Meeting the Challenges of a Modern Grid Using a Phasor-based Technology

NEDO Smart Community Summit 2018

Patrick T. Lee

President – PXiSE Energy Solutions

Vice President – Sempra Infrastructure

PXiSE Energy Solutions

KEY DRIVERS SHAPING A GLOBAL ENERGY TRANSITION

GHG Emissions

Climate Policies

Energy Security

Storms / Disasters

High Fossil Fuel Cost in Islands

Energy Need in Developing Countries

OBSERVABLE & RECOGNIZED TRENDS IN ELECTRIC ENERGY WORLDWIDE

Drivers

- Policies
- Social
- Environmental
- Economics
- Technological
- Resiliency
- Energy Independence

Trends

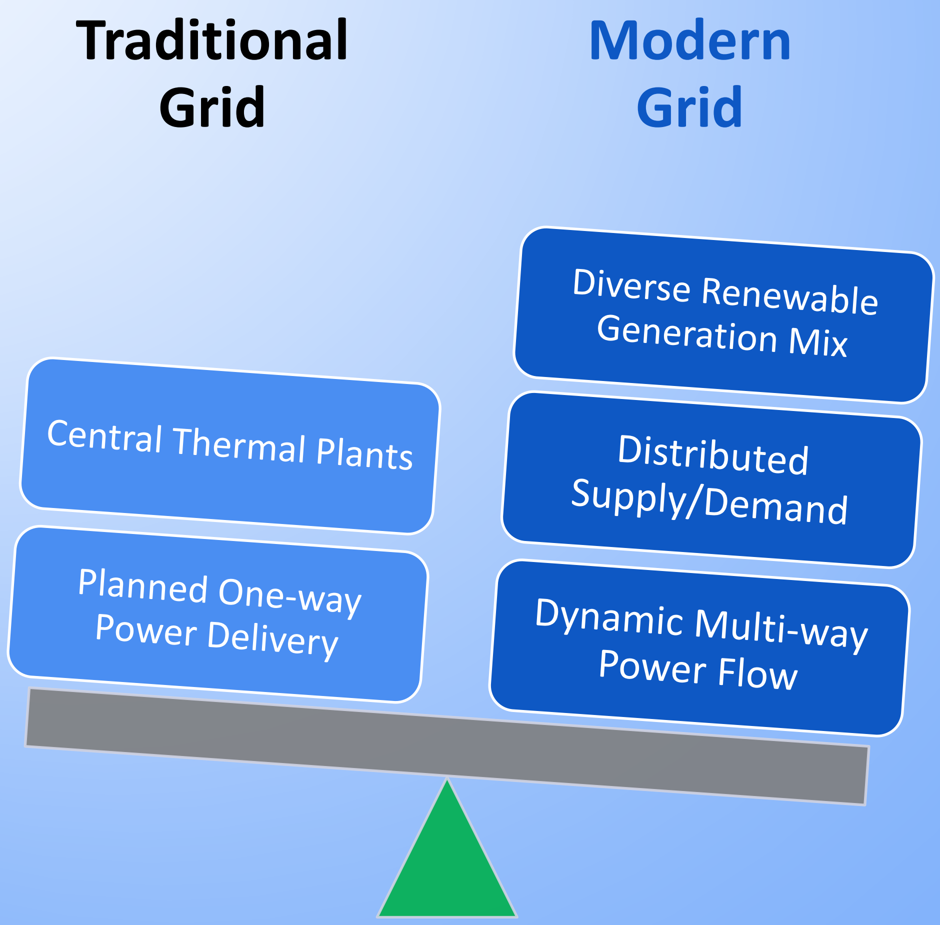
Adoption of more renewable resources

- Solar PV
- Wind
- Bio-fuel
- Geo-thermal

Shift from centralized to distributed resources

- Rooftop solar
- Energy storage
- Fuel cell
- Micro-turbines

CHANGES TO ELECTRIC GRID DISRUPT OPERATIONS AND BUSINESS MODELS



OPERATIONAL TECHNOLOGIES IN-USE – SLOW RESPONSE AND MOST INVOLVED OPERATORS

Electric Generation (frequency-based control)

- Isochronous control – control power output to maintain frequency at a set point
- Droop control – vary power output according to frequency level
- Ramp control – slow down renewable power plant output variations

Electric Delivery

- Power Flow control
  - Switch in/out of power lines
  - Reconfigure open points of distribution circuits
- Voltage control
  - Change voltage taps of transformers and voltage regulators
  - Turn on/off "static and/or dynamic" capacitors and reactors

Equipment Outage Response

- Automatic control or system operators intervention required

TECHNOLOGIES IN-USE CANNOT KEEP UP WITH THE DYNAMICS OF A MODERN GRID

Power regulation devices cannot respond timely

- Intermittent renewable supplies & distributed demands
- Reliability and power quality issues on the rise

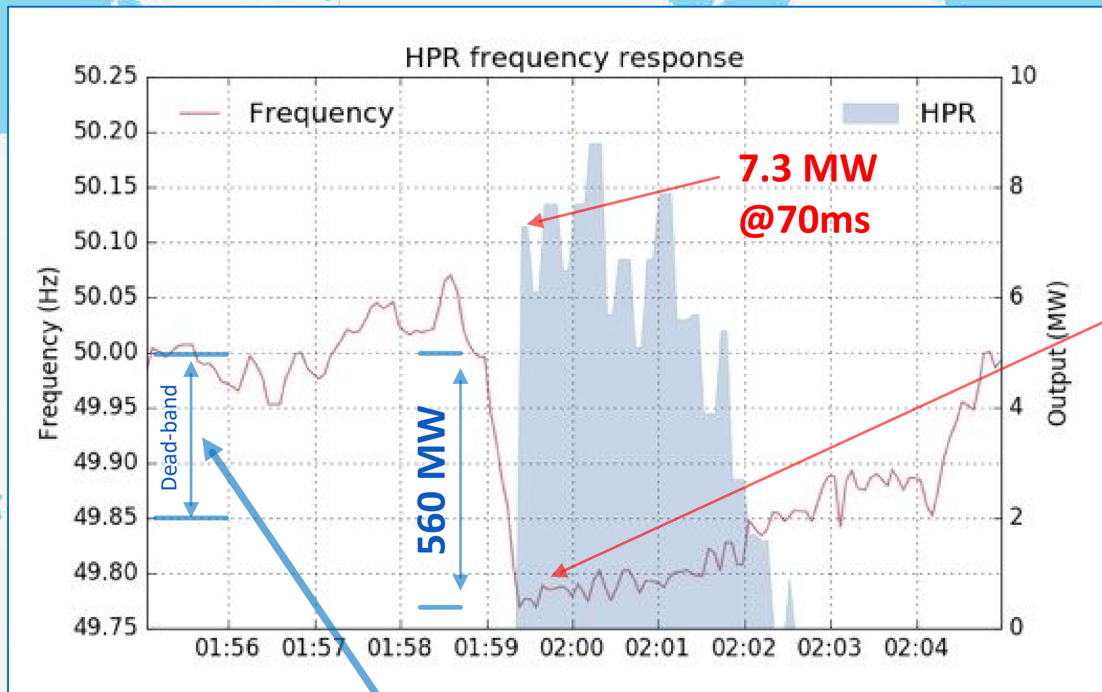
Isochronous/droop controlled generators too slow to react

- Larger swing of frequency and voltage due to smaller system inertia
- Unstable grid conditions and blackouts threaten energy dependencies

Even fast energy storage devices have limited benefits

- Frequency-based droop control helps to stabilize power surges
- Less effective in multiple devices coordination & low system inertia

FAST BATTERIES HAVE POTENTIAL BUT NEED A SYSTEM LEVEL CONTROL AND COORDINATION



3 Gladstone Power Station Responded in 6s

2 100MW/129MWh Hornsdale (HPR) Power Reserve Battery Responded at 49.85 Hz in 70ms

1 560MW Loy Yang A Power Station Dec. 14, 2017 Outage

Fast Coordination of Multiple Batteries and Power Plants is a Significant Challenge

CURRENT BATTERY CONTROL TECHNOLOGY HAS LIMITATIONS - INSIGHT FROM FREQUENCY EVENT

HPR Battery Responded Below 49.85 Hz Based On Droop Settings

- 7% output , 7.3 MW @ 70ms
- Quick but offered little help (560MW Drop)
- 3 minute duration ended when 49.85 Hz reached

Difficult to Coordinate Multiple Batteries Without Tim Synchronization & Advanced Control

- Limited to frequency-based control
- Fast response from droop settings may cause oscillations/instability in the system with multiple batteries

Specific Control Mode Limits Utilization of Battery for Additional Benefits

- Limited utilization – mostly on standby, respond only for frequency deviation outside of dead-band

PAIN POINTS FOR UTILITIES AND ASSET OWNERS

Operational problems create risks and uncertainties

- Customer complaints
- Regulatory oversights
- Reputation of energy utility

Long term investments become risky for utilities

- Fast technology and market changes affect business models
- Trade off of wired and non-wired solutions are difficult to model for long term benefits
- Regulators restrict utility investments as business model changes
  - Slow regulatory process and policy change
  - Cannot compete in behind the meter generation
  - Limited investment opportunities on energy storage
- Changing customer behaviors and expectations

KEEPING FOCUS ON OPERATIONAL OBJECTIVES AND CAPABILITIES IN A DYNAMIC MODERN GRID

Power and supply balancing

- Able to balance grid with high % of renewables in the generation mix

Power delivery management

- Able to coordinate distributed resources and loads in a network

Cost and environmental management

- Able to maximize use and predict asset conditions and performance

Reliability and quality management

- Able to stabilize the grid and improve service quality

OPERATIONAL VARIANCE INSIGHTS OFFER BETTER INFRASTRUCTURE INVESTMENT DECISIONS

Operational Variance Insights

- **Understand Operational Requirements**

Take the first step to obtain better data

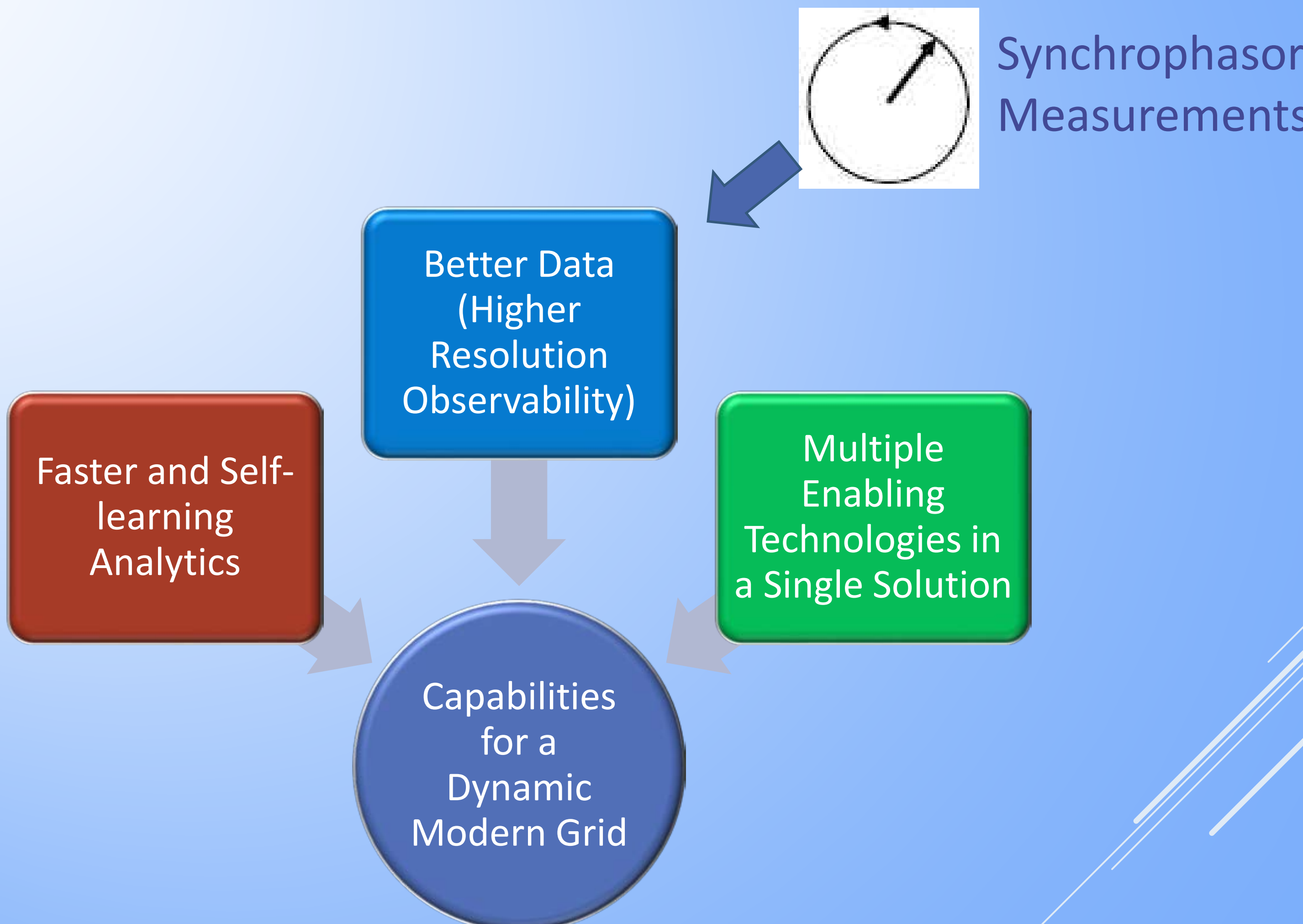
Technology and Market Insights

- **Formulate Strategic View**

Adaptive Investment Planning Tools

- **Continuous Improvement Process on Investment Decisions**

BUILDING CAPABILITIES TO MANAGE A DYNAMIC MODERN GRID REQUIRES:



PHASOR IS A PHASE VECTOR

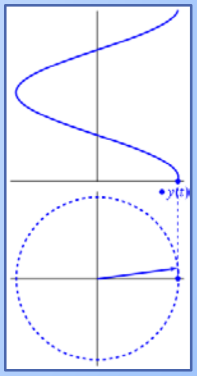
A MAGNITUDE MEASUREMENT HAS LIMITED INFORMATION

Example:
Voltage Measurement

100 Volts

100 Miles

A Vector Measurement Offers More Insights



Example:
Voltage Phasor

100 Volts At 90º

100 Miles

A Phasor is a Vector with a magnitude & direction

PHASOR-BASED DATA OFFERS A BUILDING BLOCK FOR ADVANCED CONTROL IN A DYNAMIC MODERN GRID

Time-synchronized Phasors

- **Timing & Network Topology Insights**

Industry Standard

IEEE C37.118

- **Inter-operability**

Speed and Accuracy

IEEE C37.118

- **Up to 120 Samples / Second**

Enable Further Technology Integration

- Feedback Control
- System Modeling
- Co-optimization

WHY POSSIBLE NOW PREVIOUSLY UN-TAPPED DATA IS NOW AVAILABLE

PXiSE's adaptive use of synchrophasor-based technology provides complete vision and peak performance to control electric grid assets

Phasor measurement units (a.k.a., PMUs, synchrophasors) offer new system insights

1982 - 1992
Standalone Phasor Measurement Unit (PMU) in development

2002
Electronic relays with built-in PMU functions

2005
2nd Standard IEEE C37.118

SEL standardized many relays with built-in PMU

2011
1,110 standalone PMUs, with tens of thousands of built-in PMU in relays

2017
PXiSE uses PMU for control in all areas of the grid

Time-synchronized, high resolution data (60 samples per sec.) enabling precision control capability

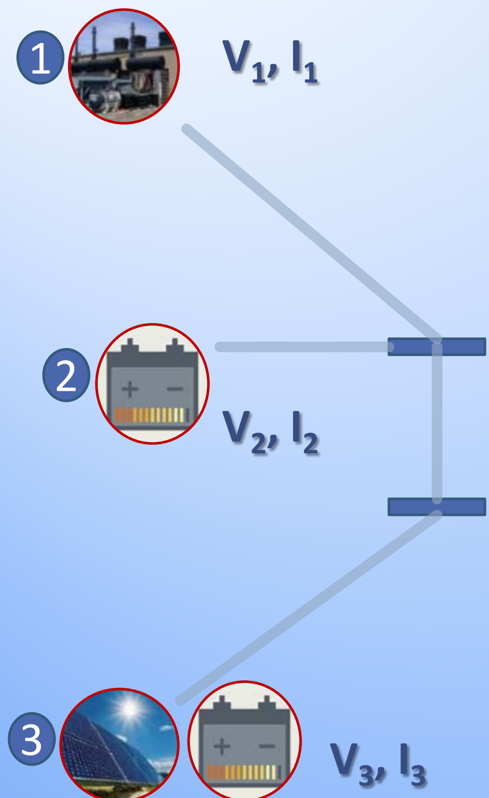
1982 - Standalone PMU
Very few used for transmission system coordination

Matured Technology

Relays with built-in PMU
Tens of thousands now available for use from generation to distribution

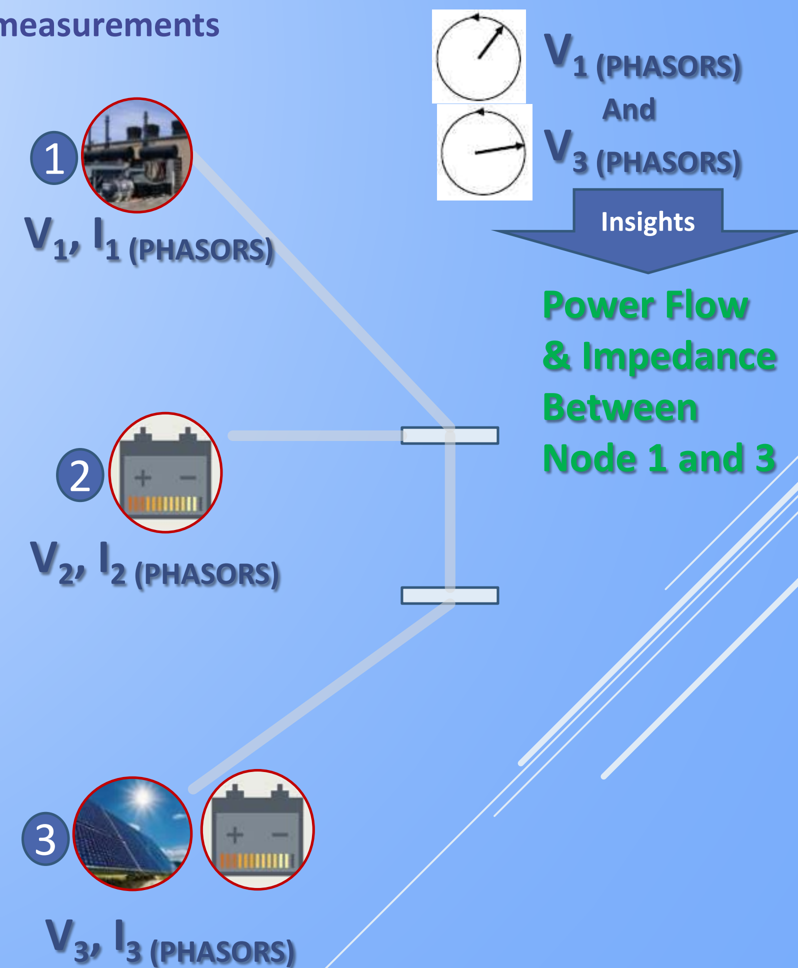
PHASOR MEASUREMENTS OFFER NEW INSIGHTS

Traditional Controls



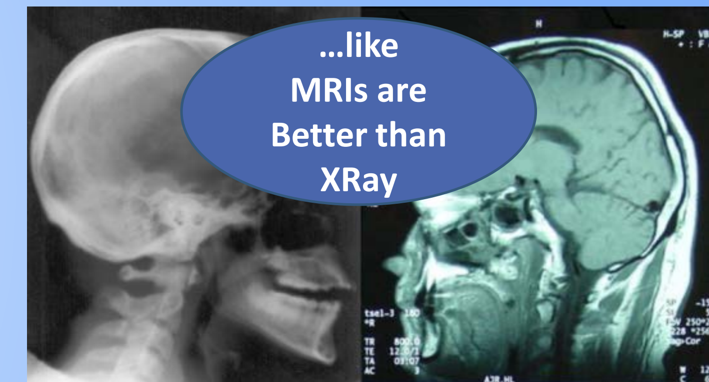
Advanced Controls

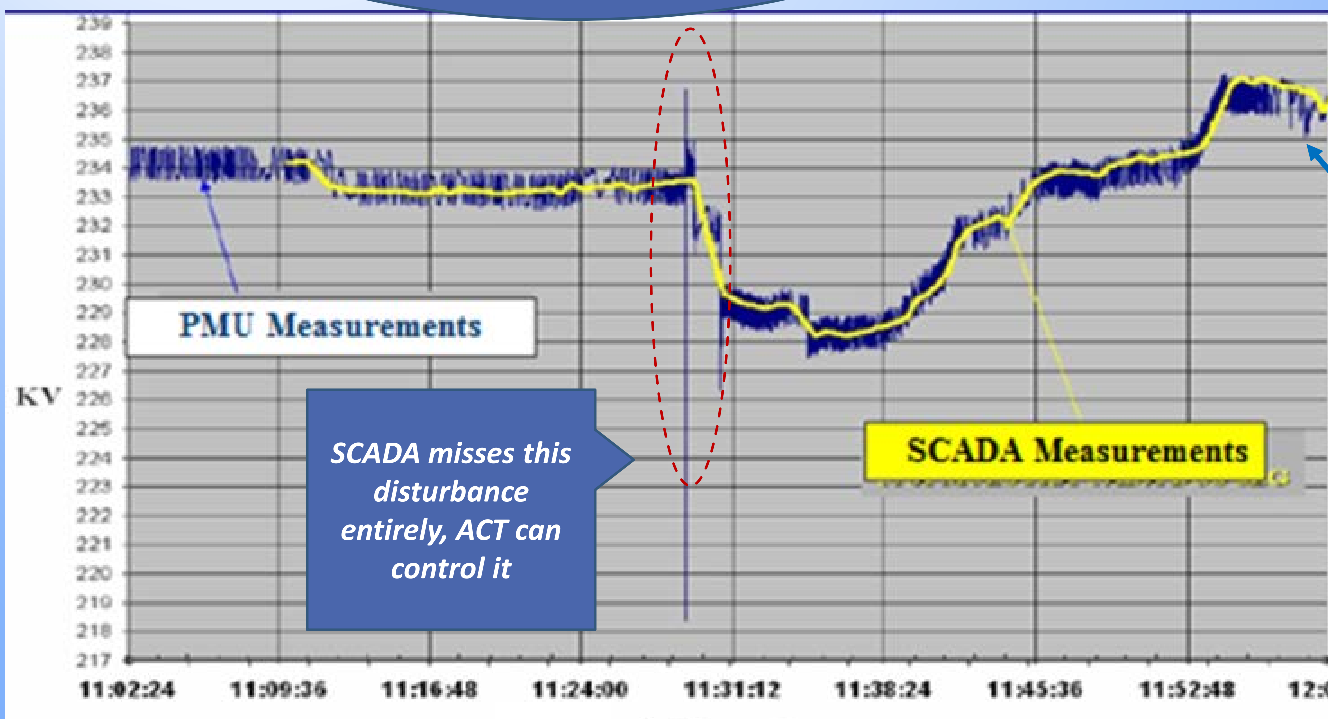
Synchrophasors offer power flow and network topology insights not available in traditional measurements



HIGH-RESOLUTION AND HIGH-SPEED DATA ENHANCE VISIBILITY AND ACCURATE CONTROL NECESSARY FOR THE MODERN, RENEWABLE, AND DER-BASED GRIDS

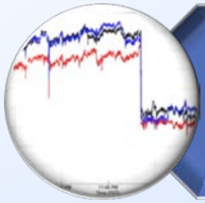
Phasor (Vector) Measurements are Superior to SCADA…



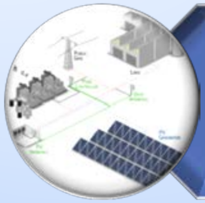


You can't control what you can't measure

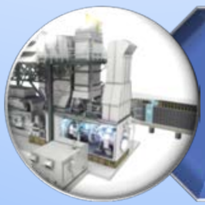
PHASOR-BASED TECHNOLOGY OFFERS BROAD APPLICATIONS AND BENEFITS:



Better Visibility of Operations and Situation Awareness



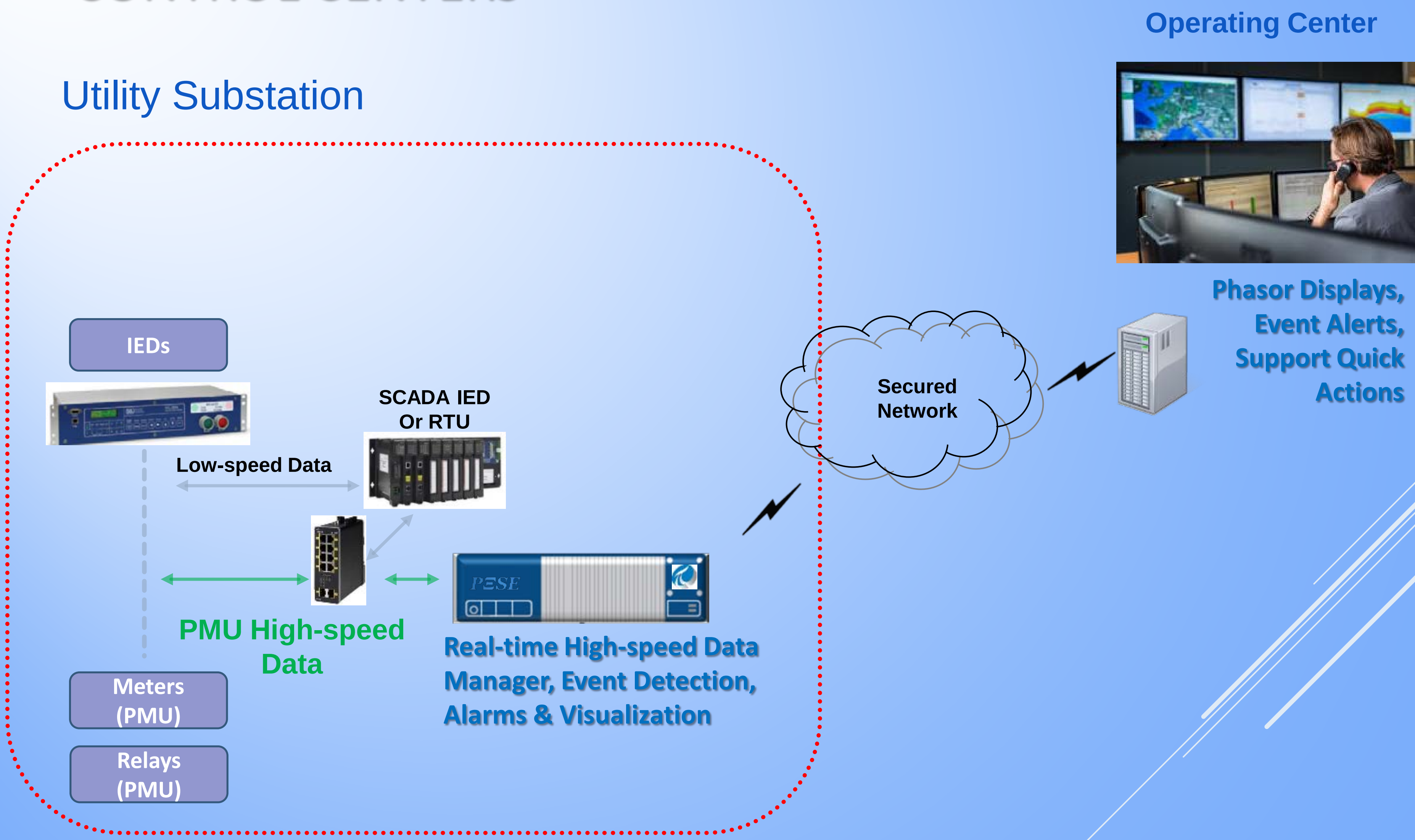
Faster and More Precise Control of Energy Resources



Better Predictive Asset Management

Insights for Operations and Investment Planning

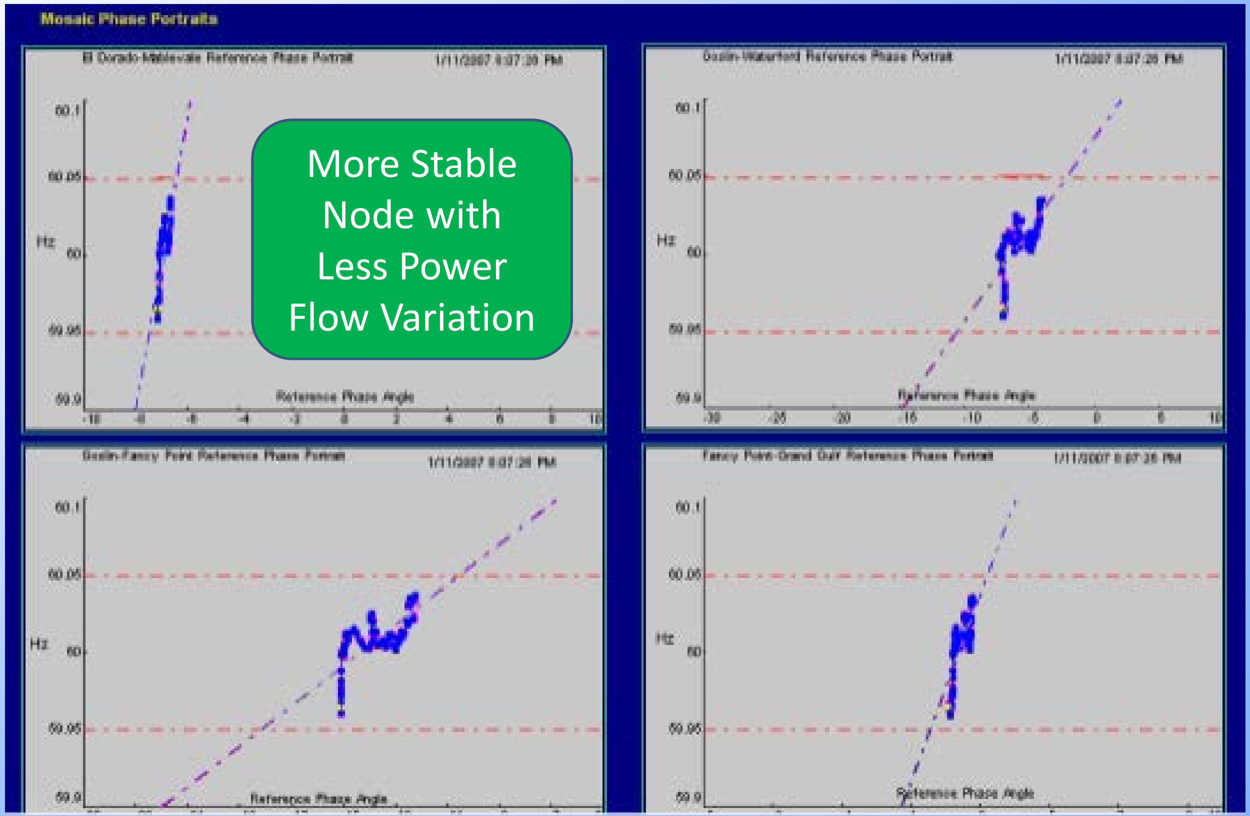
PHASOR DATA OFFERS ENHANCED INFORMATION FOR CONTROL CENTERS



PHASOR-BASED VISUALIZATION PROVIDES IMPROVED OPERATIONS AND SITUATION AWARENESS

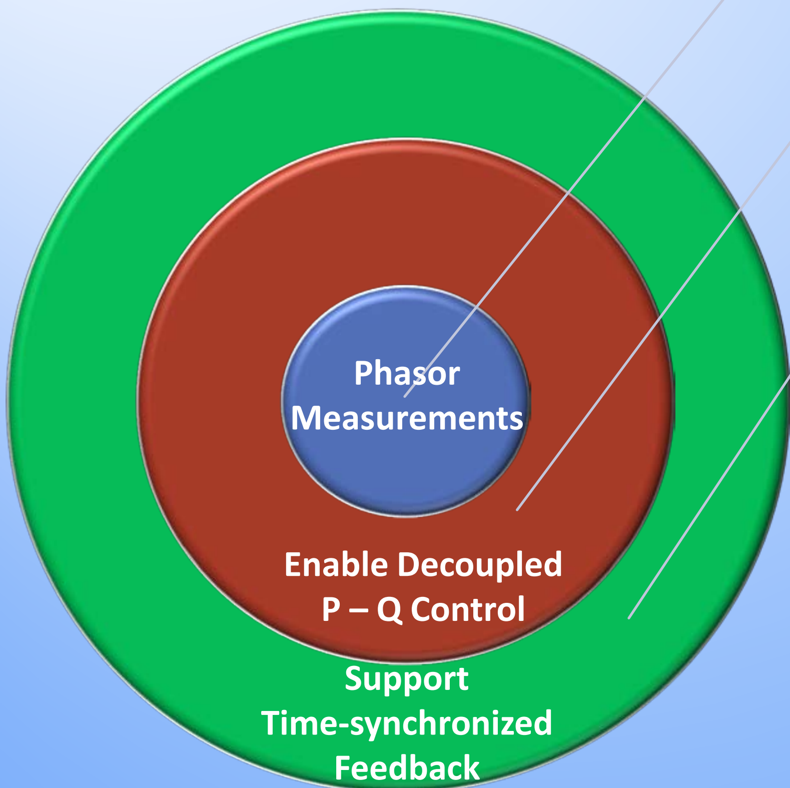
Example Use Cases	Benefits
Frequency excursion map	Offer nodal specific insights both in steady and dynamic states
System oscillation display	Early detection to prevent catastrophic events
Voltage stability margin display	Visibility to fast voltage fluctuation in transmission and distribution system
Frequency vs ACE display	Shows system's ability to maintain neutral power exchange
State measurement deviation chart	Indicate dynamic range of each power node, insights for normal versus abnormal system changes
Automatic location of disturbance event origin	Provide visibility of event originated from outside the region in a large connected system
Real-time sequence of events display	Real-time automated tool eliminate hours of semi-manual data processing post events

EXAMPLE: UNDERSTAND DEVIATION OF POWER FLOW AT NODES AS A RESULT OF SYSTEM CHANGES



Frequency and Voltage Angle Plots

PHASOR MEASUREMENT OFFERS FASTER AND MORE PRECISE CONTROL OF ENERGY RESOURCES



Meet IEEE C37.118 Standard on speed (up to 120 Hz) and accuracy of measurements

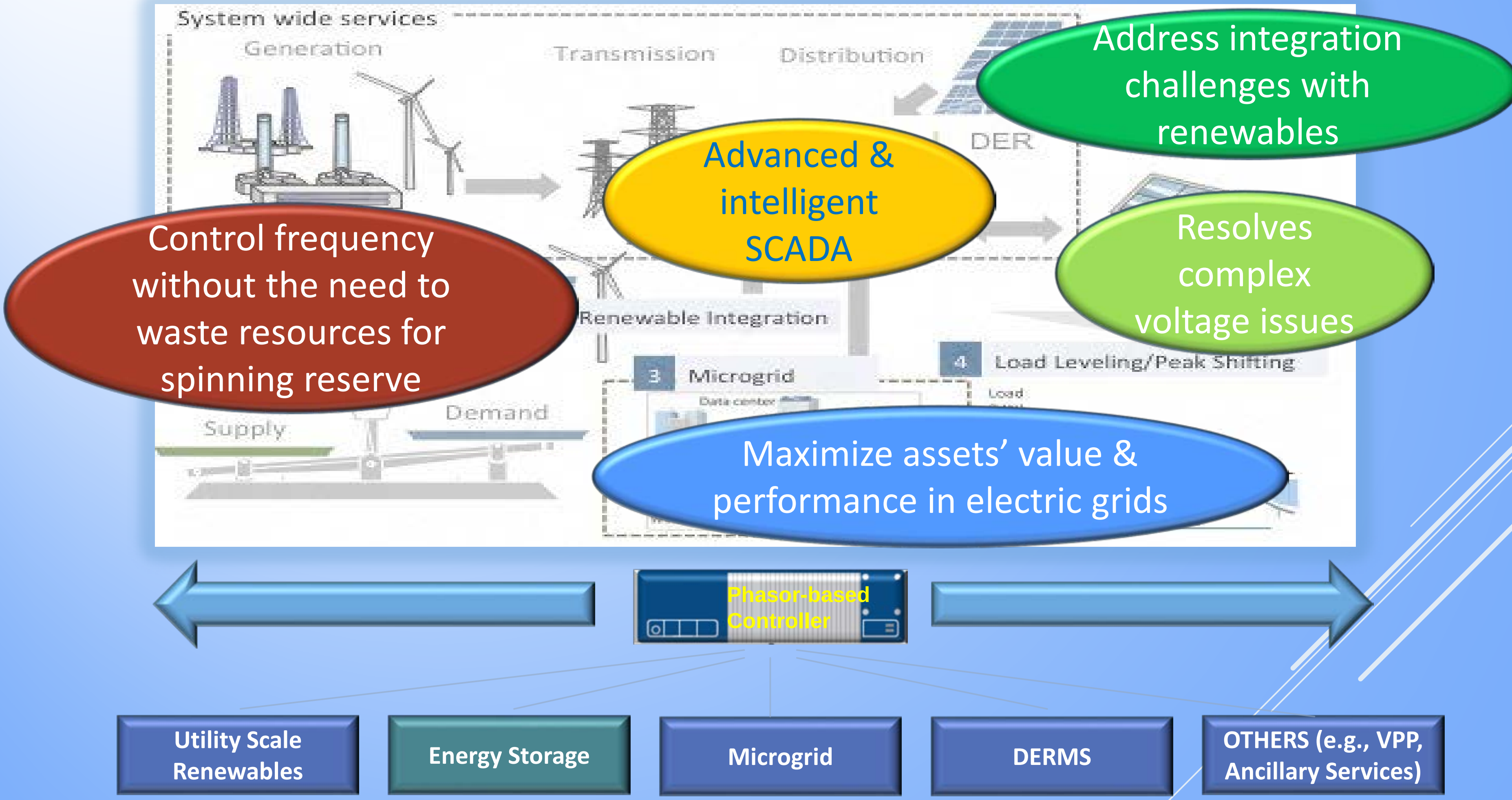
Phasors enables precise and coordinated real and reactive power control (Decoupled)

Supporting multi-level feedback control further improves accuracy

Fast & Precision Control

MANY PHASOR-BASED CONTROL APPLICATIONS

Phasor-based control has broad applications across the full power grid; it can precisely coordinate and synchronize the control of many energy assets



FAST AND PRECISE PHASOR-BASED CONTROL ENABLES ENERGY STORAGE WITH FULL VALUE STACK OPTIMIZATION

Phasor-based Control Enable a Single Control Mode to Co-optimize Value Stack

Income Opportunity

Control Variables		
P	DER electricity sales	DER energy market participation (aggregation)
P	Demand response	Demand response participation
P-Q	Energy market services	Access regulation and Frequency markets
P	Surplus sales	Revenue from excess green electricity

Cost & Reliability Benefits

Control Variables		
P	Demand reduction	Reduce demand charge and energy cost through real-time optimization of energy storage
P	TOU energy shifting	
Q	PF Penalty Avoidance	Manage Power Factor within utility requirements
P-Q	Power Quality	Improve voltage and frequency stability
P-Q	Service Reliability	Seamless islanding and reconnection to main grid with multiple DERs

PHASOR-BASED CONTROL OFFERS NEW CAPABILITIES

Magnitude-based Control

DERs & Controllers

Voltage, Current Magnitude Measurements

Proprietary Interfaces

Master Controller or Operator

Basic Control Capabilities

Basic Frequency Control

Single Mode Device Operation

Weak Device Coordination

Phasor-based Control

DERs & Controllers

Voltage, Current Magnitude Measurements

Proprietary Interfaces Maybe Eliminated

Converted Voltage & Current Timed Vectors (aka. Phasors)

Master Controller

Data I / O

Advanced Control Capabilities

Advanced Frequency Control

"State" Control - Non-Frequency

Multi-mode Device Operation

Time-synchronized Device Coordination Up to 100% Renewables

PHASOR-BASED ADVANCED FREQUENCY CONTROL - ISLAND GRID USE CASE

BEFORE
Ramp Control

IT NEEDED

Seven Generators for Primary Frequency Control

Three Batteries for Ramp and Inertia Response

TO ACHIEVE

AFTER
Advanced Frequency Control

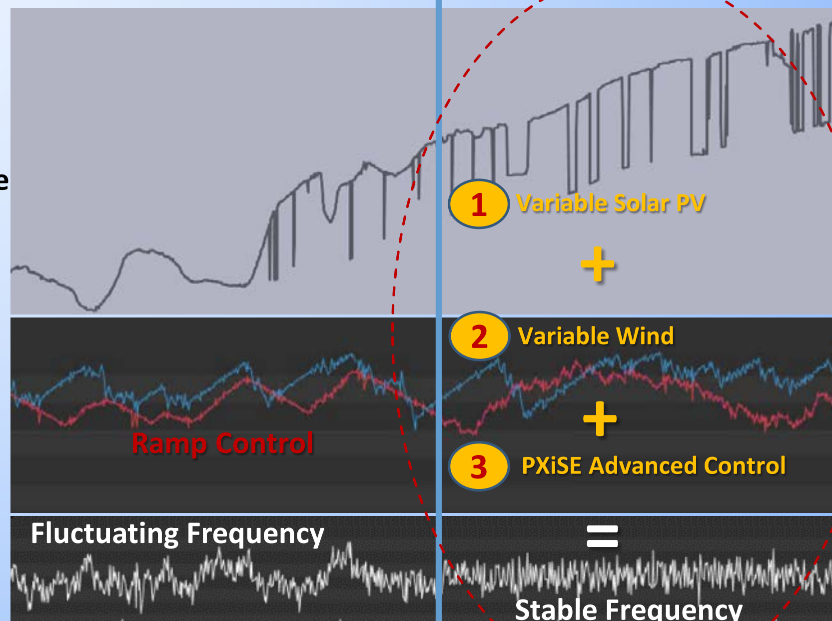
ONLY USED

One Existing Battery for Active Frequency Control

+

One Generator on Coordinated Schedule to Support Battery State of Charge

TO ACHIEVE

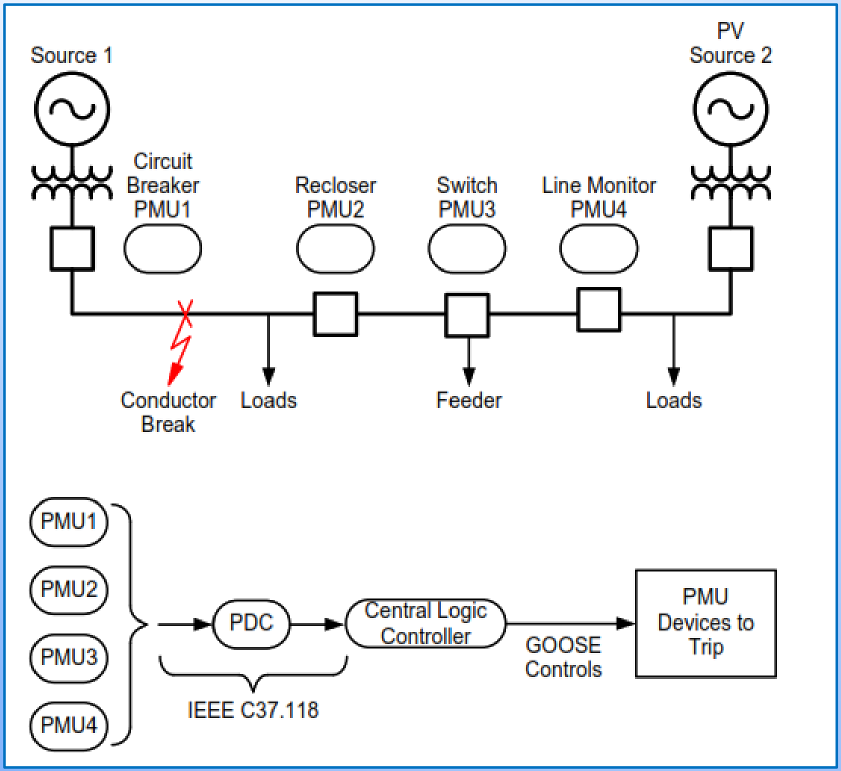


Value to Grid Owners:

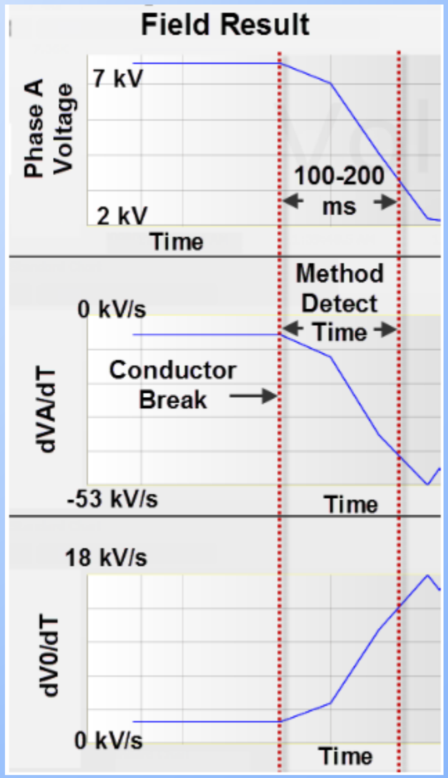
1. Reduce fossil spinning reserve
2. Improve generator's dispatch range
3. Reduce fuel costs and O&M of generators
4. Enable further increase of renewable mix to lower energy cost

PHASOR-BASED ASSET CONDITION MONITORING EXAMPLE

Setup to Monitor Conductors



Detection Algorithm



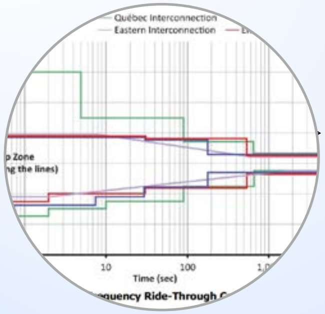
Fast Detection

Detect conductor break by comparing phasor measurements from different parts of the circuit up to 60 times per second

Quick Action

Less than 0.5 seconds from conductor broken to Circuit Breaker opened

PHASOR MEASUREMENTS CAPTURE OPERATIONAL VARIANCES THAT CONTRIBUTE TO OPERATIONS AND SYSTEM PLANNING



Baselining system performance indicators

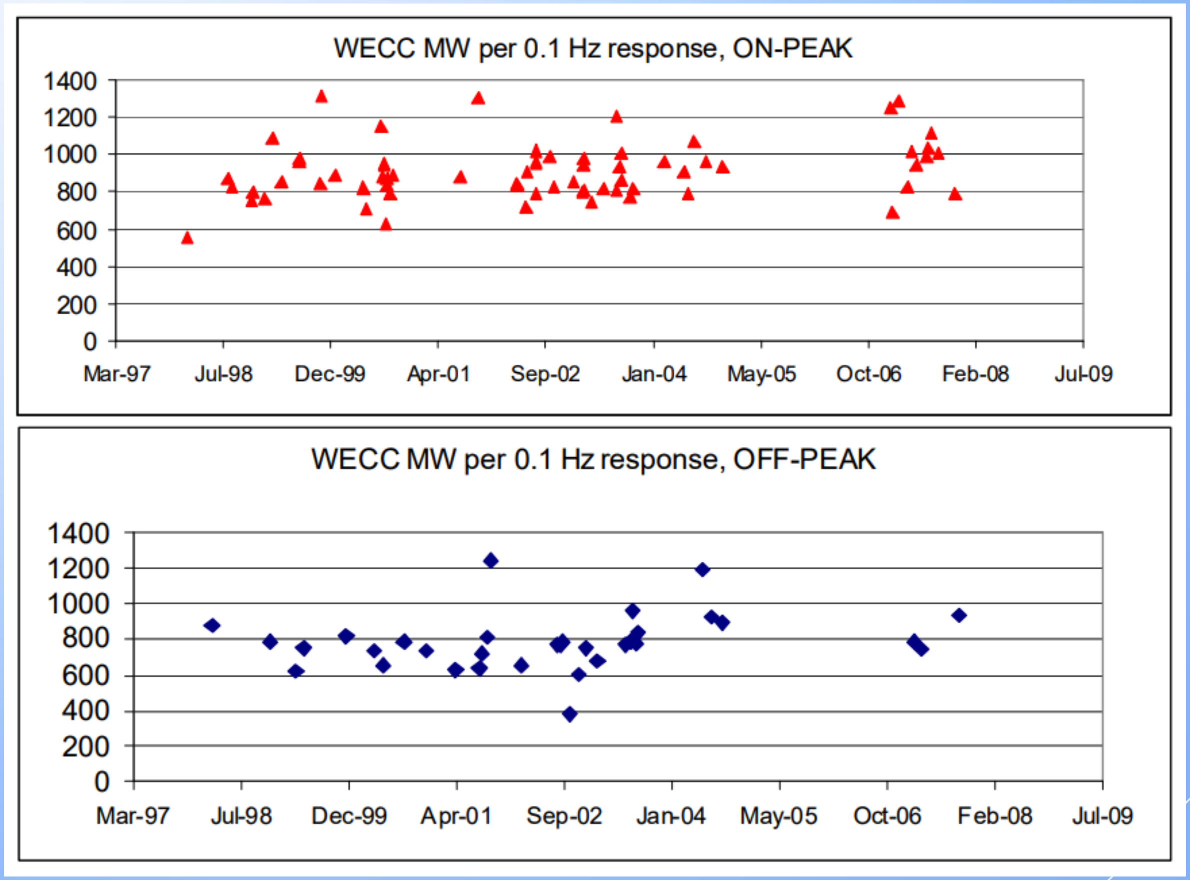
- Frequency response baseline (system inertia changes)
- Oscillation performance - frequency, damping, energy intensity
- Voltage stability indicators
- Power-angle sensitivities

Capturing power system measurements that best indicate system stress

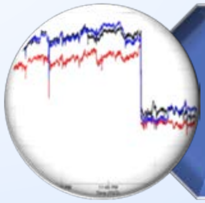
- Voltage angles deviation
- generation clusters
- Reactive reserves

Providing valuable data point for system planning as new infrastructures are proposed

FREQUENCY RESPONSE BASELINE OFFERS INSIGHT ON SYSTEM INERTIA VARIABILITY OVER TIME AND UNDER VARIOUS SYSTEM CONDITIONS



SUMMARY: PHASOR-BASED TECHNOLOGY OFFERS BROAD APPLICATIONS AND BENEFITS:



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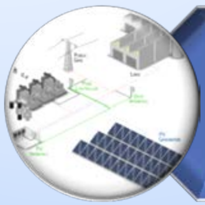

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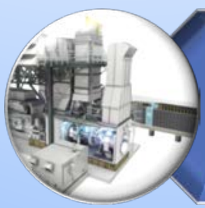

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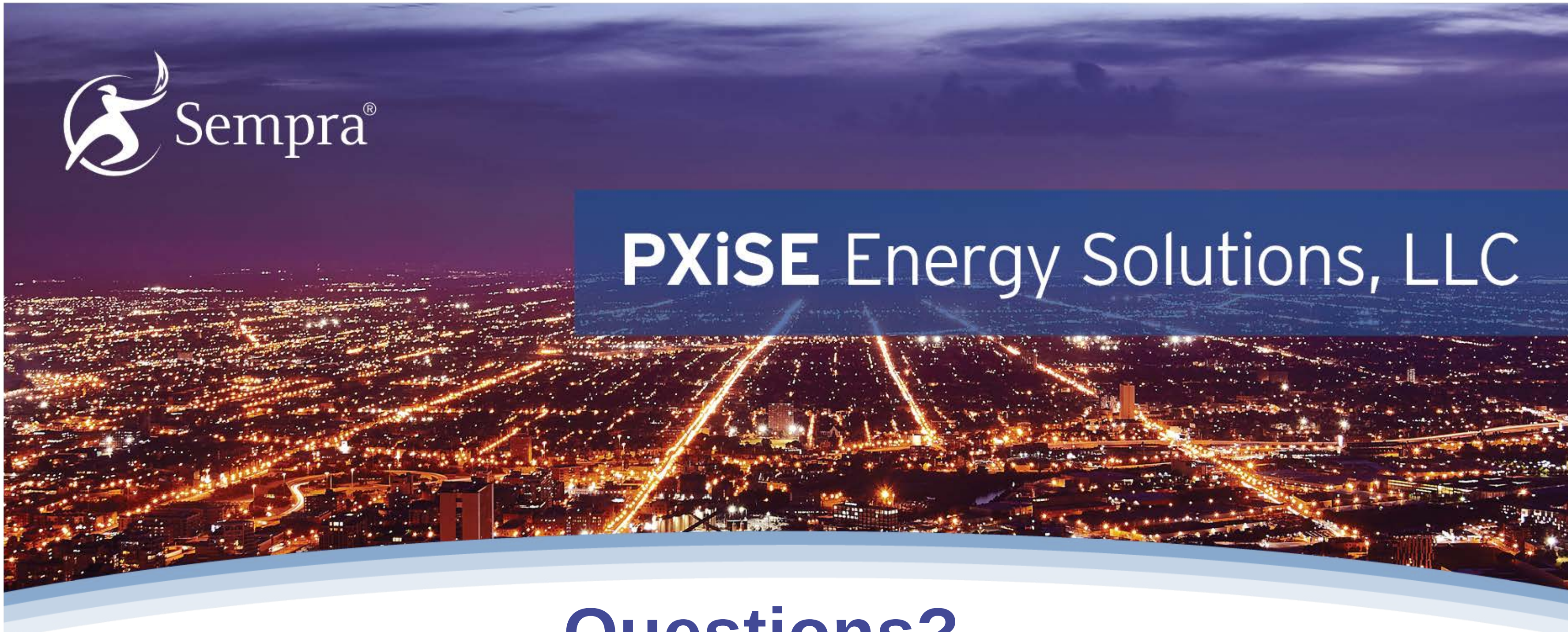

Questions?

Patrick Lee
President - PXiSE Energy Solutions
patrick.lee@pxise.com