



Phasor Measurement Unit or Synchrophasors

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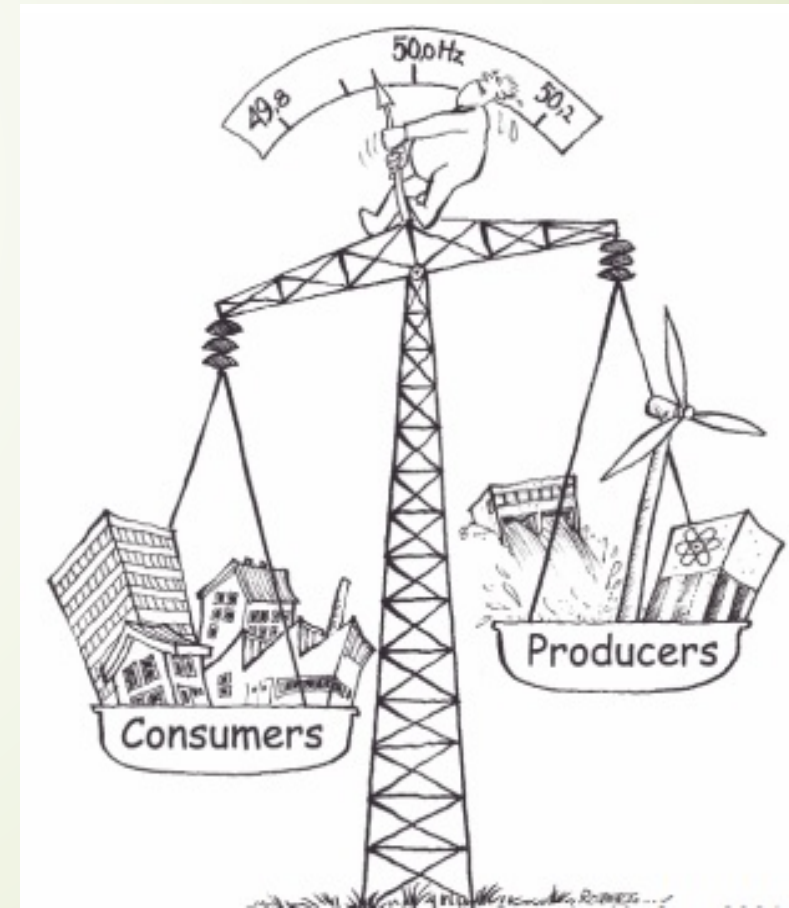
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Motivation:

- Need for more electricity
- Integration and management of renewable energy
- Optimal use of ageing assets
- Ensure reliability of supply
- Energy efficiency and security
- Dynamic operation of power system





Power System Operational Paradigm

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- Sense
 - Communicate
 - Compute
 - Visualize
 - Control
 - Situational Awareness and Decision Support

SCADA (Supervisory Control and Data Acquisition)

- SCADA system supervises, controls, optimizes and manages generation and transmission systems.

ATTRIBUTE	SCADA	PMU
Resolution	1 sample every 2-4 Seconds (steady State Observability)	10-60 samples per second (Dynamic Observability)
Measured Quantities	Magnitude only	Magnitude and phase angle
Time Synchronization	No	Yes
Total Input/output Channels	100+ Analog & Digital	~10 Phasors, 16+ digital, 16+ analog
Focus	Local monitoring and control	Wide area monitoring and control

Motivation: Estimation vs. Reality

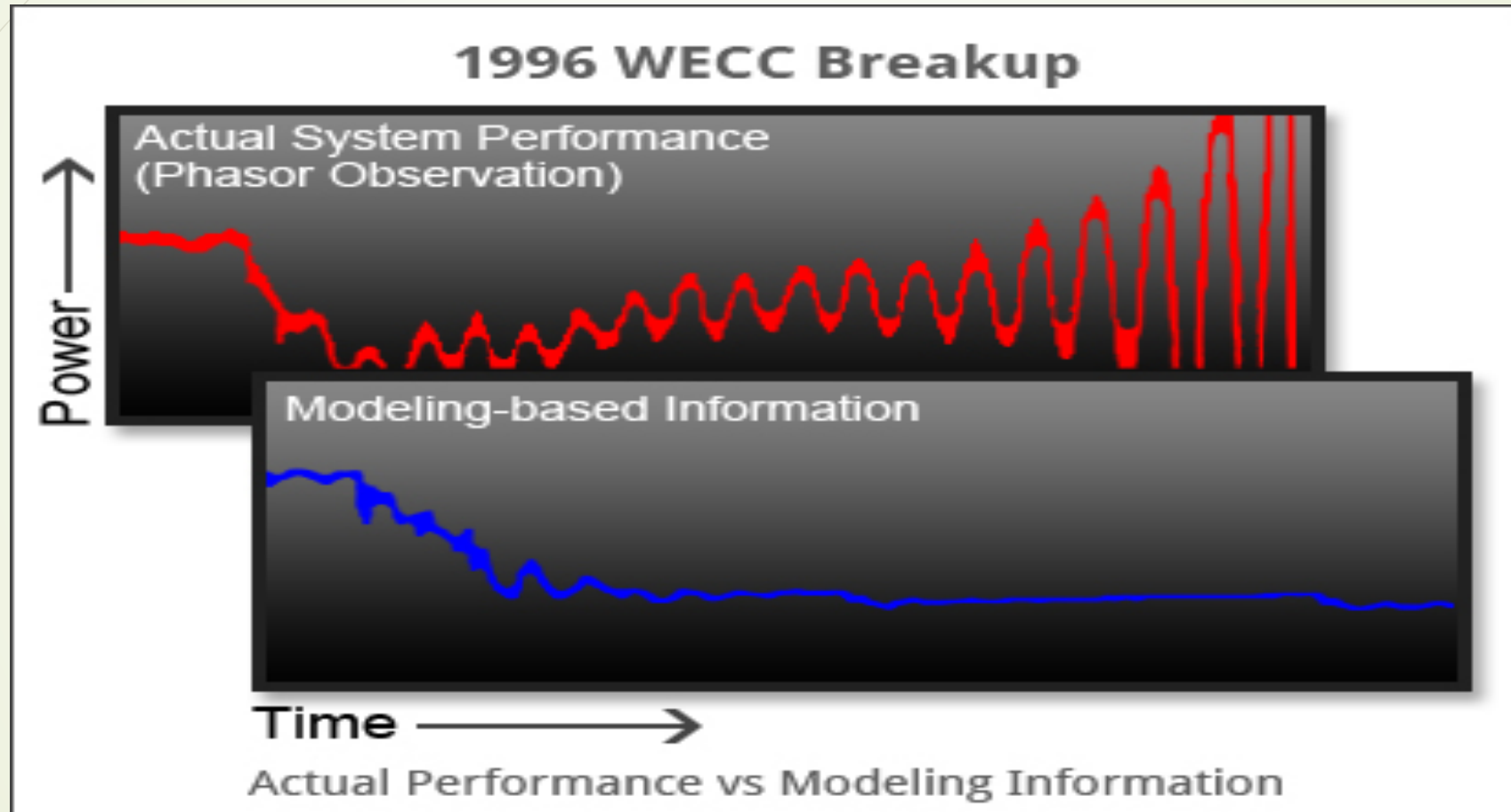


Figure: Comparison of actual system dynamics and estimated result from 1996 WECC event

Phasor:

- An AC waveform can be mathematically represented by the equation

$$x(t) = X_m \cos(\omega t + \phi) \quad \text{Eqn 1}$$

where: X_m = magnitude of the sinusoidal waveform

$\omega = 2 * \pi * f$ where f is the instantaneous frequency

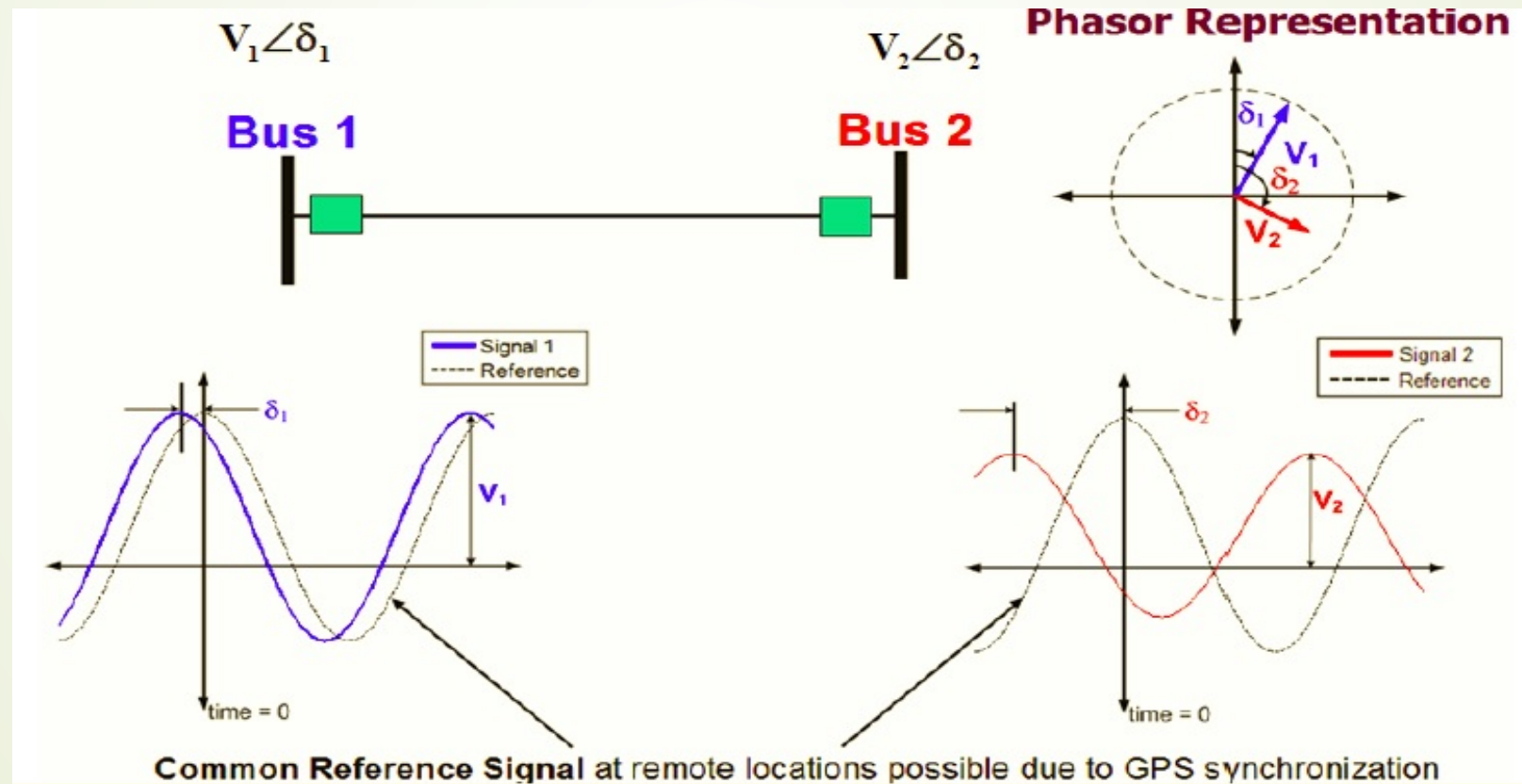
ϕ = angular starting point for the waveform

- In a phasor notation, this waveform is typically represented as

$$\bar{X} = X_m \angle \phi$$


Phasor:

- ▶ Rotating vector used to describe AC circuits which is characterized by 'Magnitude' & 'Phase'
- ▶ By definition they rotate counter-clockwise

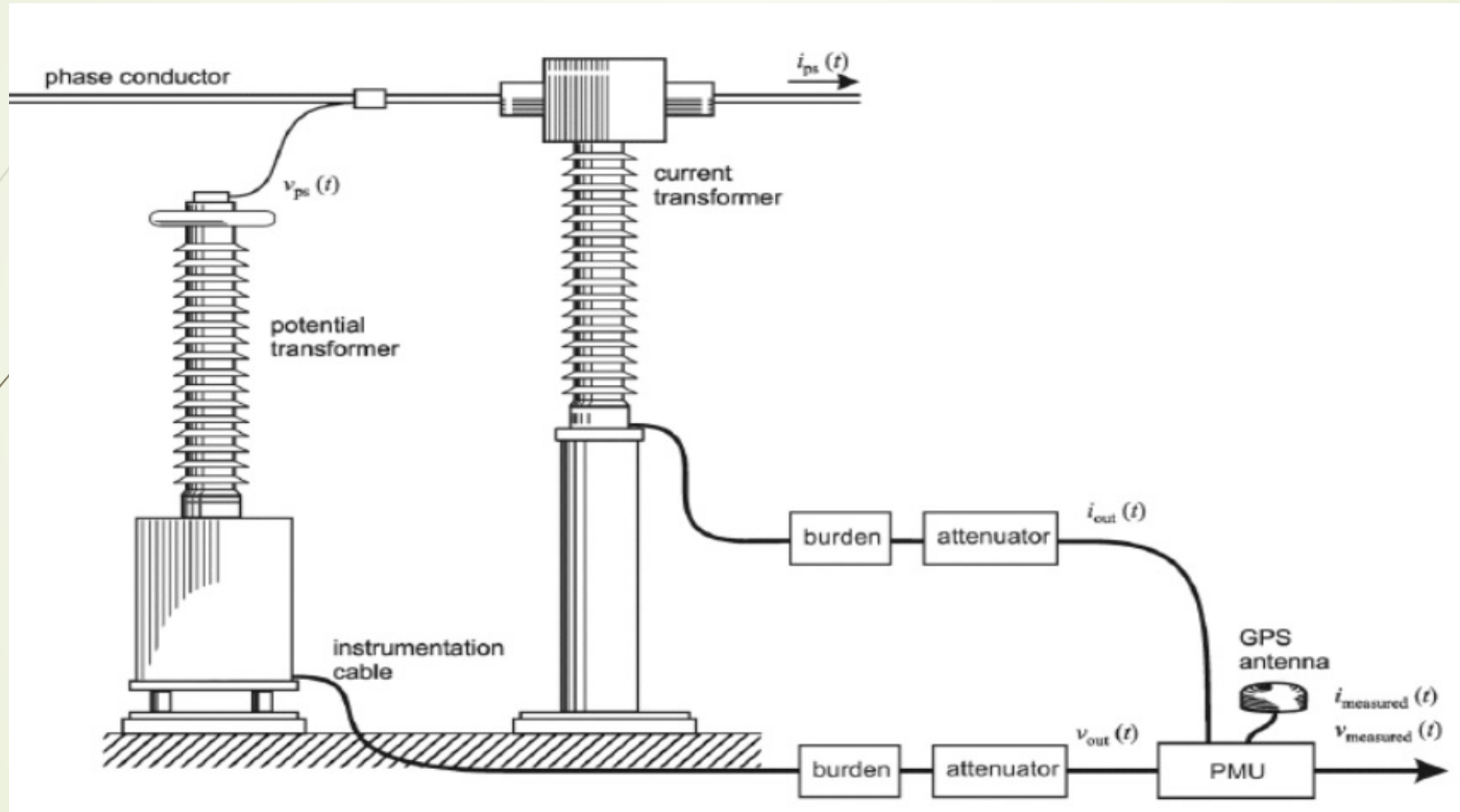




Phasor Measurement Unit

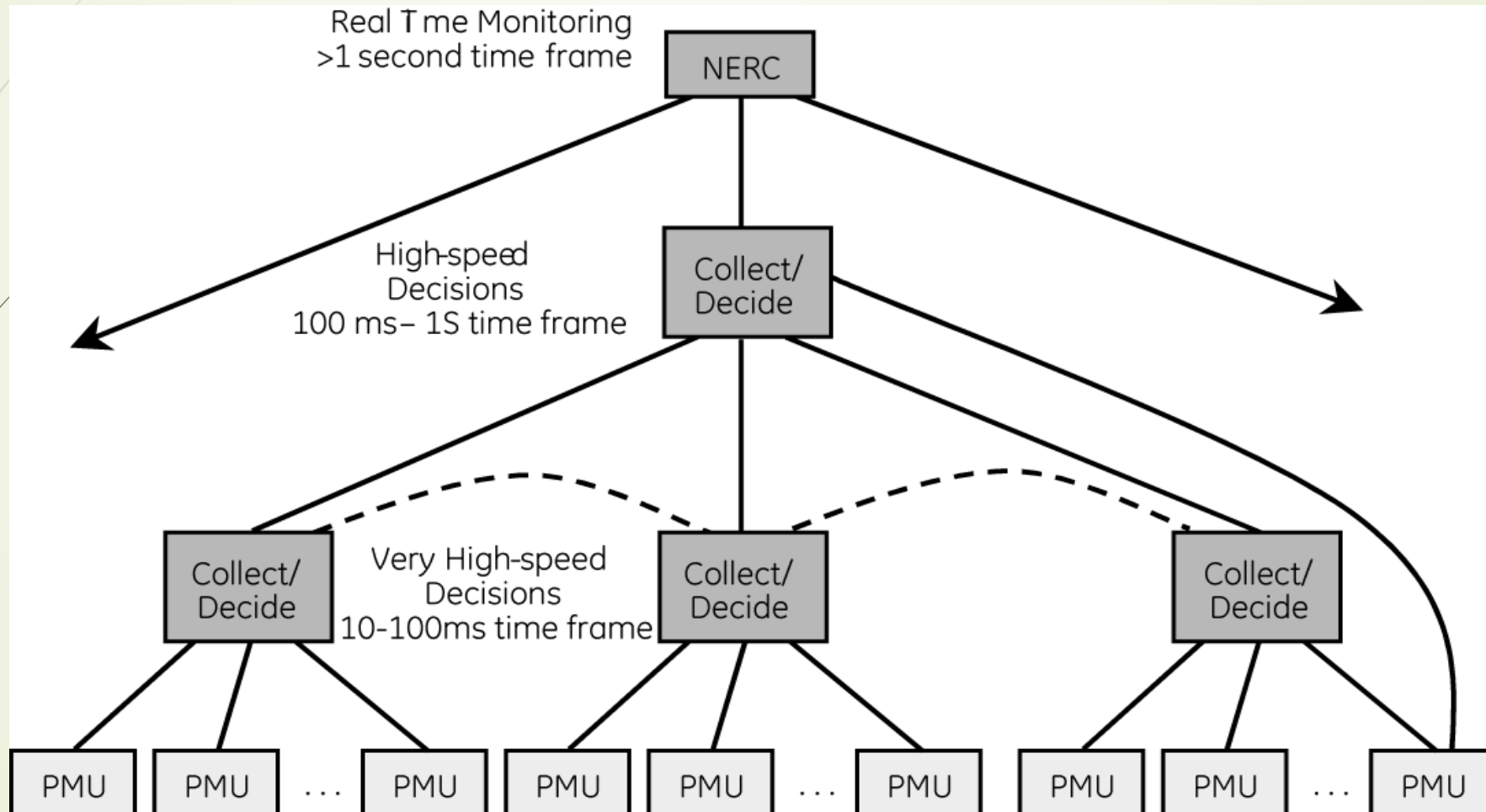
- A Synchrophasor is a phasor that is time stamped to an extremely precise and accurate time reference.
 - Basically a solid-state relay or digital fault recorder with GPS clock.
 - Synchronized phasors (synchrophasors) provide a real-time measurement of electrical quantities across the power system.
 - The resultant time tagged phasors can be transmitted to a local or remote receiver at rates up to 60 samples per second.
 - Continuously measures voltages and current phasors and other key parameters and transmits time stamped messages.
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Phasor Measurement Unit - Connections

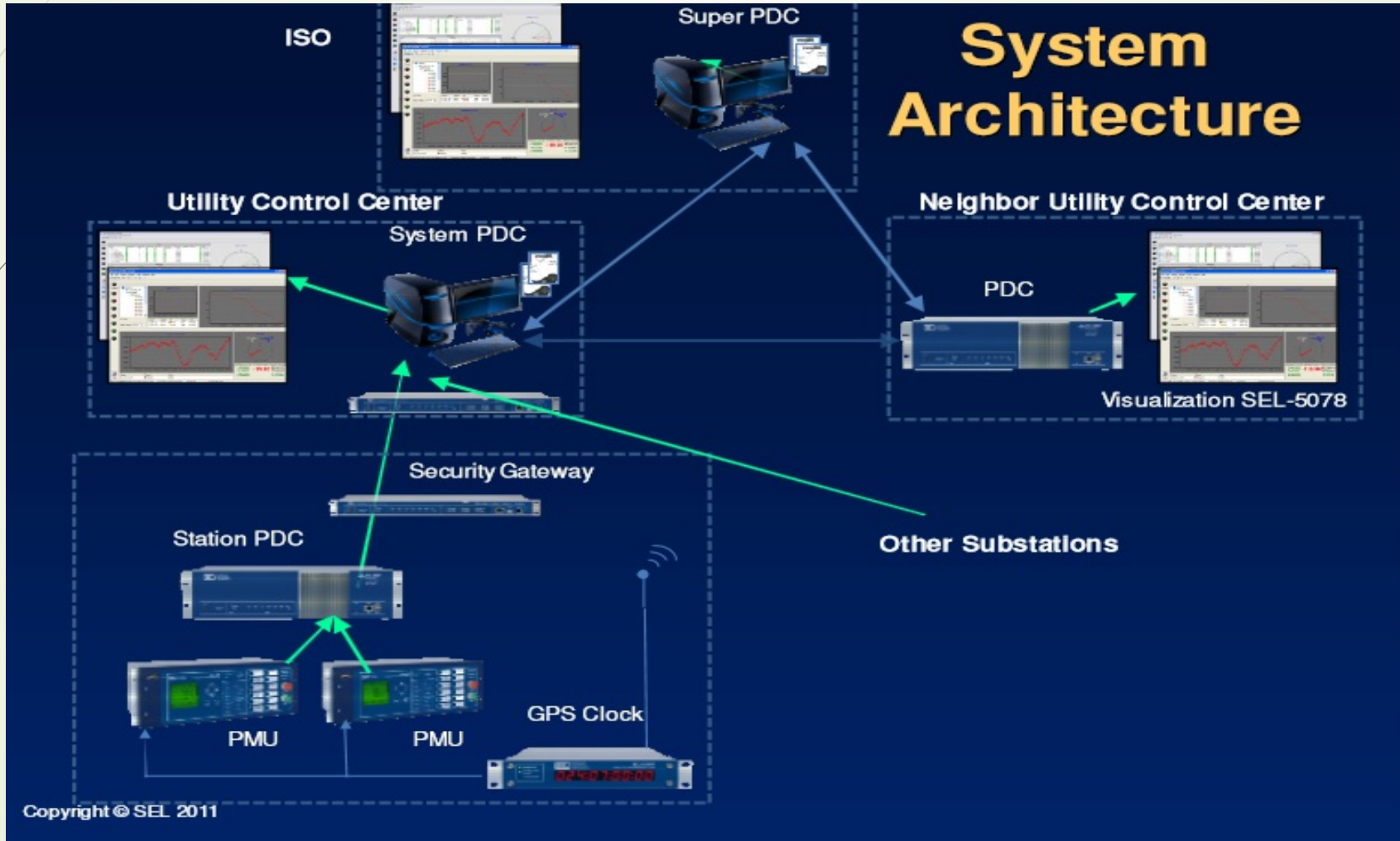


Current and potential transformer connections with PMU

Phasor Measurement Unit- Data Collection Topology



Phasor Measurement Unit – System Architecture





Phasor Measurement Unit

Phasor Data Concentrator:

- ▶ Aligns information by time the incoming PMU messages from multiple measuring devices and sends out the aggregated synchronized data set as a single data stream.
- ▶ Archive data and process the information.
- ▶ Exchange records with PDCs at other locations.

Communication:

- ▶ Links multiple PMUs to a PDC (or PDCs to other PDCs) for real time data transfer.
- ▶ Secure VPN connection from a communications center



Phasor Measurement Unit – Message Information

- ▶ The captured phasors are to be time-tagged based on the time of the UTC time reference.
- ▶ The Time Stamp is an 8-byte message consisting a 4 byte “Second Of Century – SOC”, a 3-byte Fraction of Second and a 1-byte Time Quality indicator.
- ▶ The SOC time-tag counts the number of seconds that have occurred since inception of PMU, With 3-bytes for the Fraction of Second, one second can be broken down into 16,777,216 counts or about 59.6 nsec/count and the Time Quality byte contains information about the status and relative accuracy of the source clock

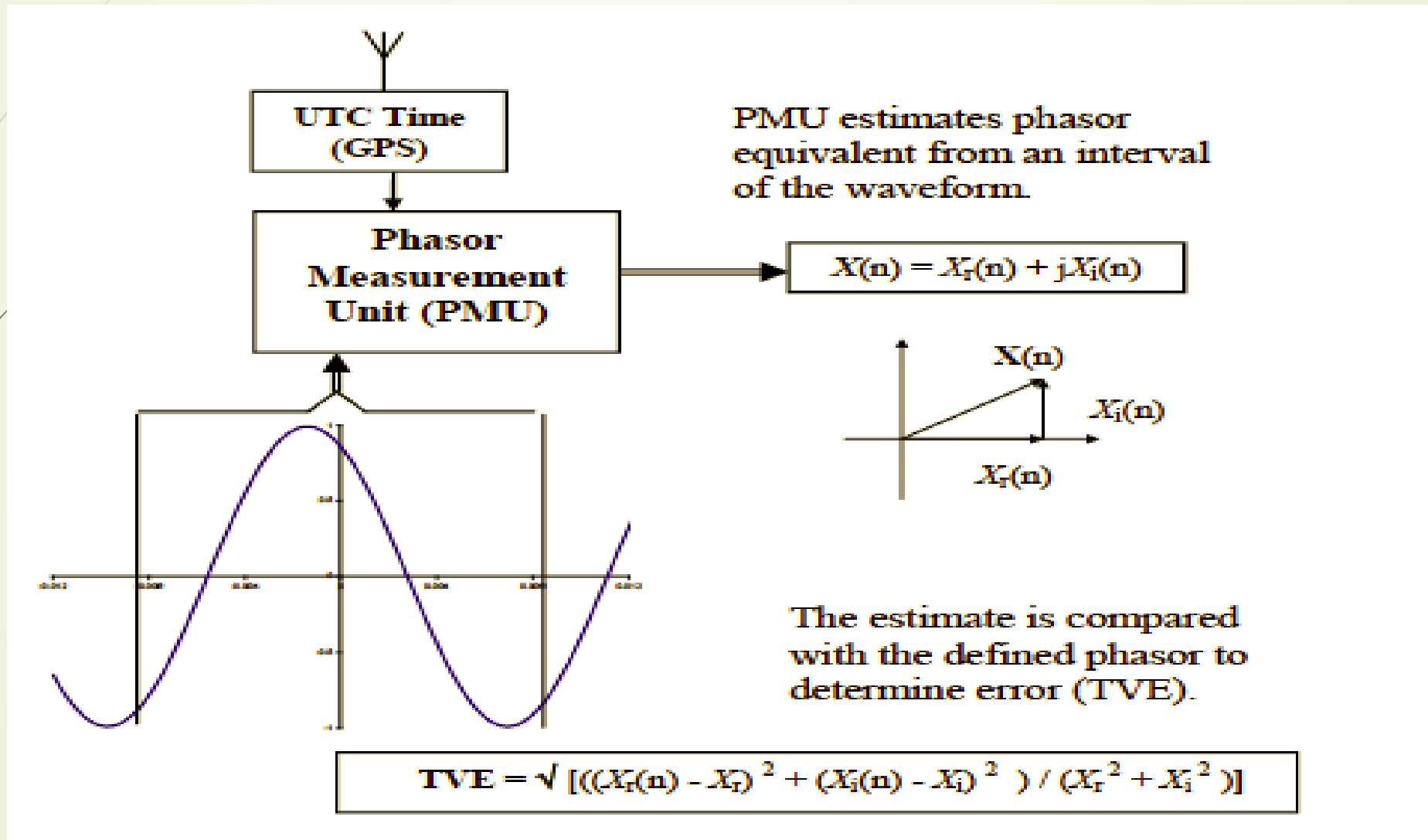
Phasor Measurement Unit – Performance criteria

- ▶ Accuracy for the Synchrophasor is measured by a value termed the “Total Vector Error” or TVE.
- ▶ TVE is defined as the square root of the difference squared between the real and imaginary parts of the theoretical actual phasor and the estimated phasor to the ratio of magnitude of the theoretical phasor and presented as a percentage.

$$\varepsilon = (\sqrt{[(X_r(n) - X_r)^2 + (X_i(n) - X_i)^2] / (X_r^2 + X_i^2)}) * 100 \quad \text{Eqn. 2}$$

- ▶ Phasor Measurement Unit (PMU) that must maintain less than a 1% TVE under conditions of ± 5 Hz of off-nominal frequency, 10% Total Harmonic Distortion, and 10% out-of-band influence signal distortion.

Phasor Measurement Unit – Performance criteria






Phasor Measurement Unit - Measurements

PMUs measure (synchronously):

- Positive sequence voltages and currents
- Phase voltages and currents
- Local frequency
- Local rate of change of frequency
- Circuit breaker and switch status



Real Time Dynamics Monitoring System (RTDMS)

- ▶ RTDMS is a Synchrophasor software application for providing real time, wide area situational awareness to Operators, Reliability Coordinators, Planners and Operating Engineers, as well as the capability to monitor and analyze the dynamics of the power system.
- ▶ RTDMS provides critical metrics of grid dynamics, like
 - ▶ Phase Angle Differences (Grid Stress)
 - ▶ Small Signal Stability (Oscillations & Damping)
 - ▶ Frequency Instability
 - ▶ Generation-Load Imbalance
 - ▶ Power-Angle Sensitivity
 - ▶ Power-Voltage Sensitivity

Real Time Dynamics Monitoring System (RTDMS)

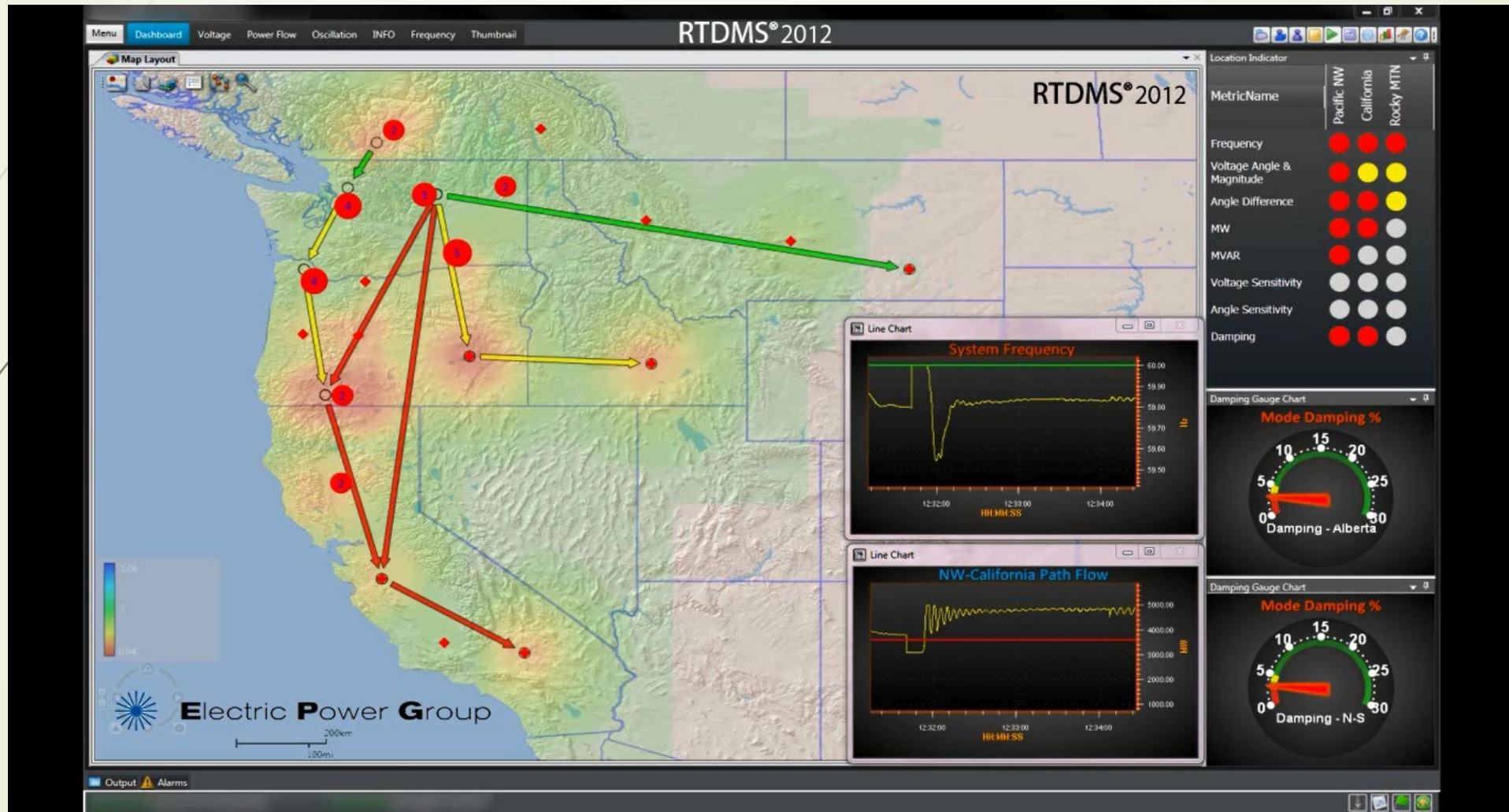


Figure: RTDMS application dashboard

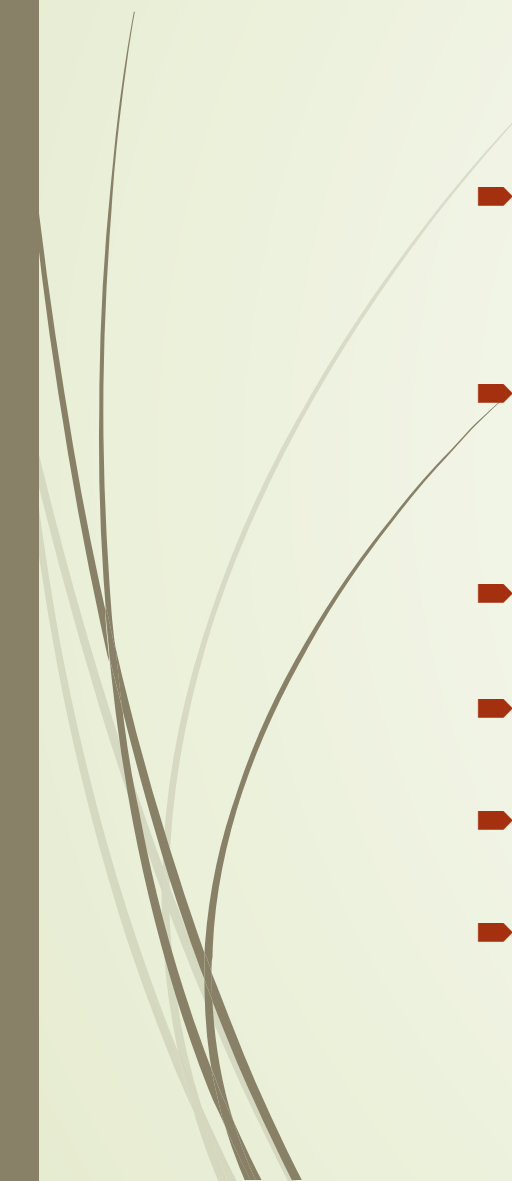


Phasor Measurement Unit – Applications

- Global behavior may be understood from local measurement
- Phasor measurement data can be used to supplement/enhance existing control center functions and provide new functionalities.
- Phasor measurement data with GPS signal can provide synchronized voltage and current phasor measurements across a wide region
- By measuring the phase directly, the power transfer between buses can be computed directly
- High sampling rate (30 samples per second) Extended visibility: beyond one's own operating region
- Disturbance monitoring –transient and steady-state responses



Phasor Measurement Unit - Challenges:

- Visualization of PMU data – Difficult to visualize and manage large amounts of data.
 - Communication of PMU data – Expensive communication network required.
 - Optimal Placing of PMU's.
 - High investment.
 - Diverse requirements from the utilities.
 - Communication delays.
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Questions ..?

Thank you