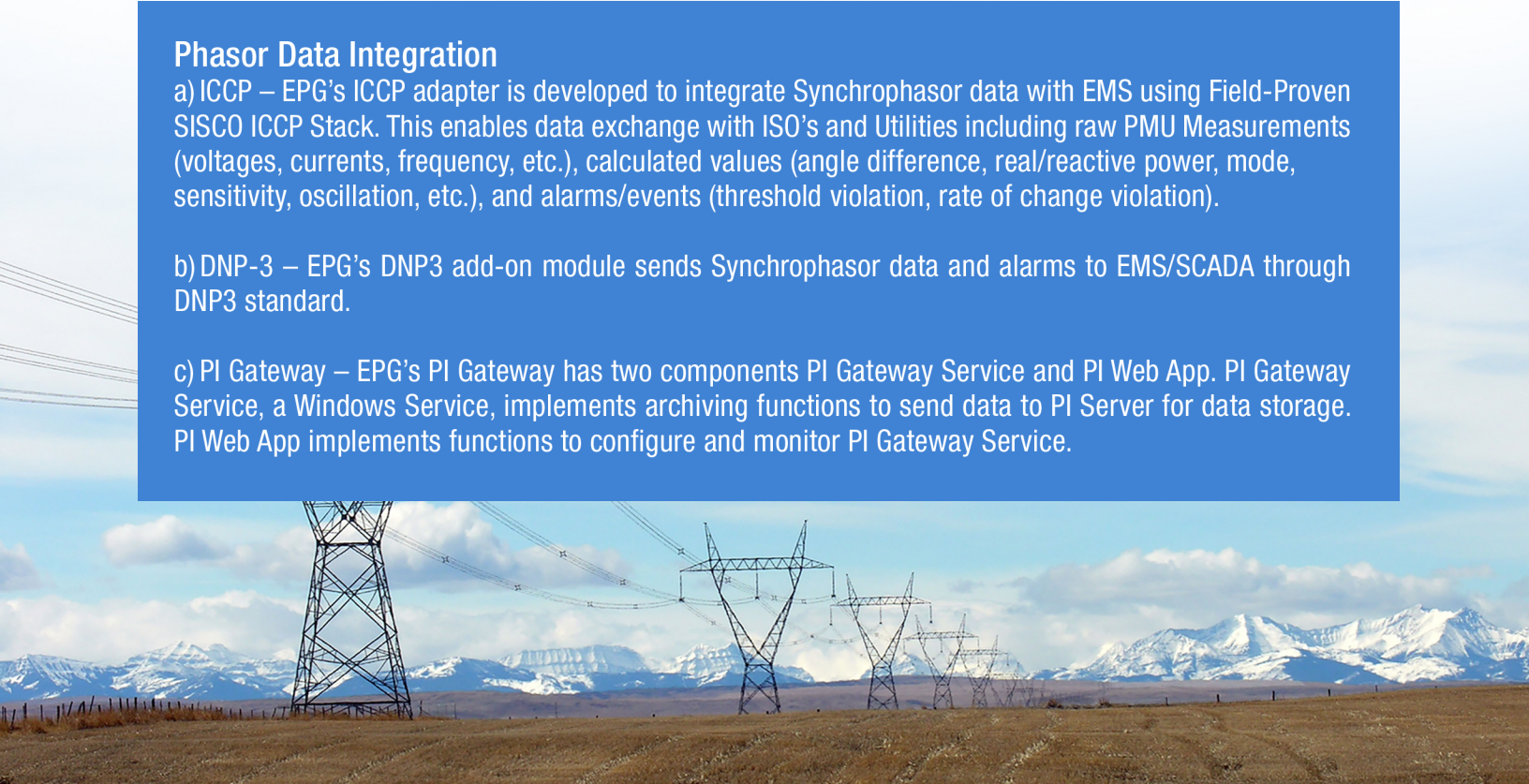
Phasor Data Validation and Conditioning

a)DataNXT™ – The DataNXT™ platform uses both model-less and model-based validation and conditioning procedures to manage advanced synchrophasor data quality. The platform includes algorithms for data validation, conditioning, and flagging of bad data. There is also optional reports add-on module for diagnosing and identifying root causes and sources of data-quality problems, optional data archiving including derived data-quality flags.

Real-Time Analytics, Monitoring and Reports

a)Real Time Dynamics Monitoring System (RTDMS®) – EPG's RTDMS® platform is a comprehensive platform for real-time wide-area analysis and monitoring using synchrophasor data for use in control centers. RTDMS® enables operators to Monitor and identify stressed grid conditions, severe oscillations, limit violations etc. and take timely corrective actions to address vulnerabilities like oscillations, low damping, large phase angle, diverging phase angle trend, high voltage sensitivity etc. It helps make better use of the transmission system by knowing how far we are from the edge and improve models by comparing actual system behavior with model results.

b)GridSmarts® – GridSmarts® is a Web-based application that integrates with RTDMS® to provide insight on grid performance and generates ad-hoc and daily reports based on the grid metrics such as RTDMS® alarms and events summary, Interconnection frequency performance, selected frequency performance, selected voltage performance, selected angle difference performance, selected power flow performance, RTDMS® advanced calculation performance, and PMU data quality.

Linear State Estimation

a)enhanced Linear State Estimator (eLSE™) – eLSE™ is available as an add-on module in DataNXT™ for performing linear state estimation of synchrophasor data values estimated using the Power System Network model and real-time breaker status from EMS. In DataNXT™ this estimation is used to perform model-based data validation and conditioning.

Grid Resiliency

a)PhasorNXT® Platform – PhasorNXT® is a platform with modules for independent synchrophasor state estimation and situational awareness. This enables grid resiliency by providing a redundant system to the existing state estimation systems. The modules include DataNXT™, Network Builder, eLSE™, One-Line Diagram, RTDMS®, and data Integration Adapters.
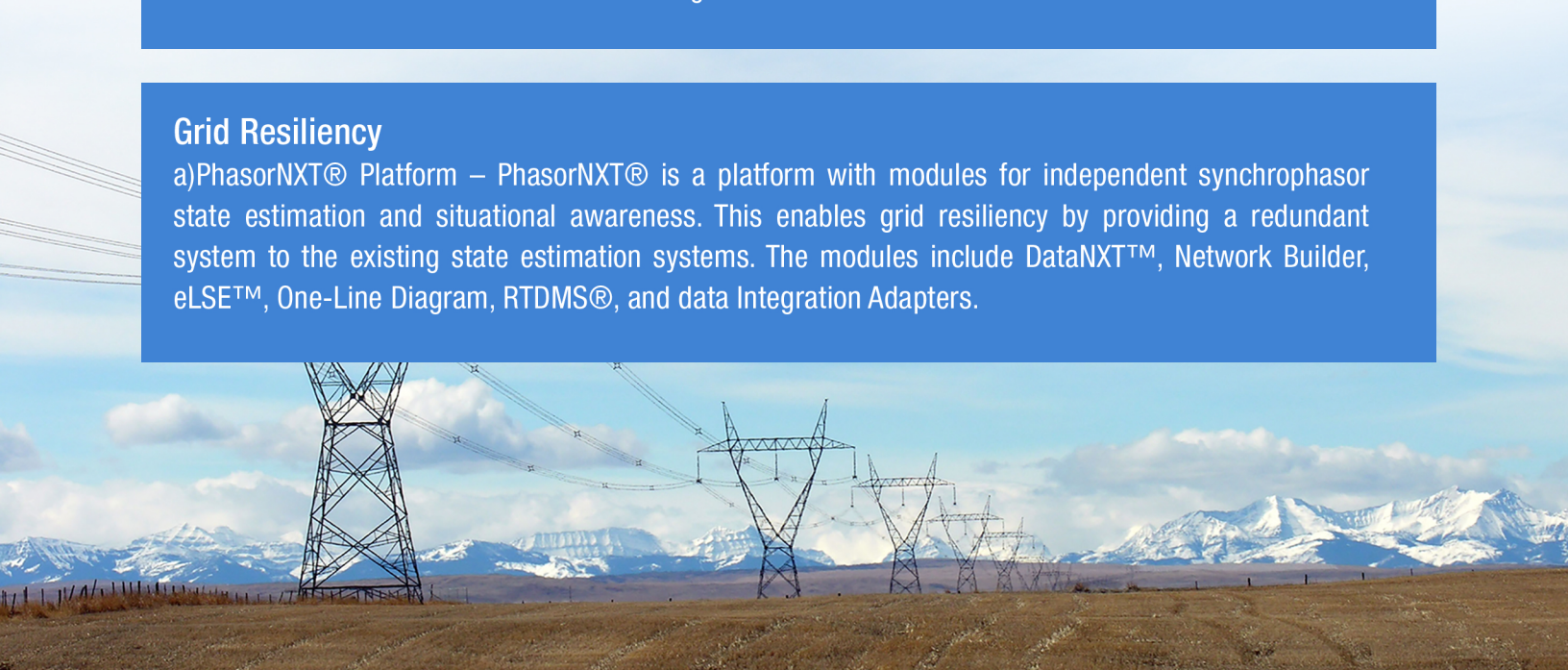
Offline Analytics Platform

a)Phasor Grid Dynamics Analyzer (PGDA®) – PGDA® is an offline data analytics tool enabling planners and engineers to perform post-event analysis to answer commonly asked questions related to event – When, Where, What and Why? PGDA® can be used to study oscillations using Spectral, Modal and Ring-down Analysis, identify alarm parameters using Sensitivity and Statistical Analysis, and perform model validation using Plot Analysis to identify first responder, and estimate primary and inertial frequency response using Event Analysis.

b)Automated Event Miner (AEM) – Automated Event Miner (AEM) is an add-on application to PGDA® which provides the ability to search for events based on user-defined criteria. AEM is designed to assist planning and operations support engineers to mine historical and near real time power system events. Mined events are reported by location, severity, duration and count to provide engineers an event library for use in event analysis, model validation, training operators and fine tuning real-time alarm parameters. AEM can be used to mine for different event types including oscillations, low voltage, high phase angle difference and frequency signatures.

Training

a)Phasor Simulator for Operator Training (PSOT) – PSOT simulates power system events, along with their mitigation actions; converts the outputs results to an IEEE C37.118 synchrophasor format; and provides an easy to use GUI module to easily play and replay an event/mitigation on RTDMS® screen for training the operators. PSOT helps train the operators on using phasor technology to help diagnose an event. Such trainings include the use of advanced power system metrics provided by phasor technology, such as wide-area visualization, angle differences, oscillation detection etc., in addition to the metrics available in EMS SCADA technology.

b)Synchrophasor Training Courses – EPG has developed a web based online training portal providing courses on synchrophasor technology which can be taken on demand, anytime, anywhere that internet access is available. The courses are developed to train engineers, planners, operators and others on synchrophasors and their use in operations and include lectures, presentation slides, videos and interactive quizzes.

EPG WAMS Applications

Phasor Data Management

Collection and Synchronization

e•SPDC
Substation PDC

e•PDC
Control Center PDC

Storage

PHASOR ARCHIVER

Integration

ICCP

DNP-3

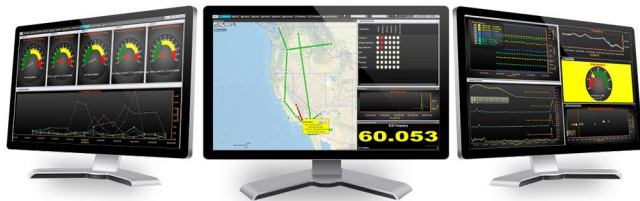### Validation and Conditioning

DATANXT

Algorithms

Models

Real-Time Analytics, Monitoring and Reports

PHASOR RTDMS®
Real Time Dynamics Monitoring System

Analytics and Monitoring

GridSmarts

Reports

Offline Analytics Platform

Phasor Data Extractor

ePDE

Automatic
Event
Miner

BIg Data
Analytics

Generator
Parameter
Validation

Phasor Grid
Dynamics Analyzer

Linear State Estimation

eLSE

enhanced
Linear State Estimator

Grid Resiliency

1576.907

PhasorNXT Platform

Training

PSOT

**Phasor
Simulator**
for Operator Training

SYNCHROPHASOR
TECHNOLOGY

**Synchrophasor Training
Courses**

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