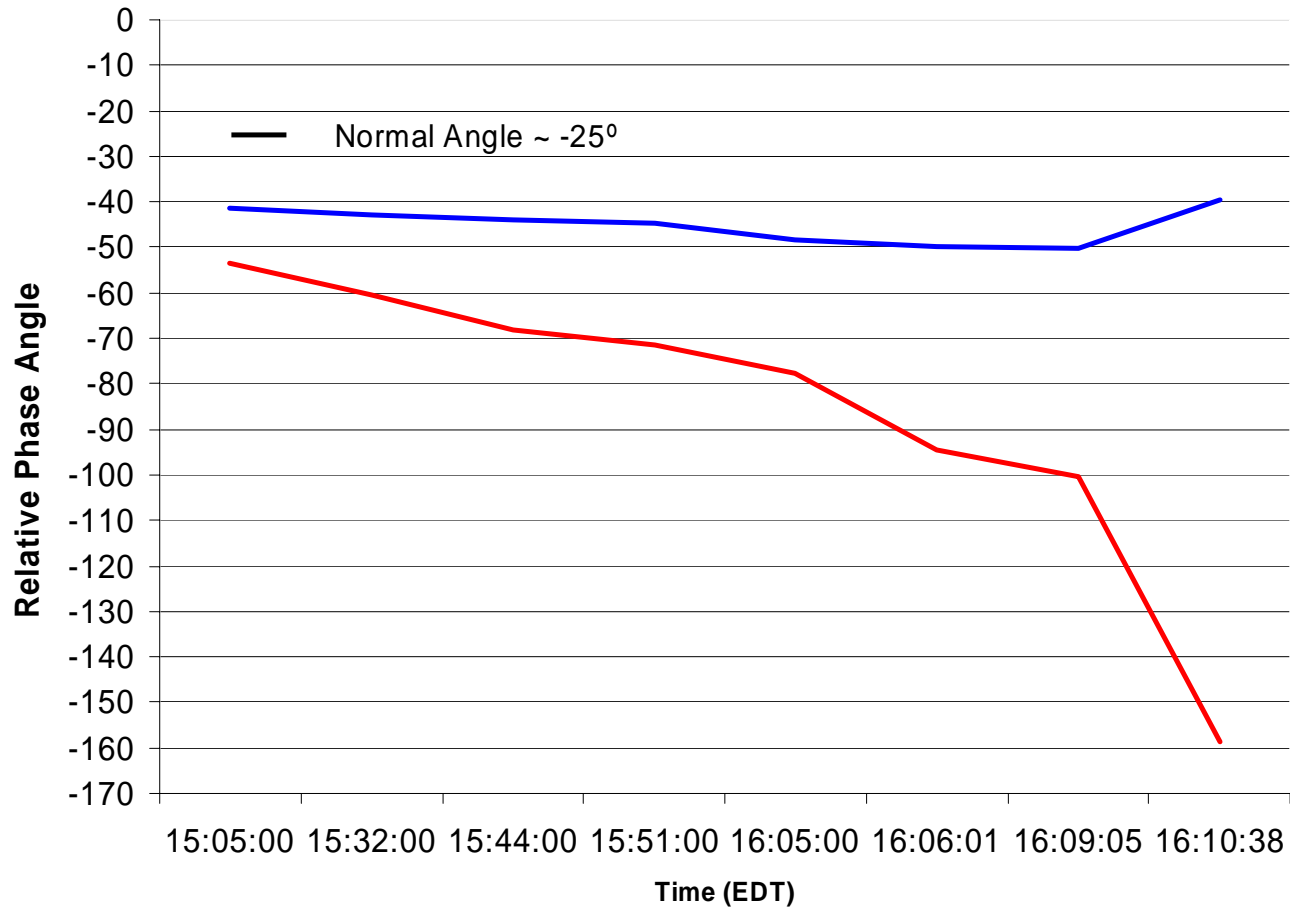


Wide Area Monitoring & Synchrophasors

Definition, Measurement, and Application



Cleveland Separation – Aug 14, 2003



Reference:
Browns Ferry

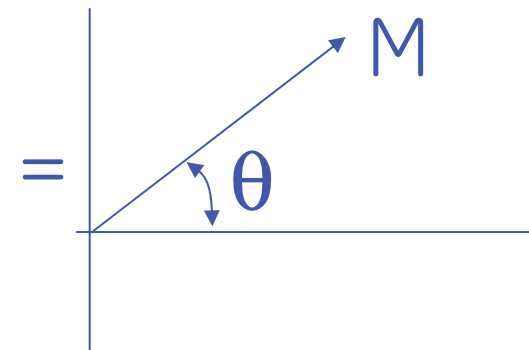
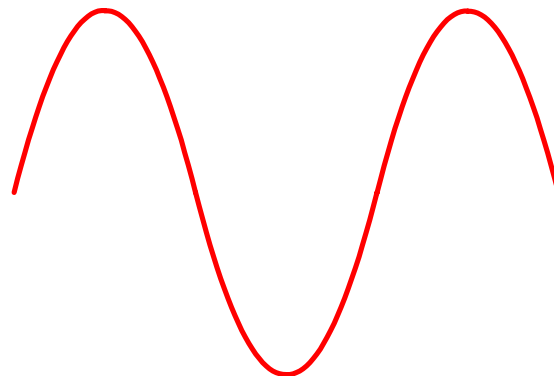
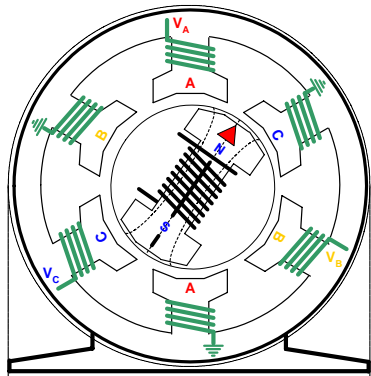
— Cleveland — West MI

Drivers

- Operating the grid is not going to get easier:
 - Insufficient stability margins
 - Generation and load centers displaced even more
 - Environmental and cost constraints on new transmission
 - Deregulations and pressure on asset utilization
 - No recognition for maintaining system security and margins
- Logical response:
 - With limited capabilities to strengthen generation and transmission (*natural stability*) need to rely more on active controls (*forced stability*)
 - Better visualization and assistance tools for operators
 - Closed-loop control for events beyond response time of manual control:
 - fight to stay together
 - island controllably
 - restore quickly

Phasors

> Rotating rotors = alternate currents / voltages



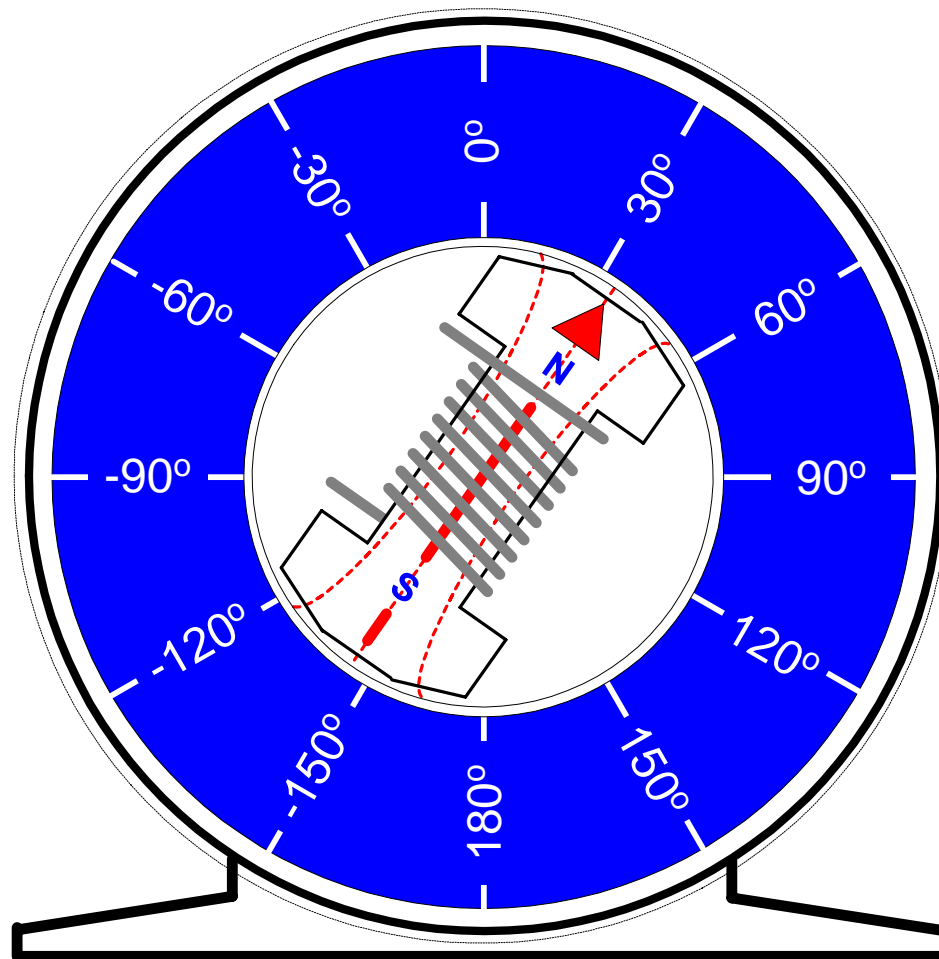
> Phasors are well established means of representing ac circuits



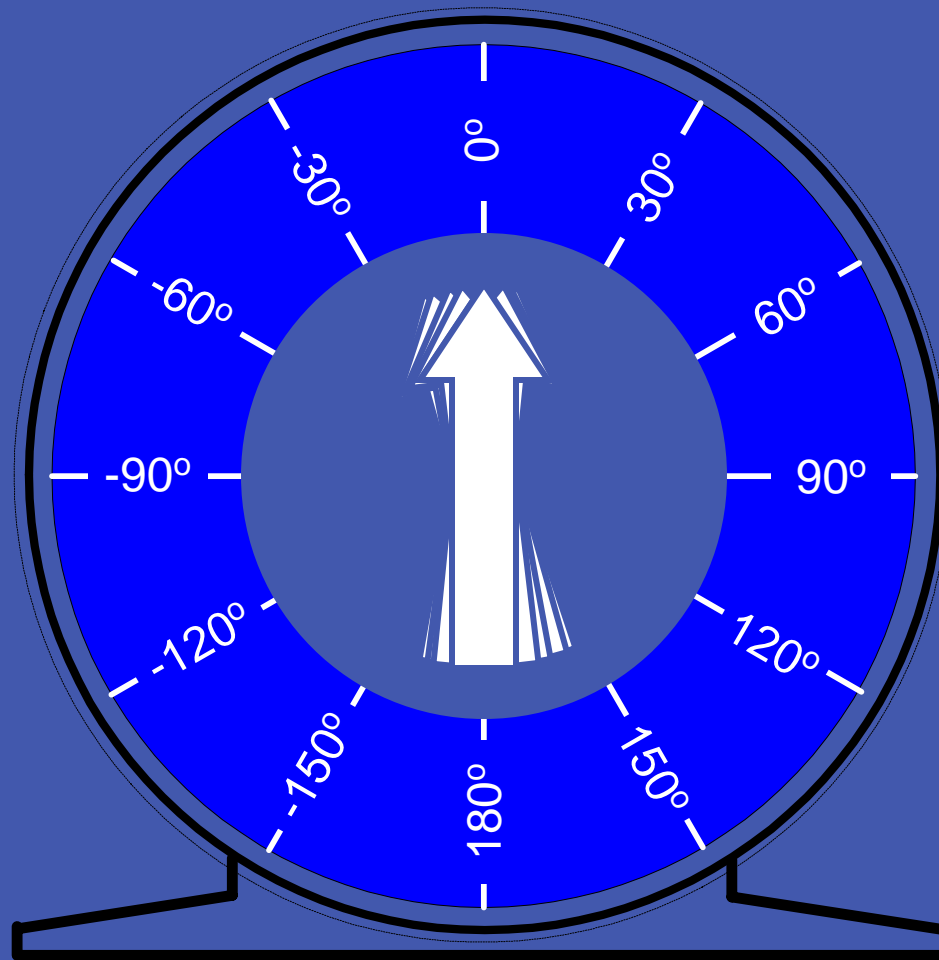
Charles Proteus Steinmetz (1865-1923)

Complex Quantities and their use in Electrical Engineering; Charles Proteus Steinmetz; Proceedings of the International Electrical Congress, Chicago, IL; AIEE Proceedings, 1893; pp.33-74.

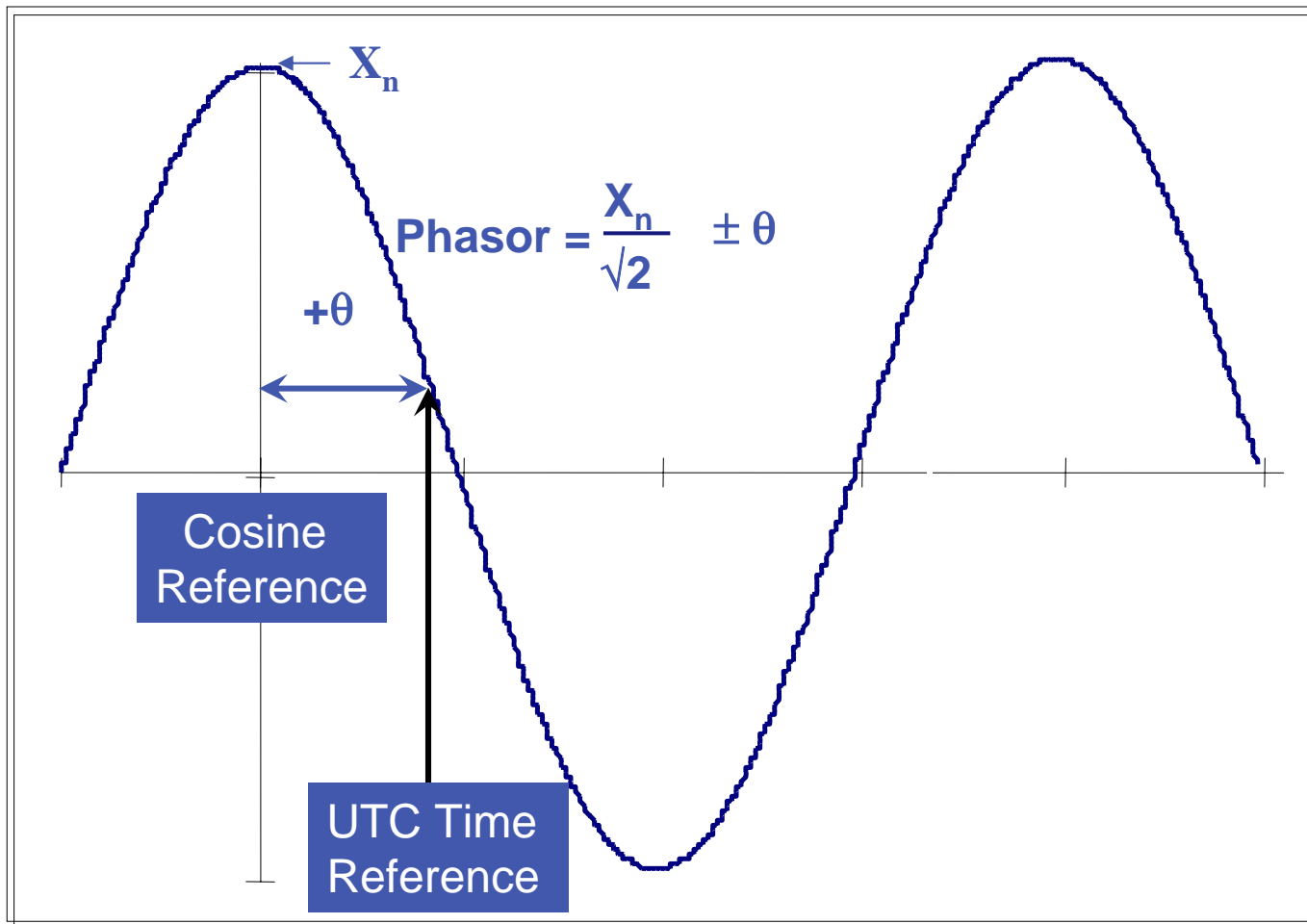
Synchrophasors Strobe Light Analogy



Strobe Light Analogy



Phasor Definition per C37.118



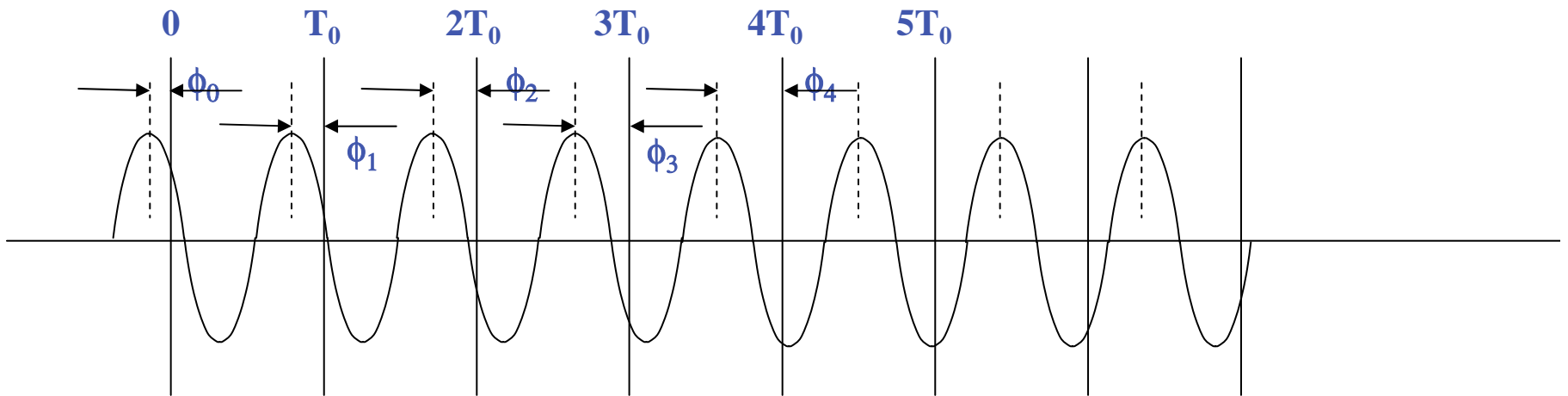
Standardized Synchronous Reporting Rates

System Frequency	50 Hz		60 Hz				
Report rates (phasors/sec)	10	25	10	12	15	20	30

Optional Phasor Reporting Rates:
50 phasors/sec on 50 Hz systems
60 phasors/sec on 60 Hz systems

UTC Based Synchronized Reporting

Report Rate = 60 Phasors/second

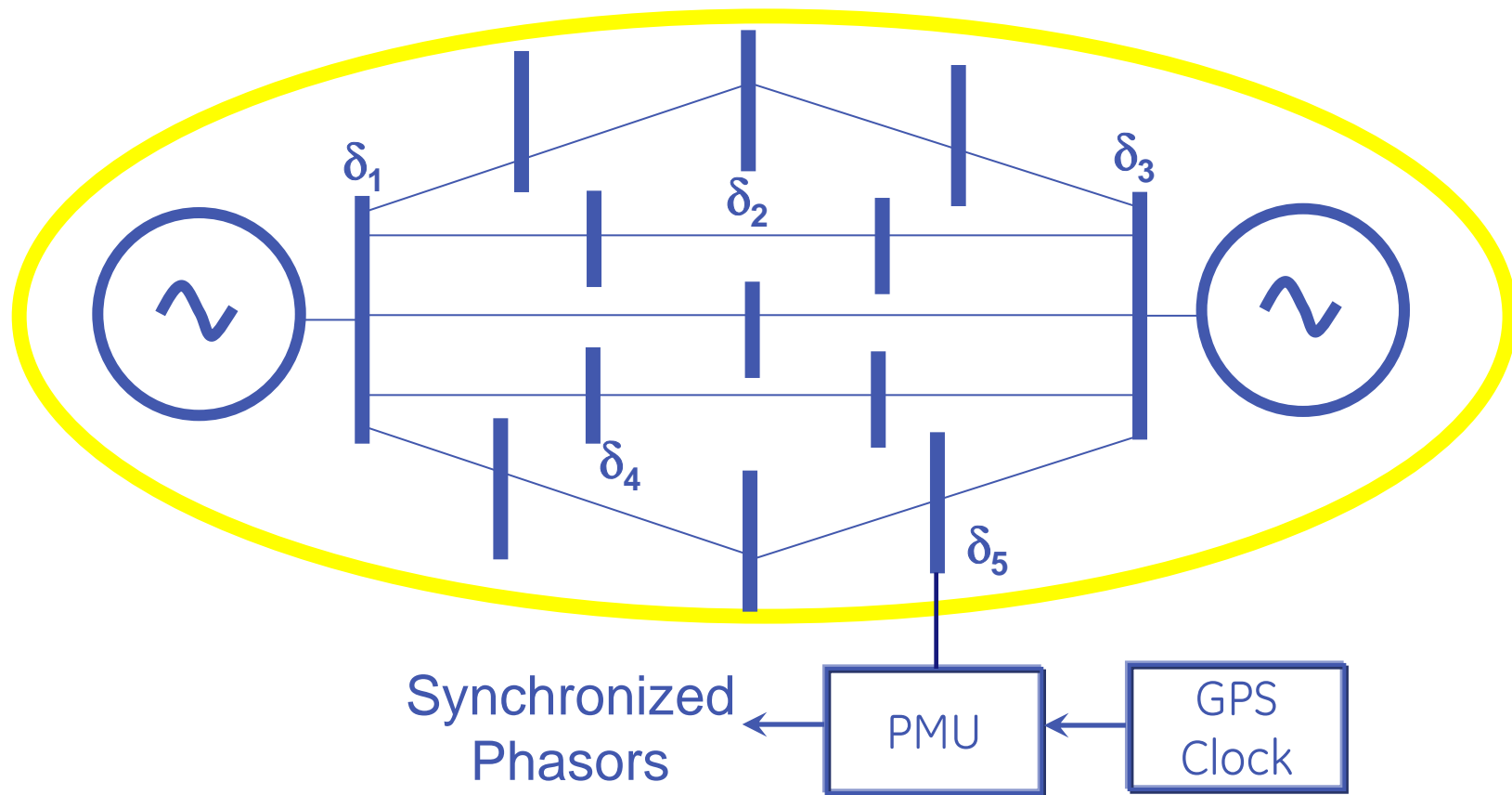


Where: 0 = Top of Second

$T_n = 0 + n*(1/F_s)$ from top of second

PMU Implementation

PMU – Phasor Measurement Unit



Synchrophasor Report Format

Second of Century (SOC) – from Jan 1, 1970 - 4 bytes

Fraction of Second (modulo 2^{24}) + Time Quality

Phasors (mag and angle) – Integer or Float – 4 or 8 bytes

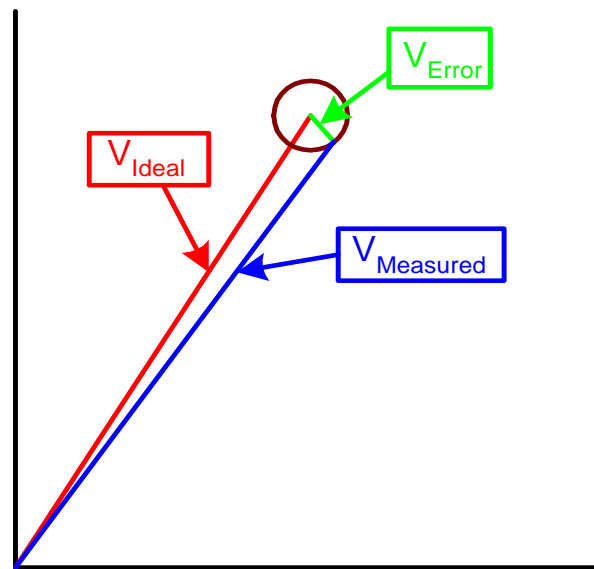
Other Measurements (f, df/dt, W, Var, Events)

Time Quality Byte

<u>Bit#</u>	<u>Function</u>
0-3	Time Server quality per PC37.118
4	Leap Second Pending
5	Leap Second Occurred
6	Leap second Direction (0 for add, 1 for delete)
7	Reserved

Total Vector Error

$$\text{TVE} \equiv \frac{|\mathbf{V}_{\text{Measured}} - \mathbf{V}_{\text{Ideal}}|}{|\mathbf{V}_{\text{Ideal}}|}$$



Influence Quantities and Error Limits

± 5 Hz Frequency range resulting in:

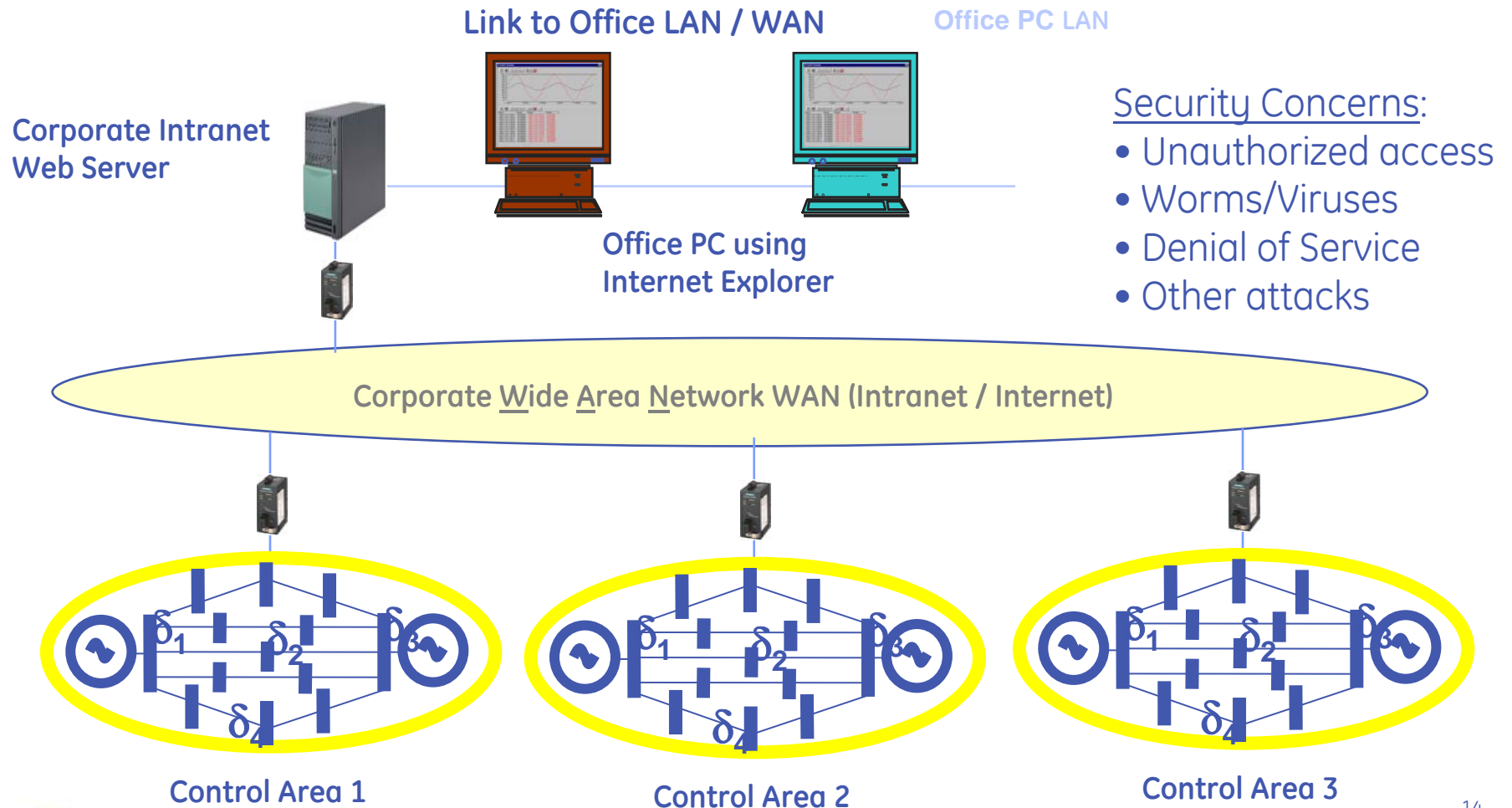
- > Magnitude Errors
- > Angle Errors

10% Total Harmonic Distortion

10% Interfering Signal

TVE from all Sources must be $< 1\%$

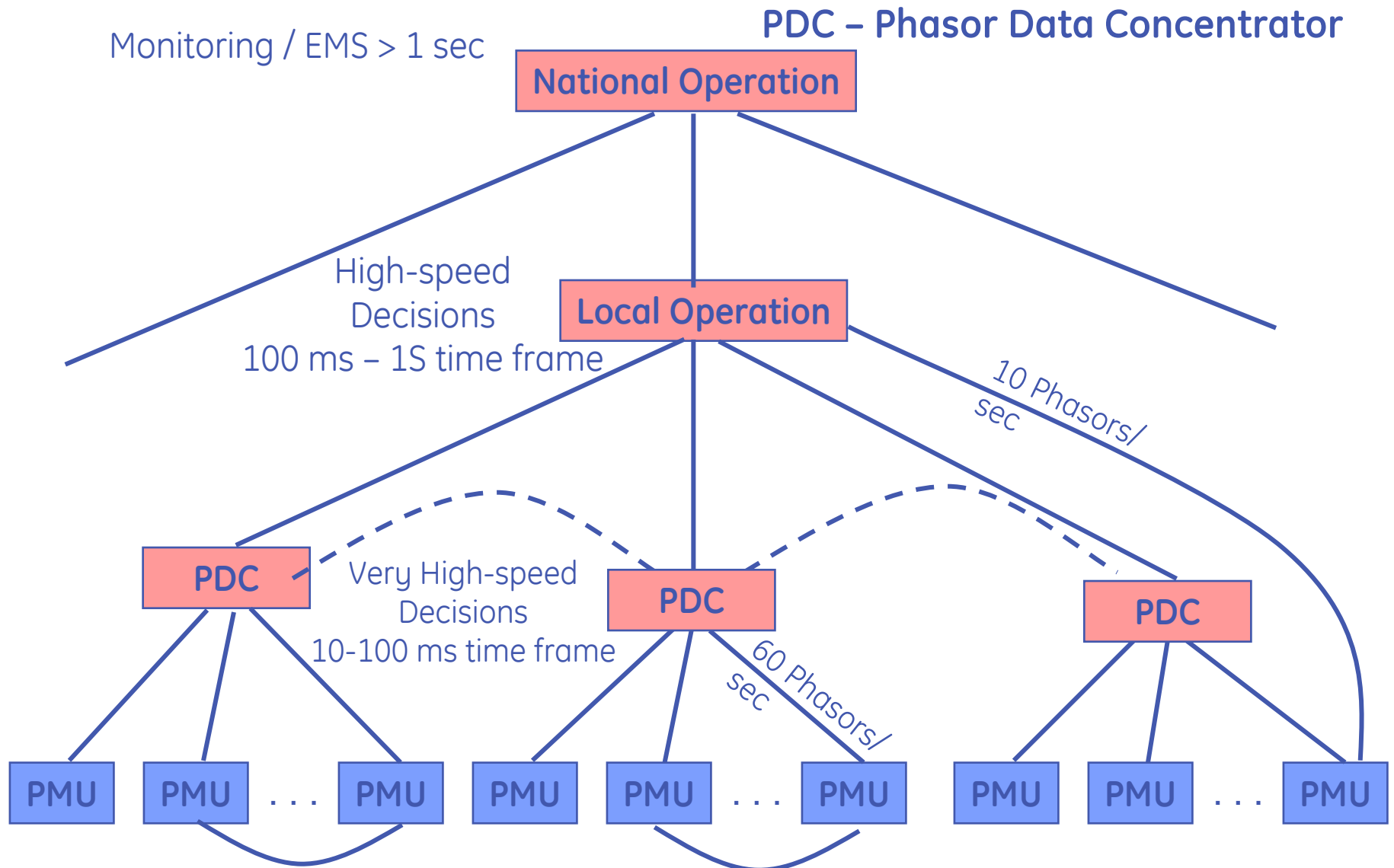
Wide Area Network Structure

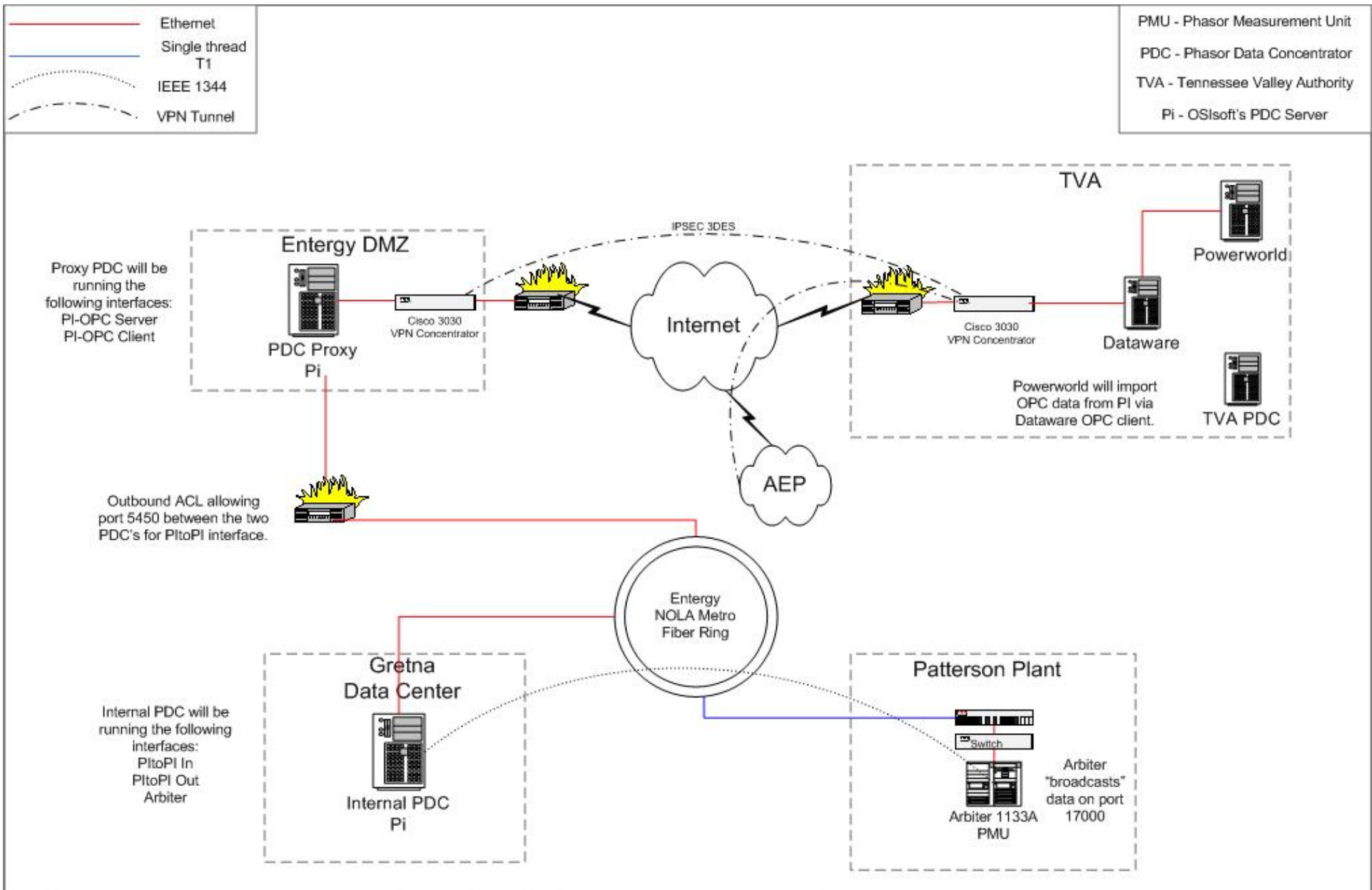


Security Concerns:

- Unauthorized access
- Worms/Viruses
- Denial of Service
- Other attacks

Reporting Hierarchy Options





REV.	DESCRIPTION	DATE	BY
0	Original Issue	06/04/04	LMC



REVISED 6/17/2004

FILENAME EIPP.vsd

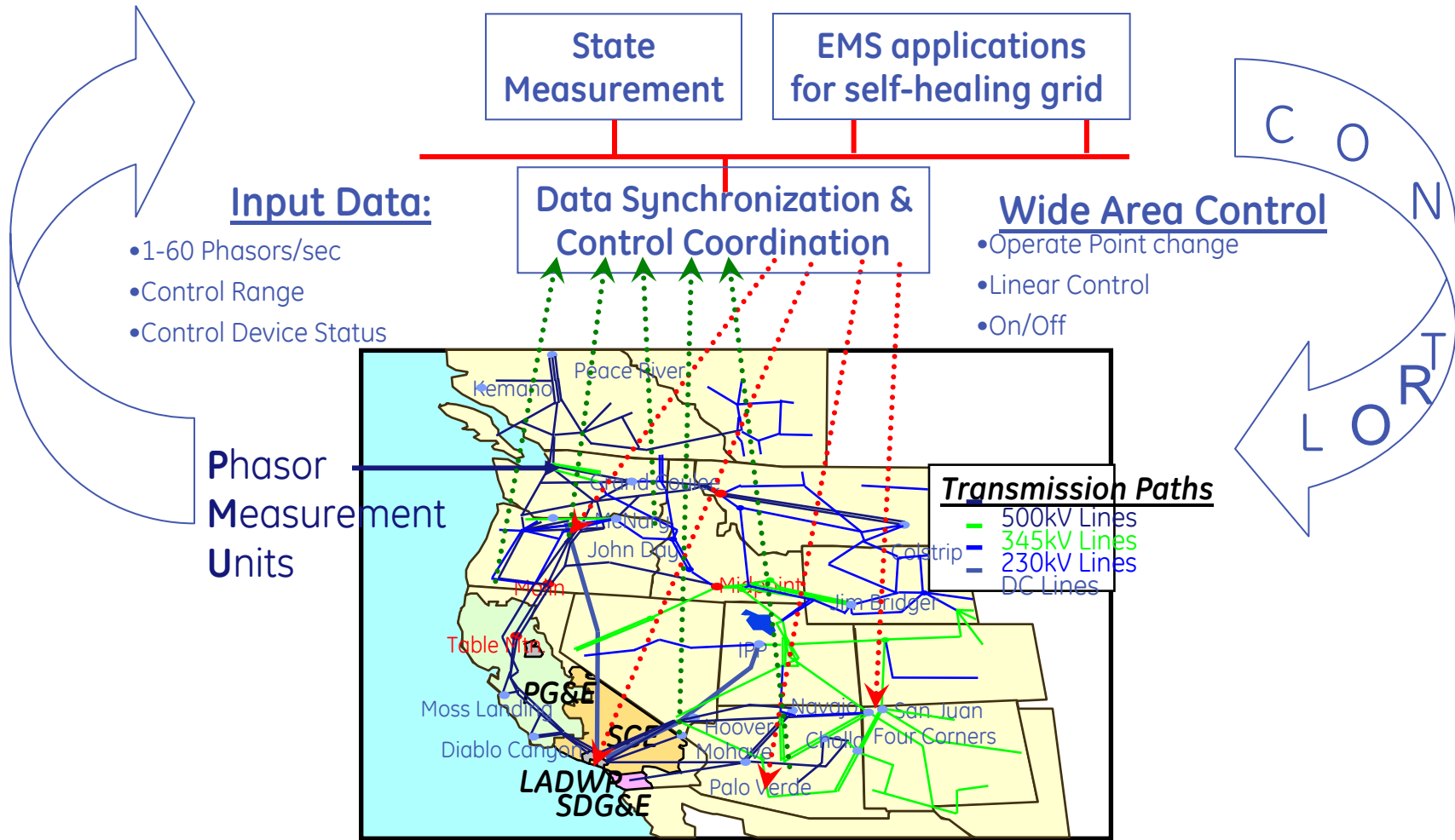
EIPP (Eastern Interconnect Phasor Project)

Phase One Design

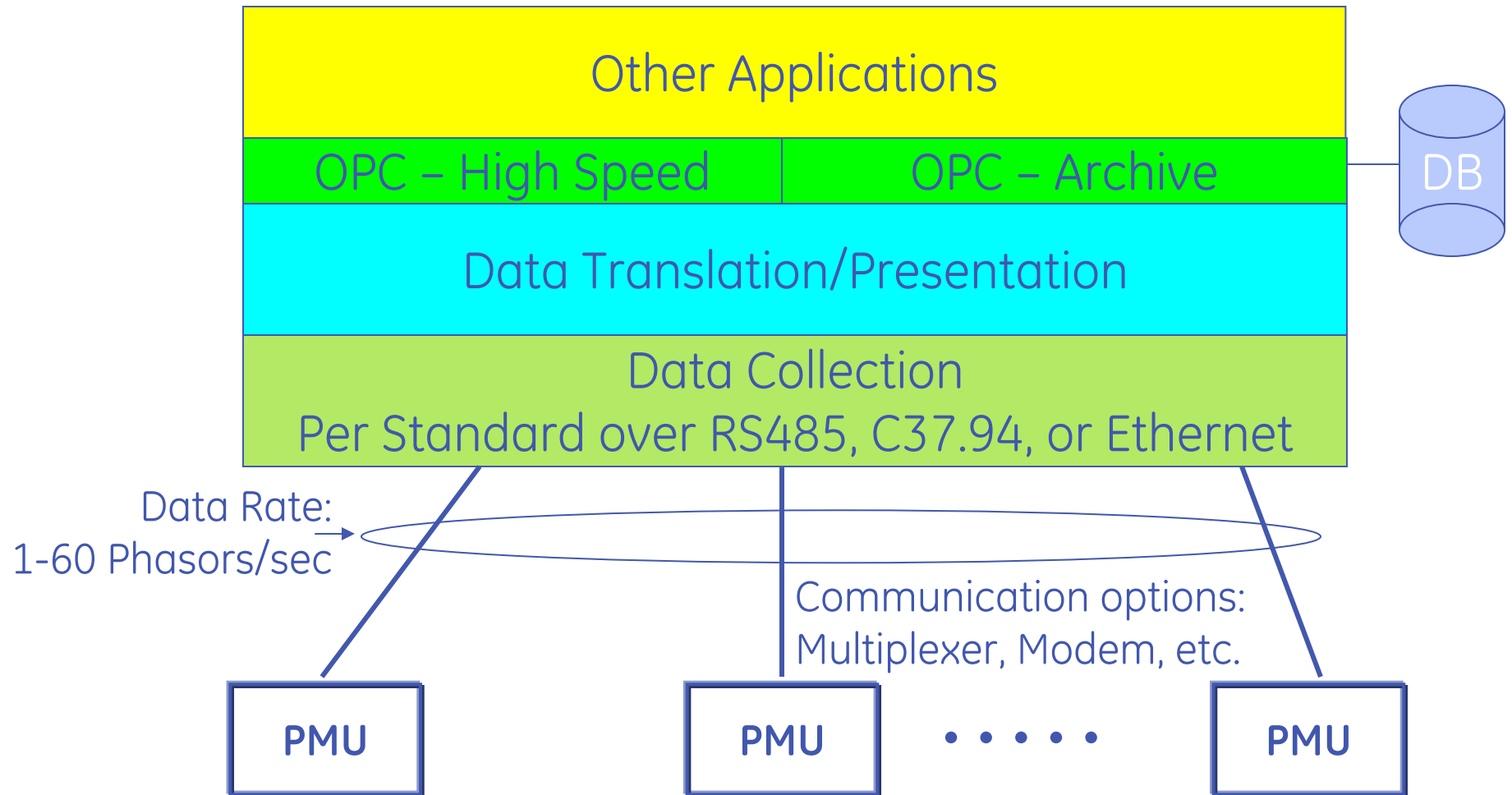
TVA Demonstration

SCALE None ENG. Leonard Chamberlin SHEET 1 OF 2

Wide Area Monitoring and Control



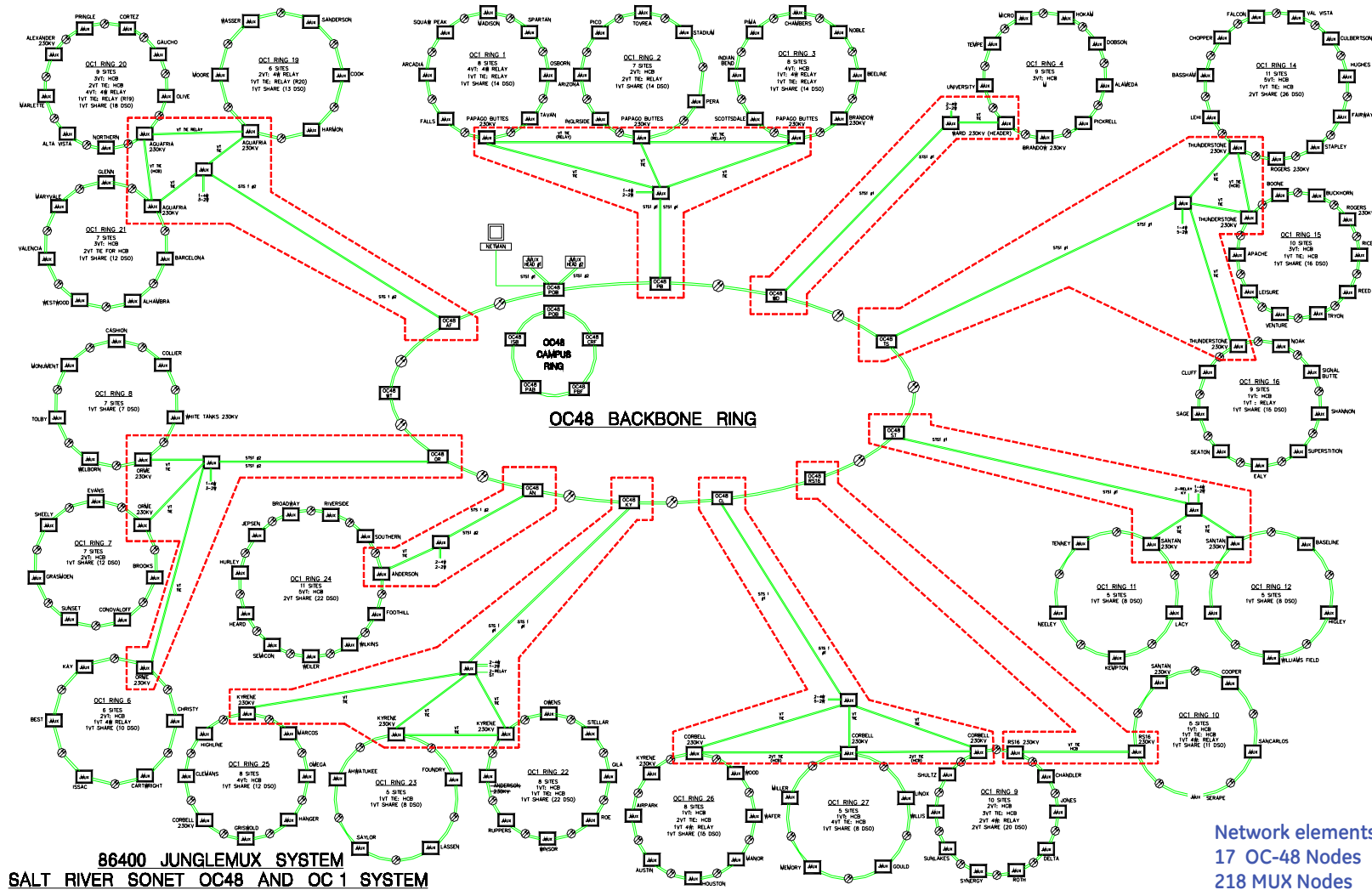
Phasor Data Concentrator Function



Communication Network Requirements

- Guaranteed bandwidth
- Adjustable bandwidth
- Settable priority
- High-availability (99.99%)
- Low latency
- Standards based
- Scalable
- High noise immunity
- Support for other functions
- Automatic Configuration
- Network monitoring/management

SRP Communication Network

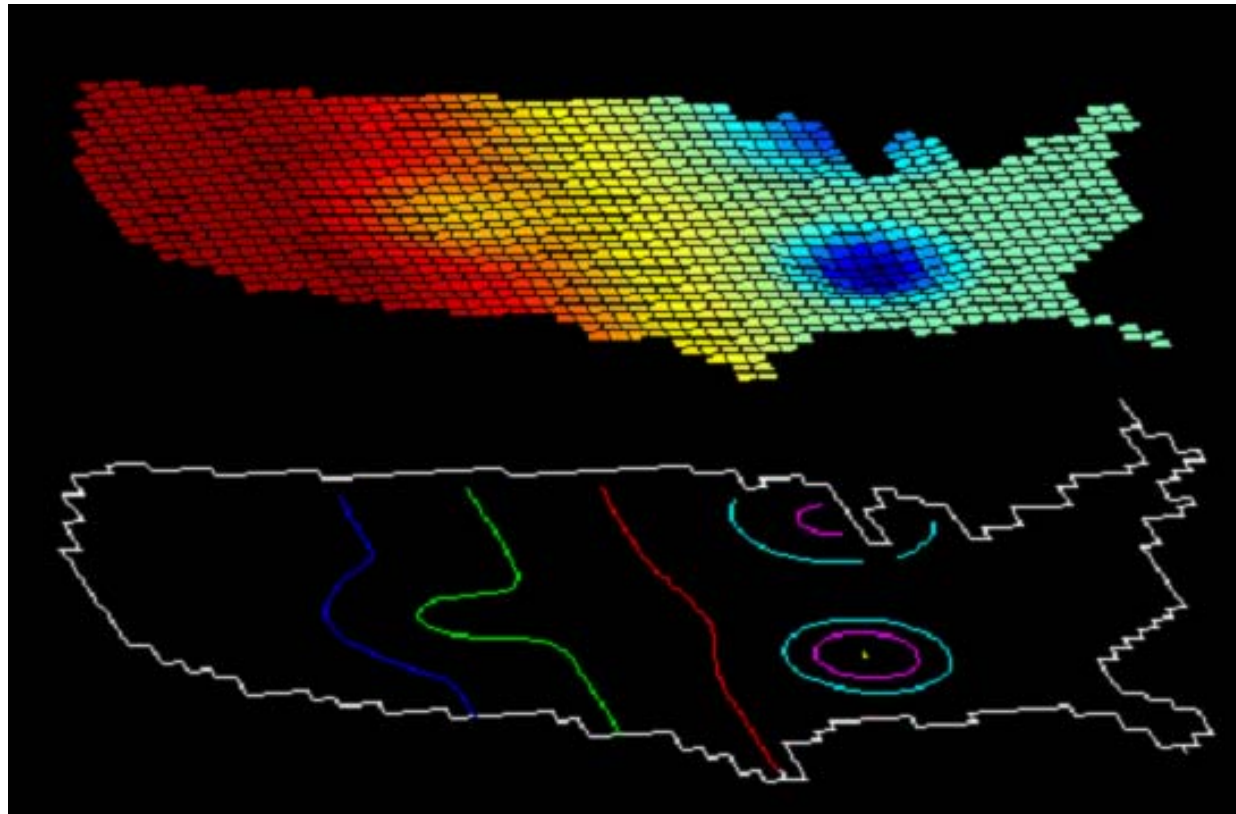


Palo Verde *Round Trip* Communication Timing

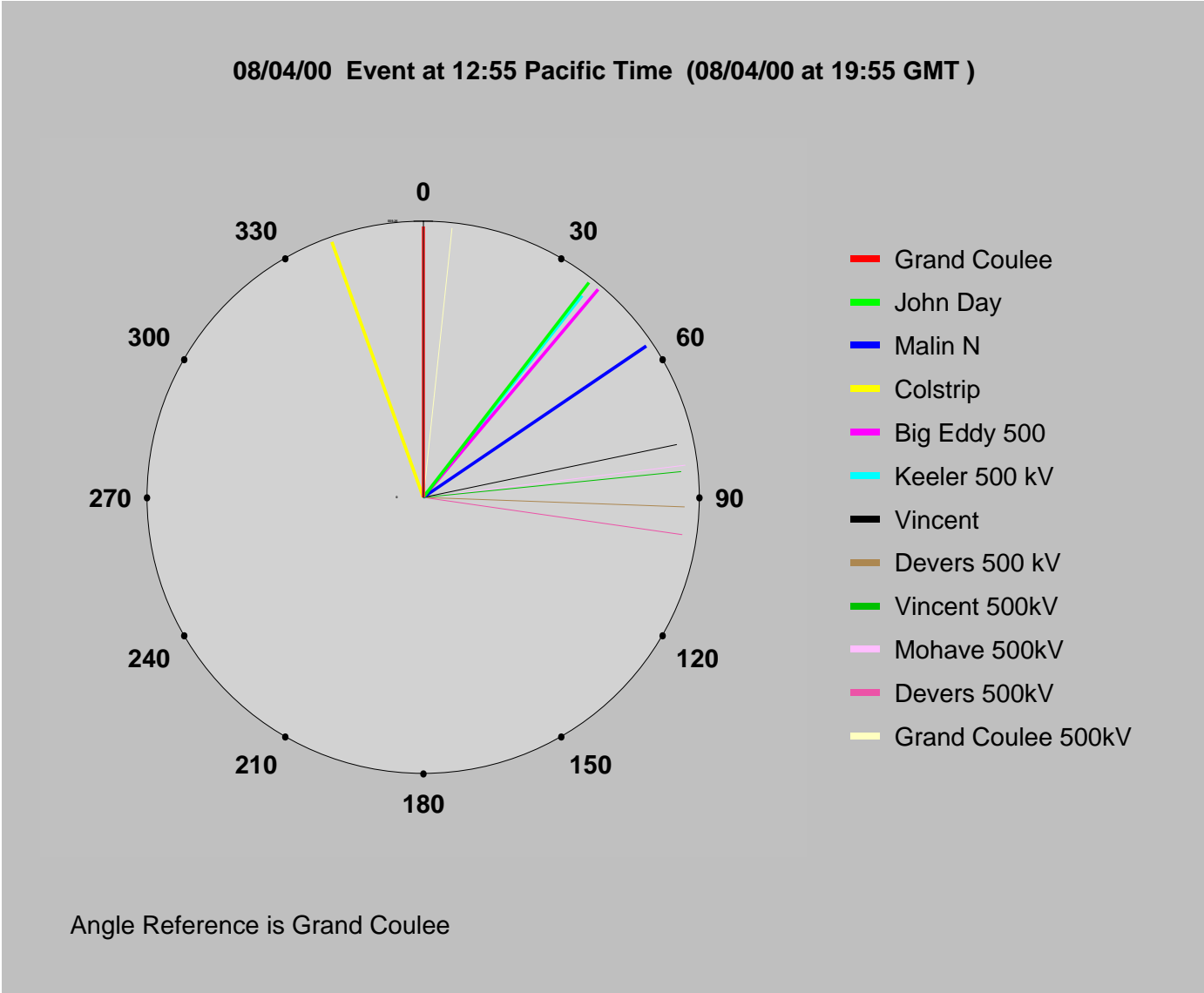
Site	Ethernet	G.703
Gaucha	14ms	11ms
Alameda	14ms	20ms
Indian Bend	14ms	33ms
Buckhorn	14ms	46ms

Wide Area System View

Phase Angle

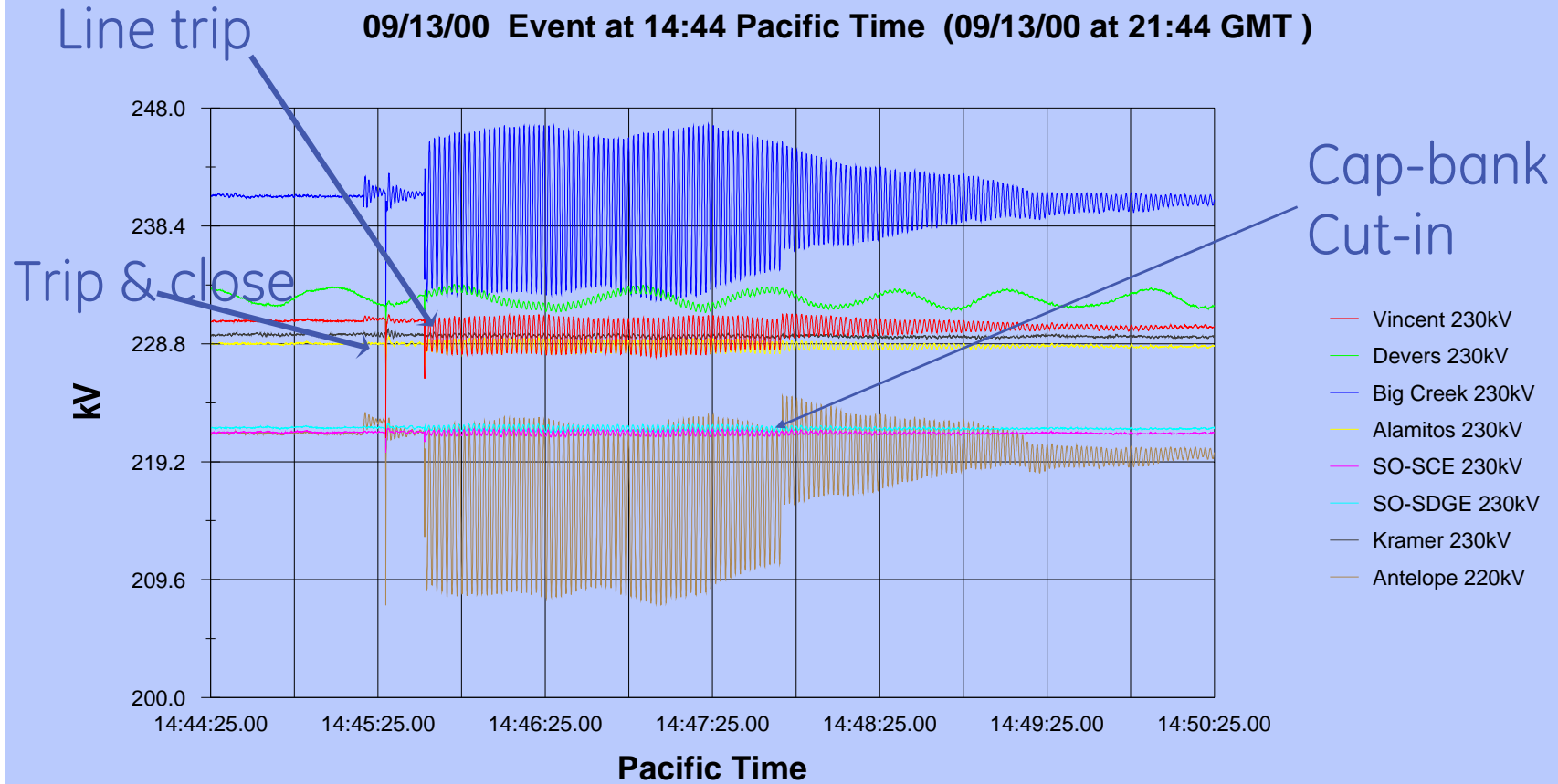


Phasor Viewing



Big Creek System Oscillations of September 13, 2000

Voltage plots for 230 busses



Other Visualization Applications

- Frequency and rate-of-change of frequency
- Positive, negative, and zero sequence plots of system voltage
- Damping constant calculations
- Power flow / change in power flow / general change detection
- Oscillation Identification / frequency calculation
- Historical Trends
- Event Signature Analysis

Functions & Applications

- Wide Area Monitoring and Advance Warning Systems
- Telemetry & Inter-utility Data Exchange
- Load/Generation Shedding
- Angular Instability Detection
- Wide-area Voltage Regulation
- Remedial Action & Power System Protection Schemes
- System Back-up Protection & Related Applications
- Coordinated Restoration
- Self Recovering Systems

Theoretically-founded opportunities