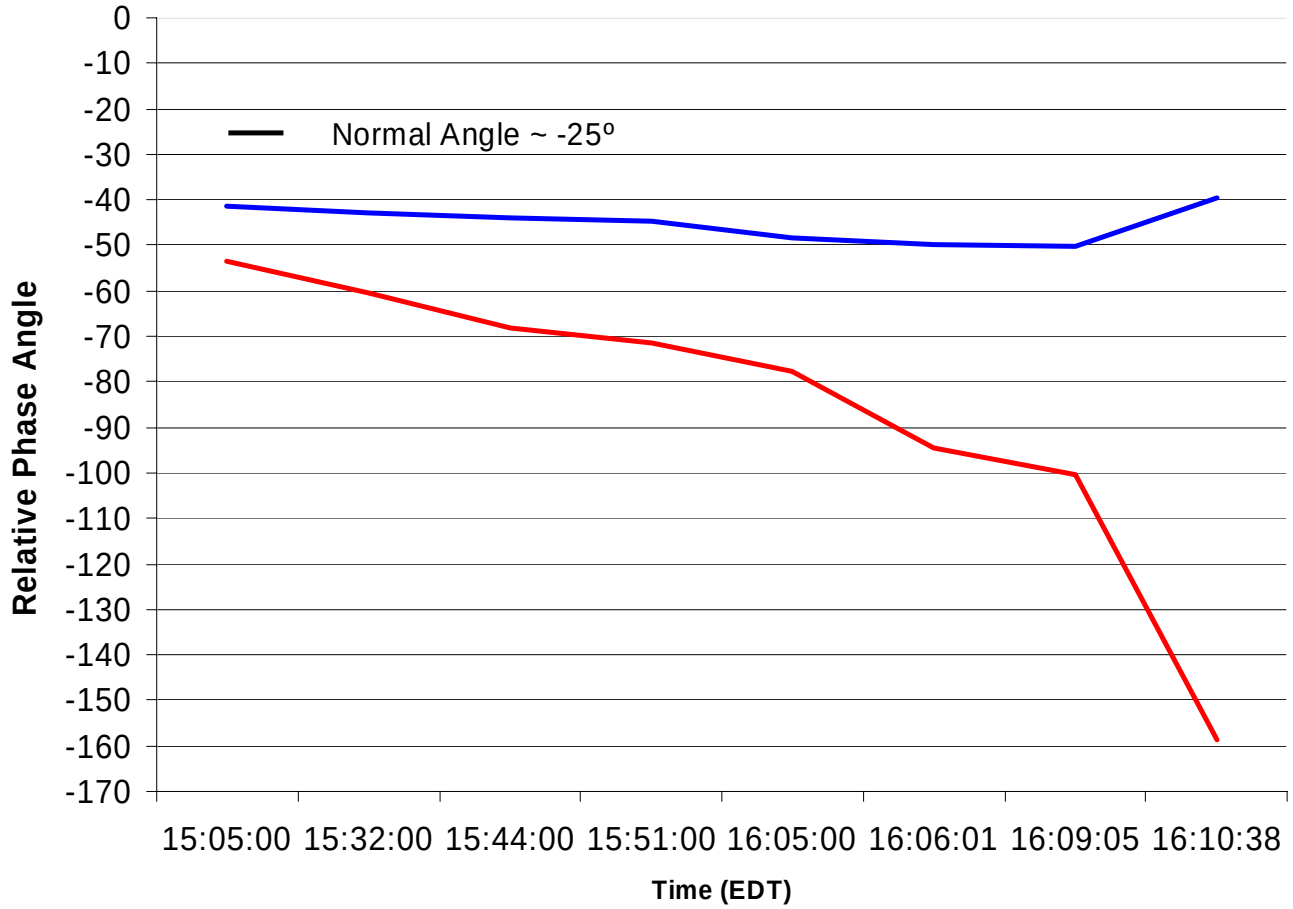
Wide Area Monitoring & Synchrophasors

Definition, Measurement, and Application

imagination at work

Cleveland Separation – Aug 14, 2003



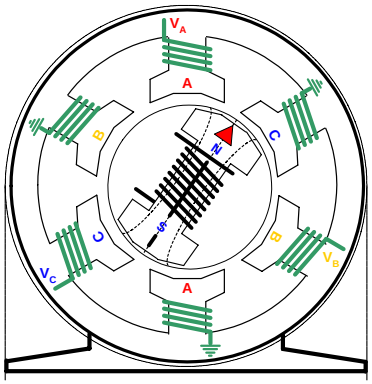
Reference:
Browns Ferry

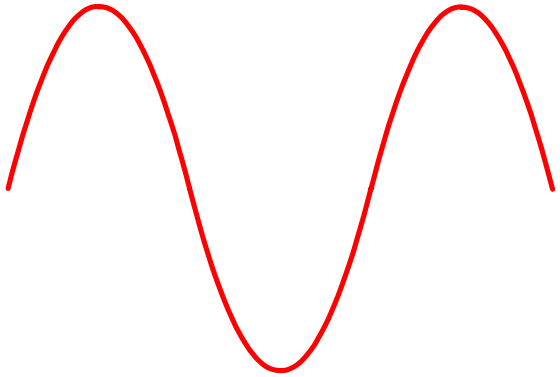
Drivers

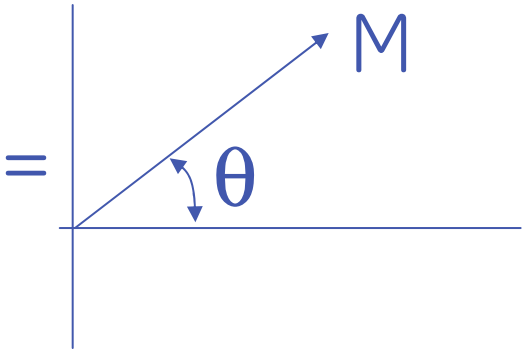
- Operating the grid is not going to get easier:
  - Insufficient stability margins
  - Generation and load centers displaced even more
  - Environmental and cost constraints on new transmission
  - Deregulations and pressure on asset utilization
  - No recognition for maintaining system security and 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



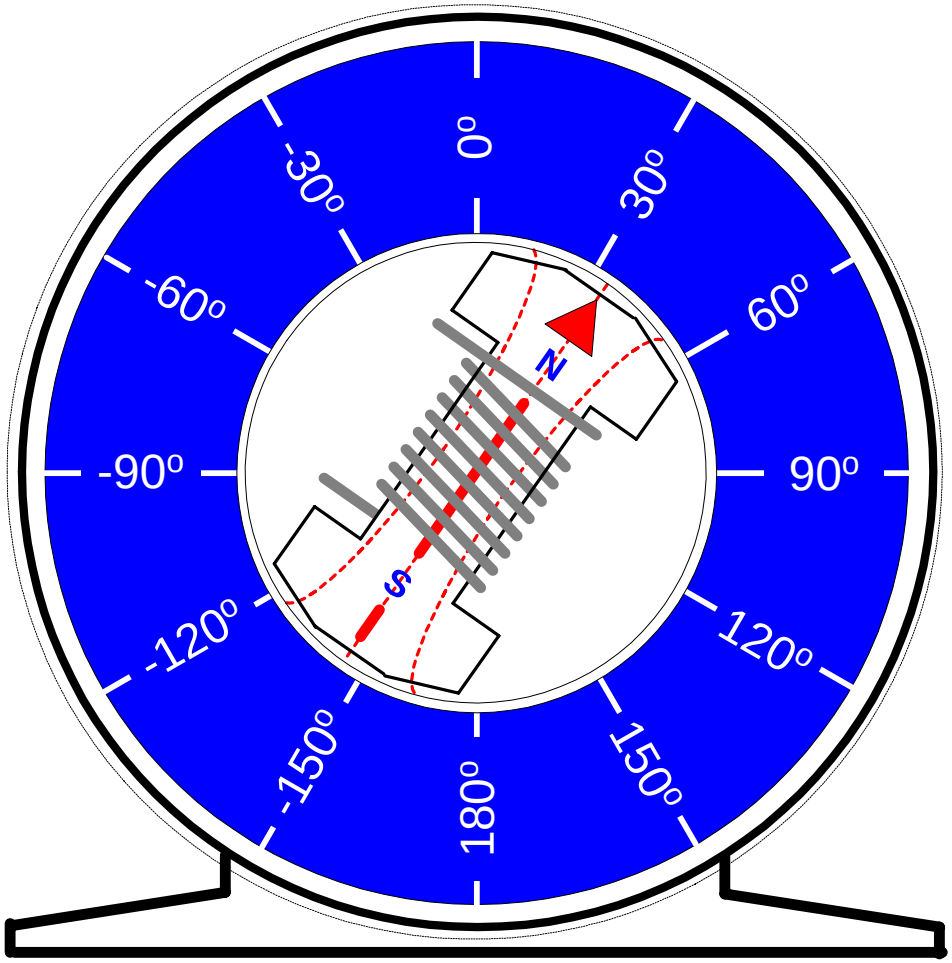




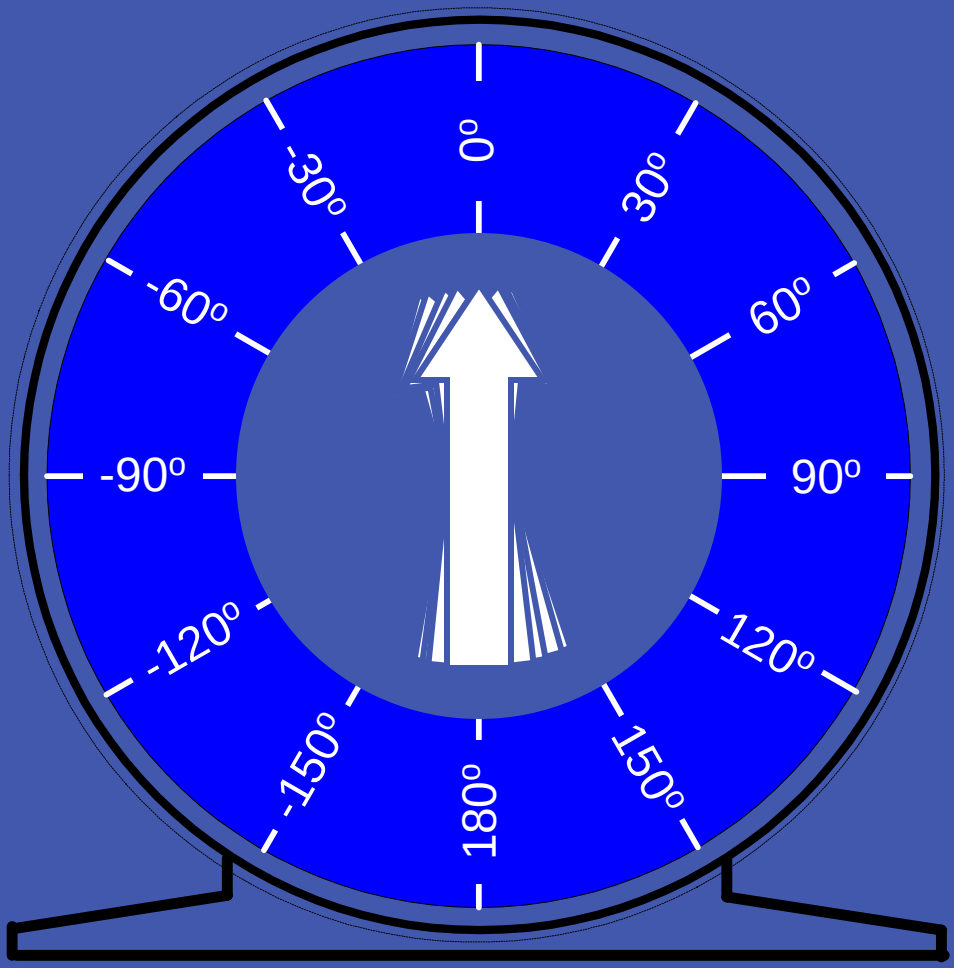
> Phasors are well established means of representing ac circuits

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.

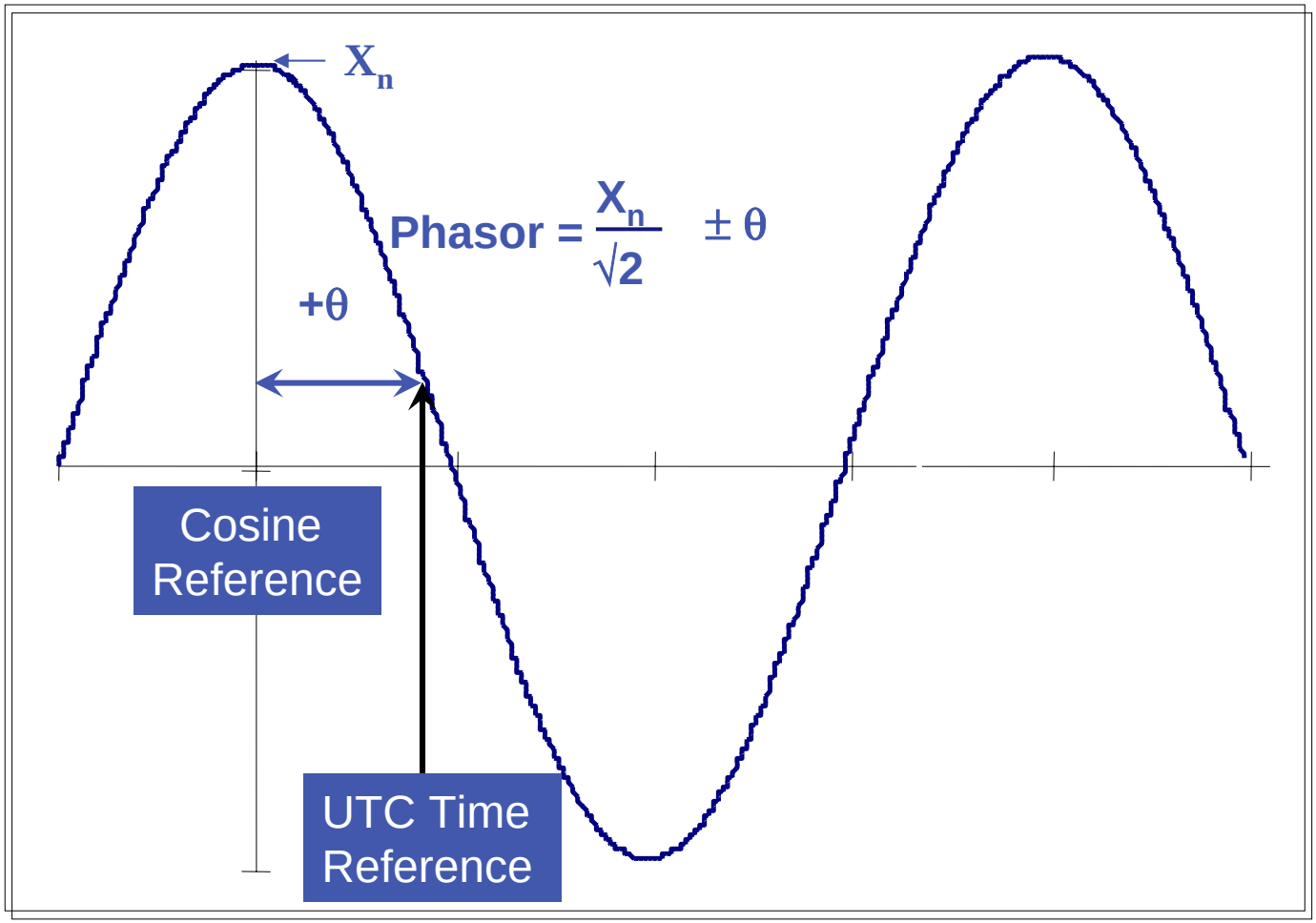
Synchrophasors
Strobe Light Analogy



Strobe Light Analogy



Phasor Definition per C37.118



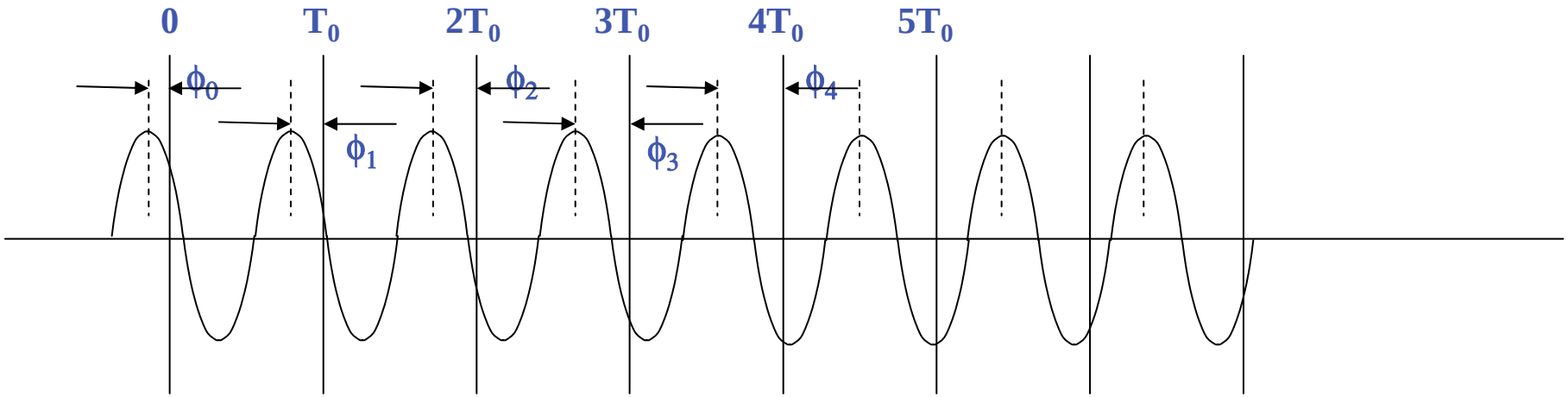
Standardized Synchronous Reporting Rates

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

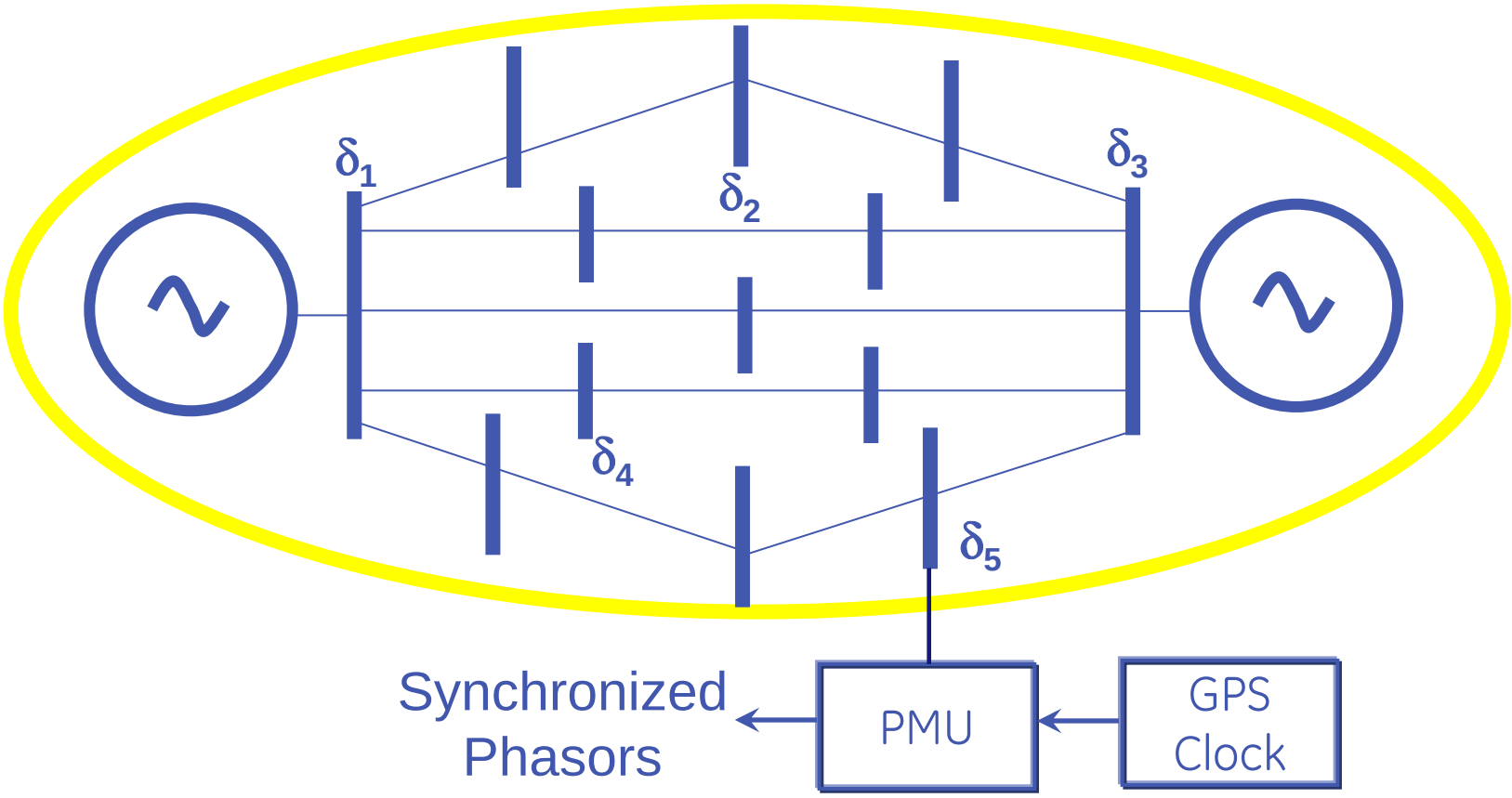


Where: 0 = Top of Second

$T_n = 0 + n*(1/Fs)$ 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

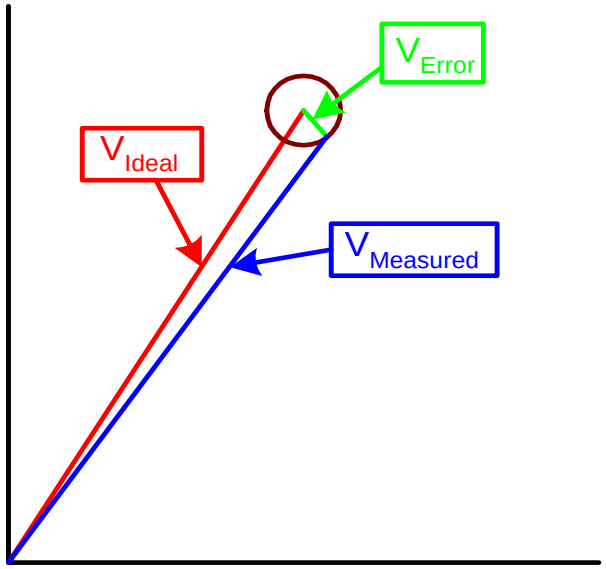
Other Measurements (f, df/dt, W, Var, Events)

Time Quality Byte

Bit#	Function
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

$$TVE \equiv \frac{\left| V_{Measured} - V_{Ideal} \right|}{\left| V_{Ideal} \right|}$$



Influence Quantities and Error Limits

±5 Hz Frequency range resulting in:

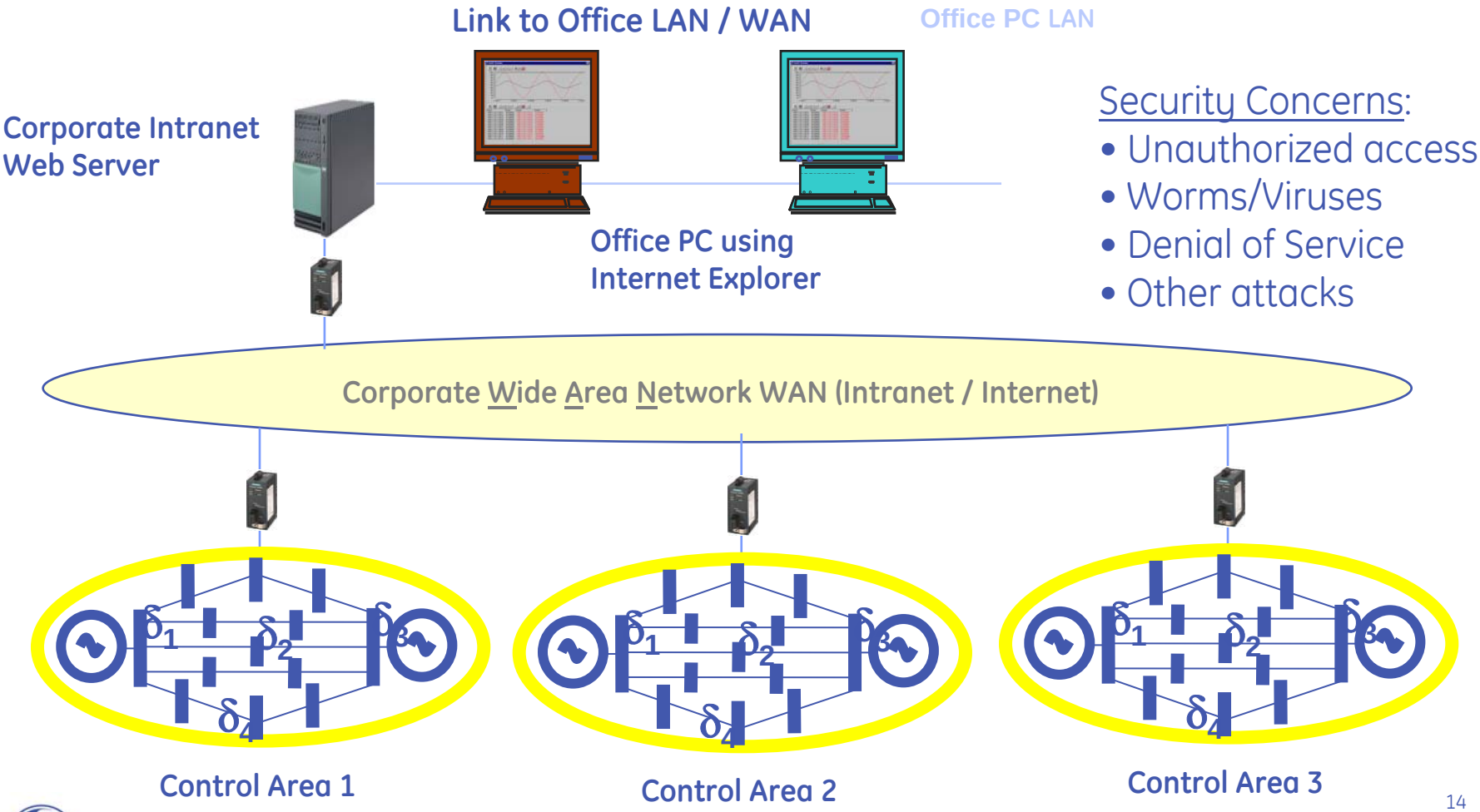
- > Magnitude Errors
- > Angle Errors

10% Total Harmonic Distortion

10% Interfering Signal

TVE from all Sources must be < 1%

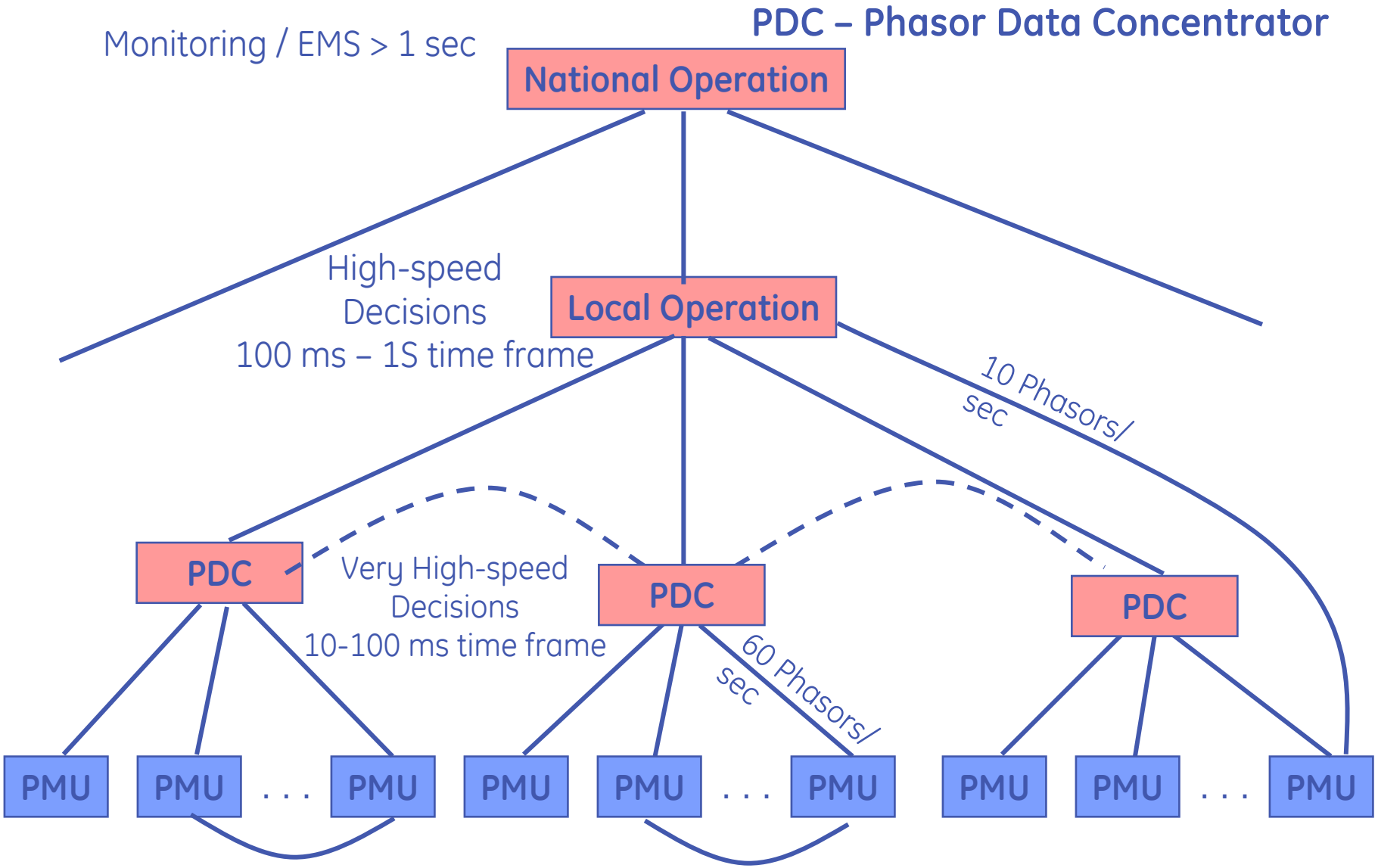
Wide Area Network Structure

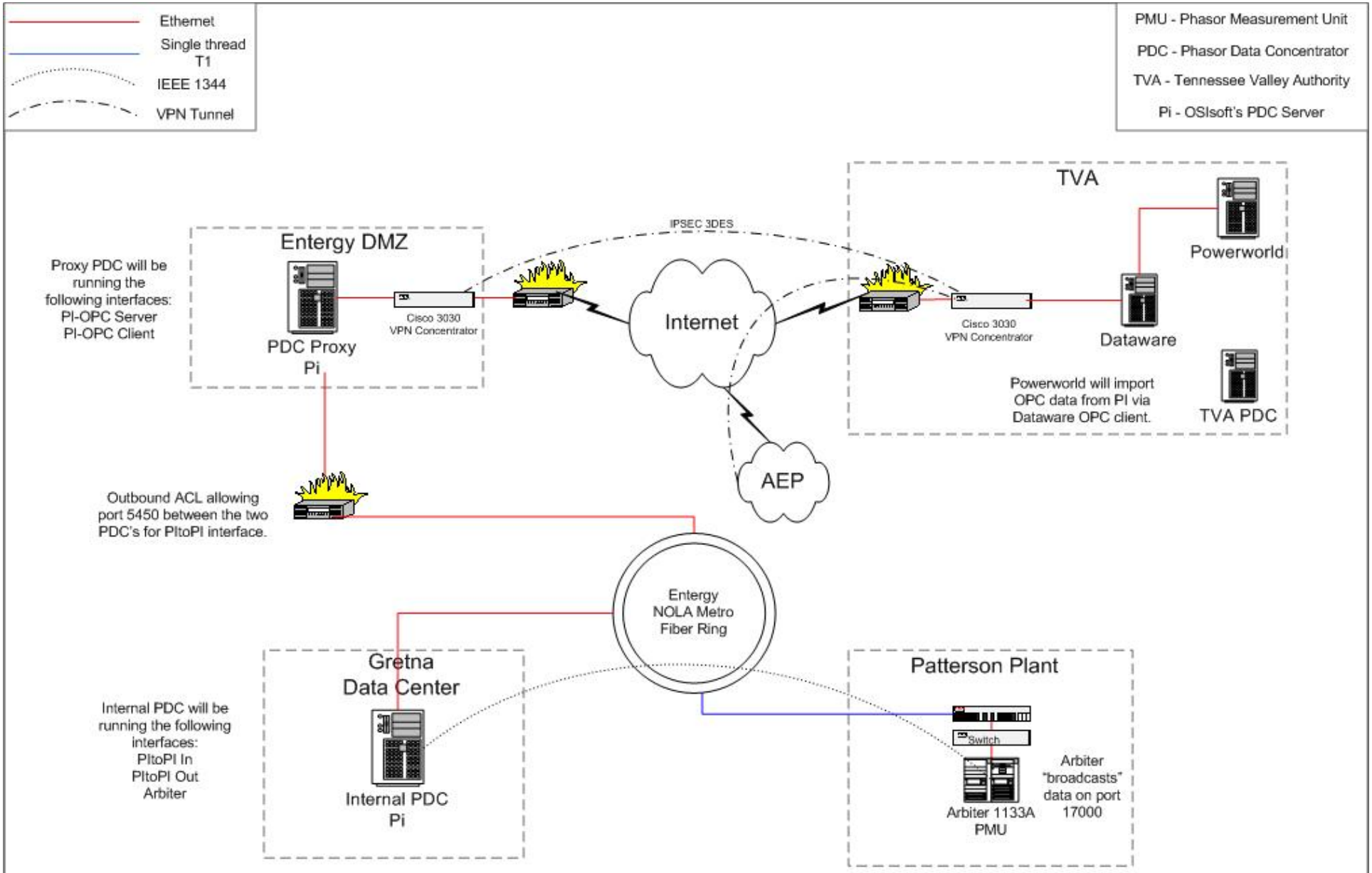


Security Concerns:

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

Reporting Hierarchy Options





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

Entergy

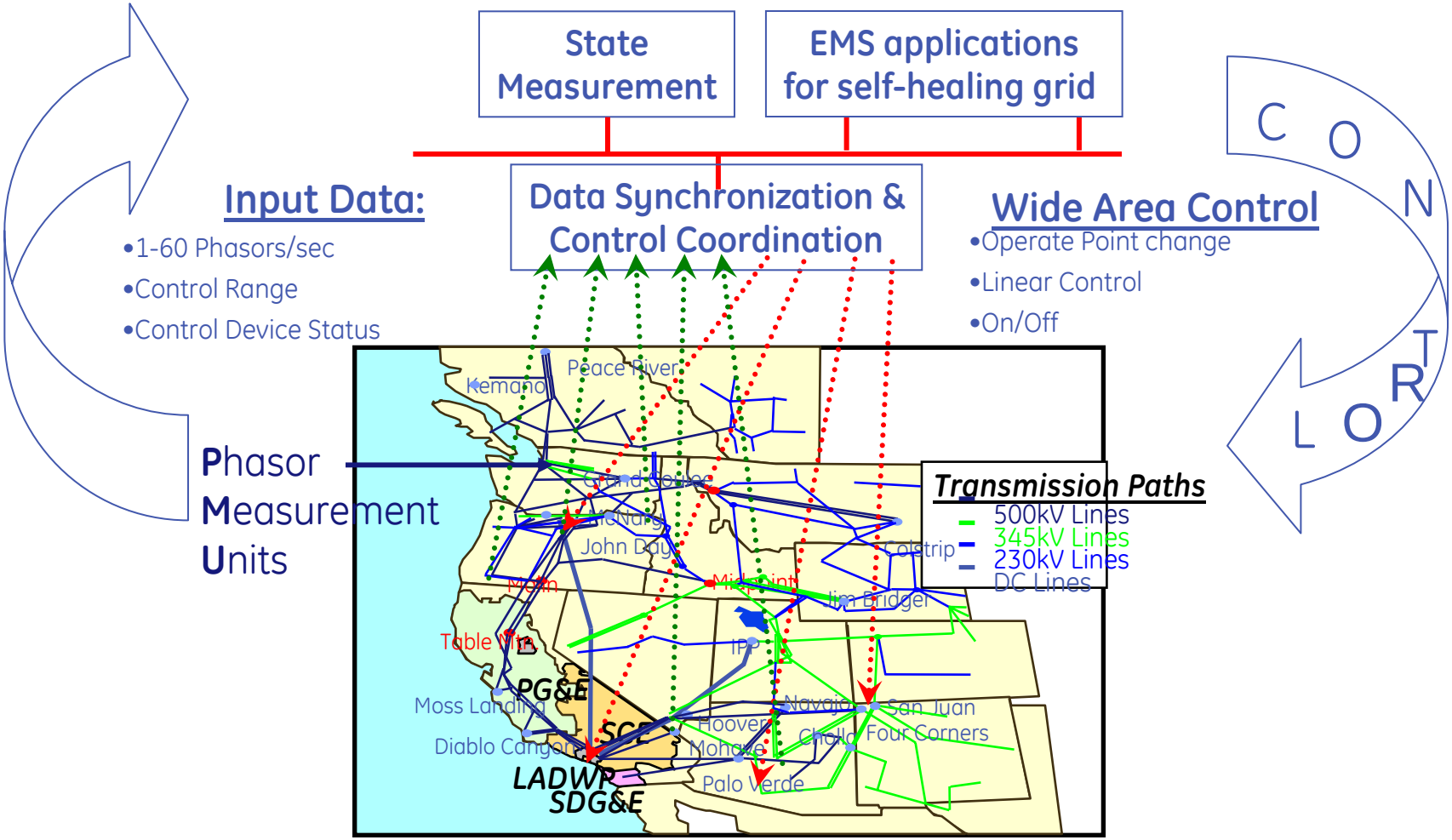
REVISED 6/17/2004

FILENAME EIPP.vsd

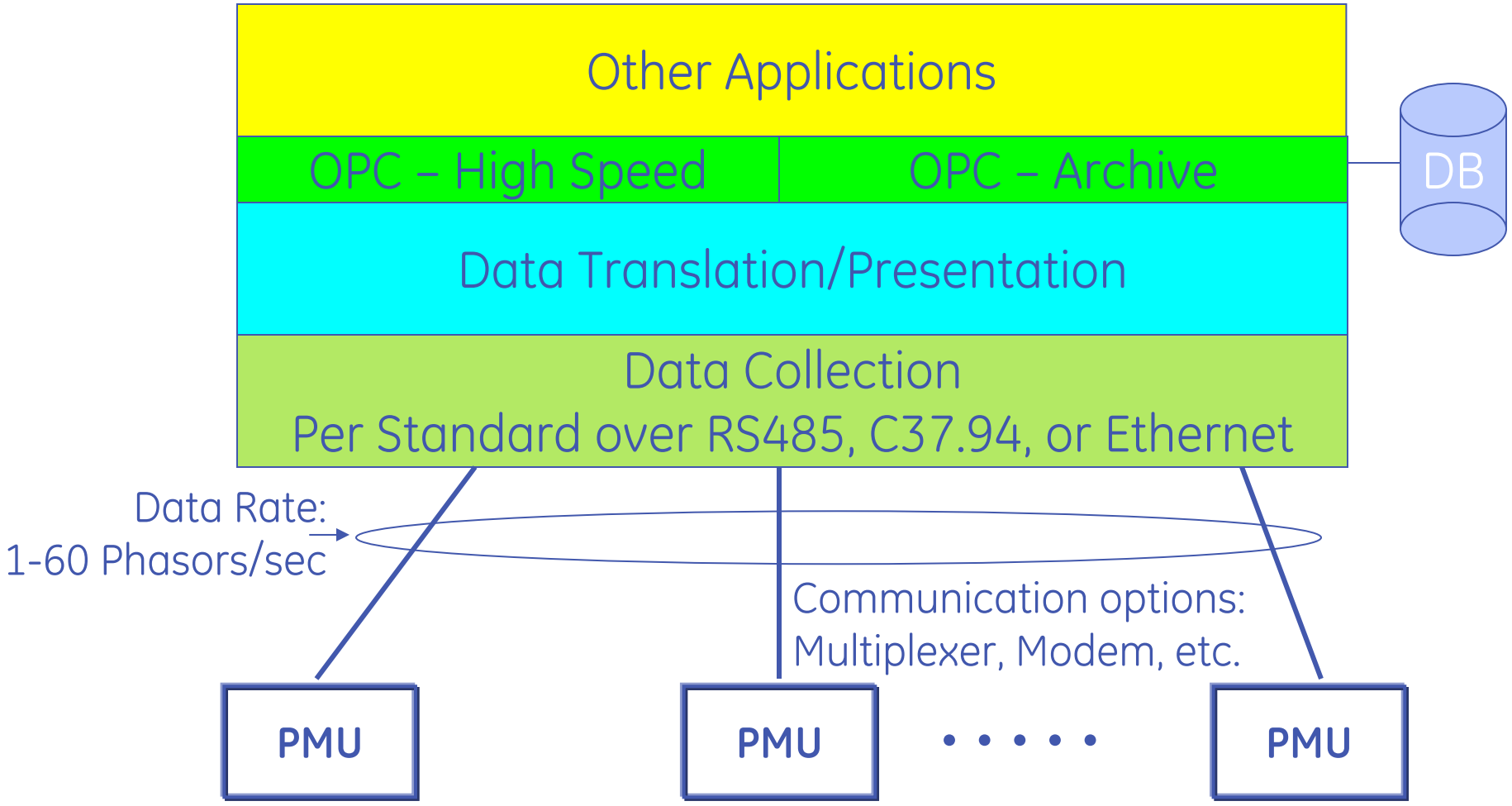
EIPP (Eastern Interconnect Phasor Project)
Phase One Design
TVA Demonstration

SCALE None | ENG. Leonard Chamberlin | SHEET 1 OF 2

Wide Area Monitoring and Control



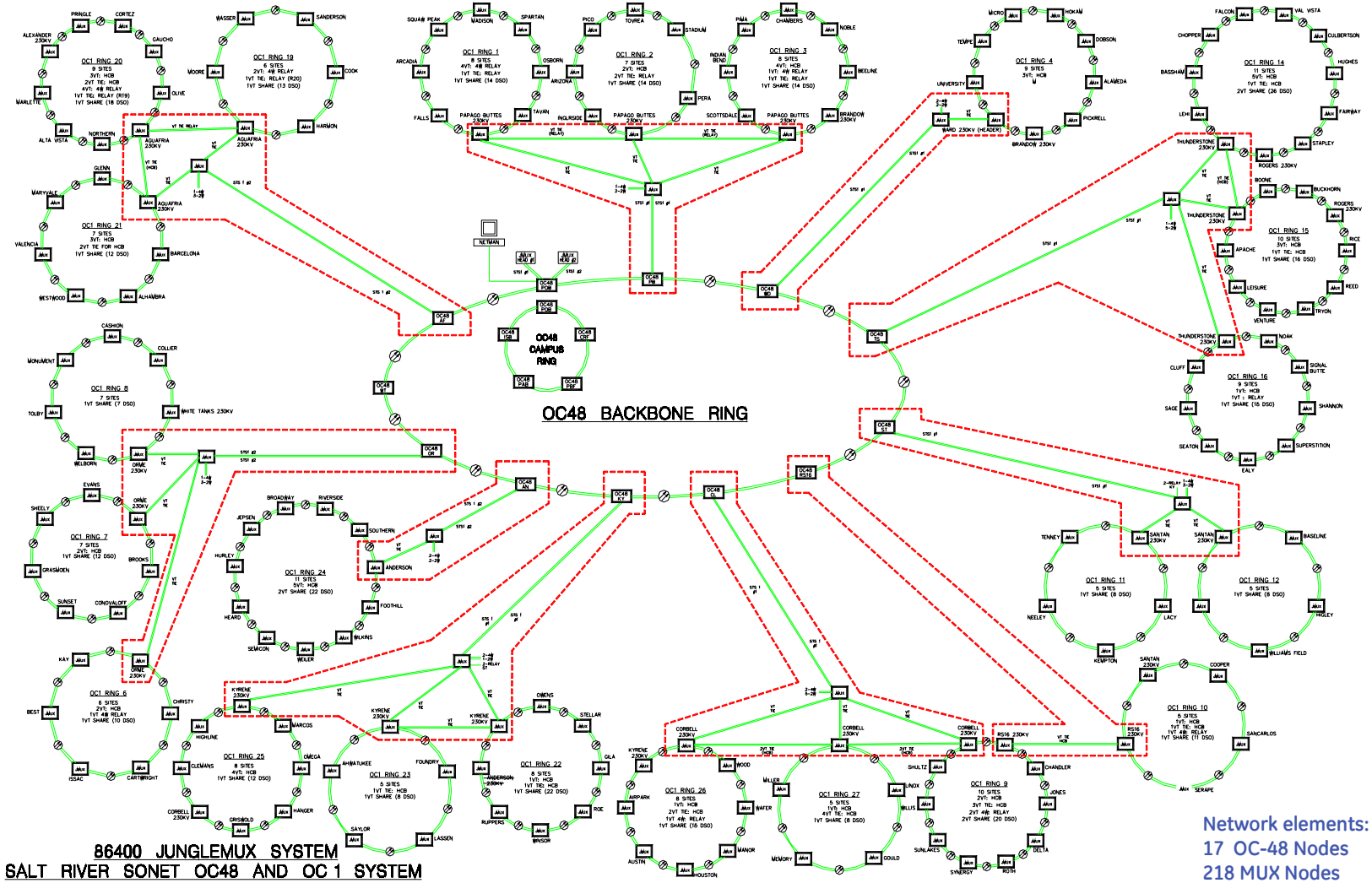
Phasor Data Concentrator Function



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



Network elements:
17 OC-48 Nodes
218 MUX Nodes

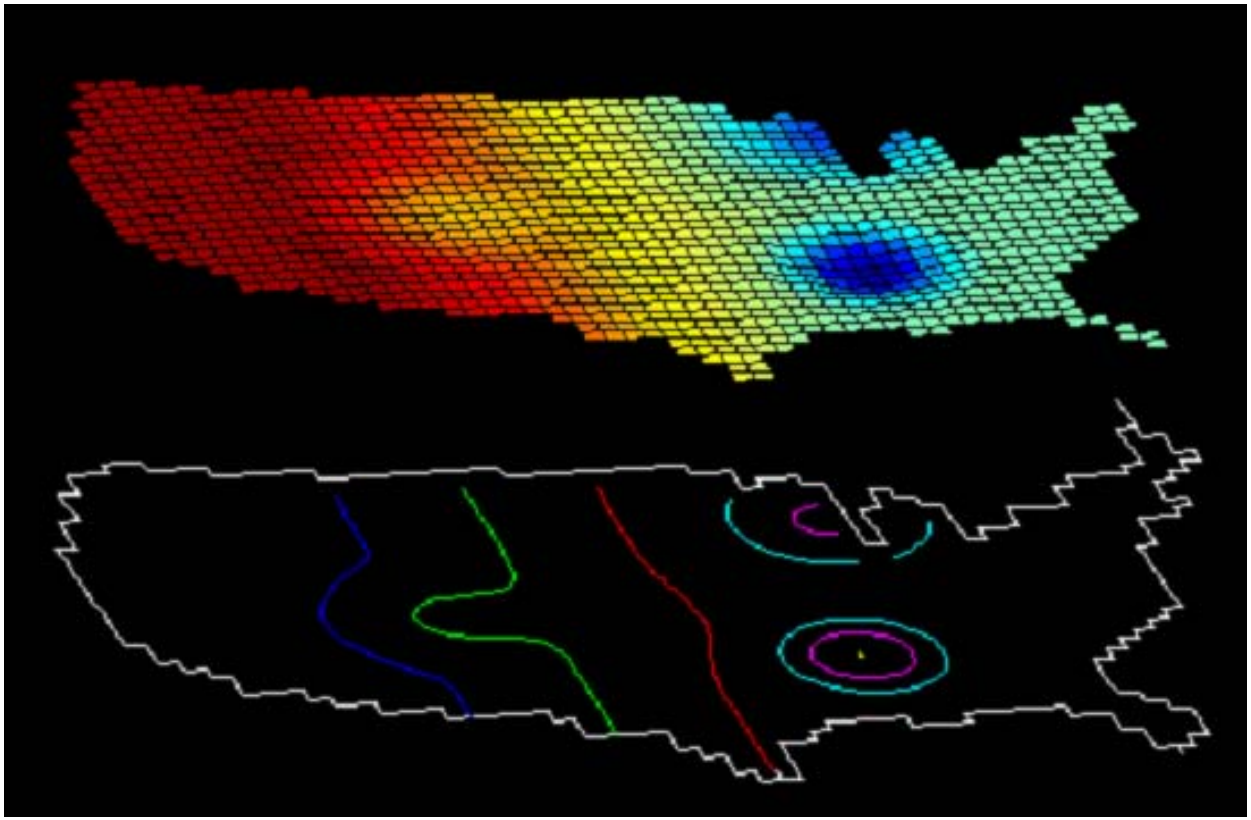
Palo Verde ***Round Trip*** Communication Timing

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

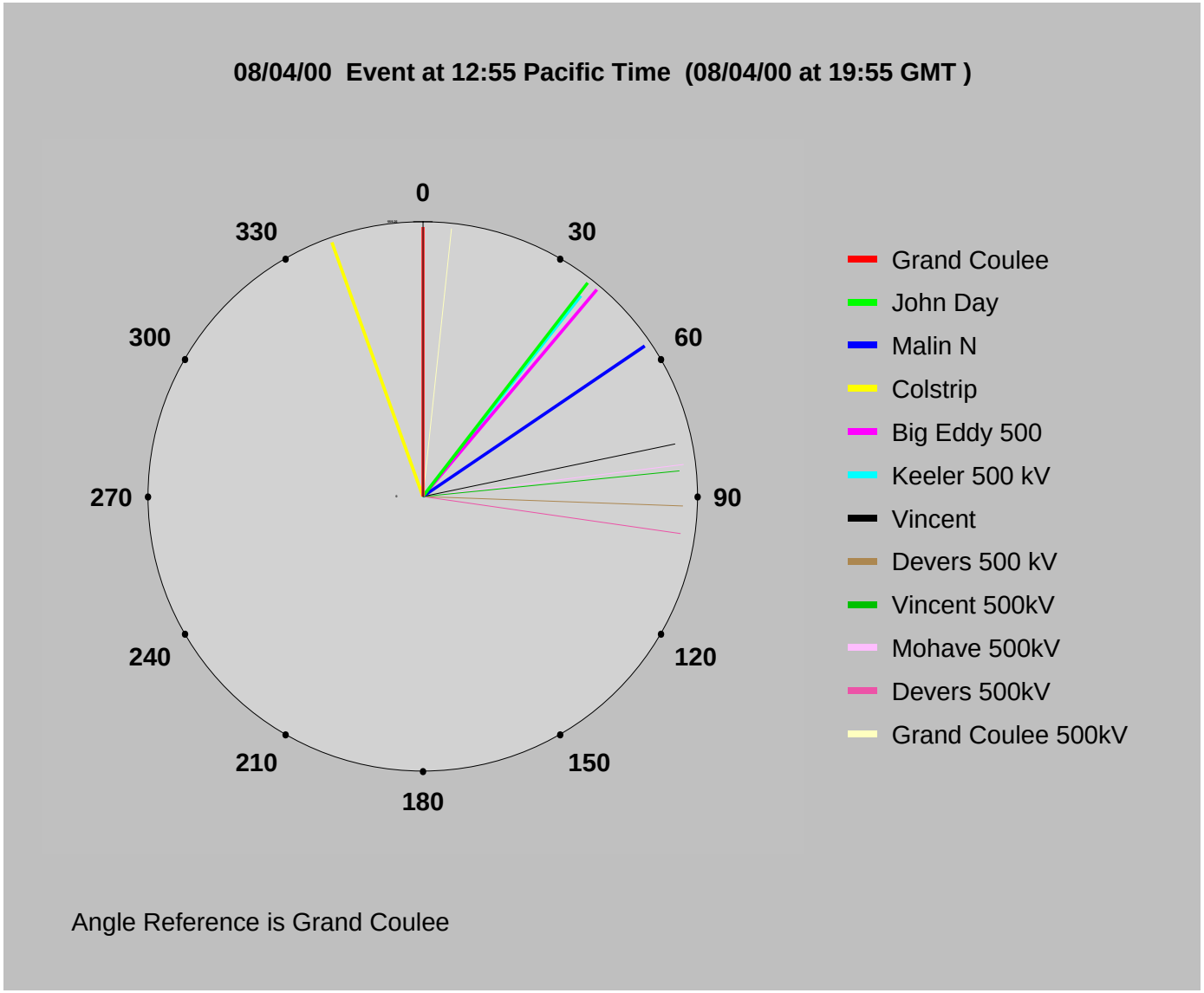
Wide Area System View

Phase Angle

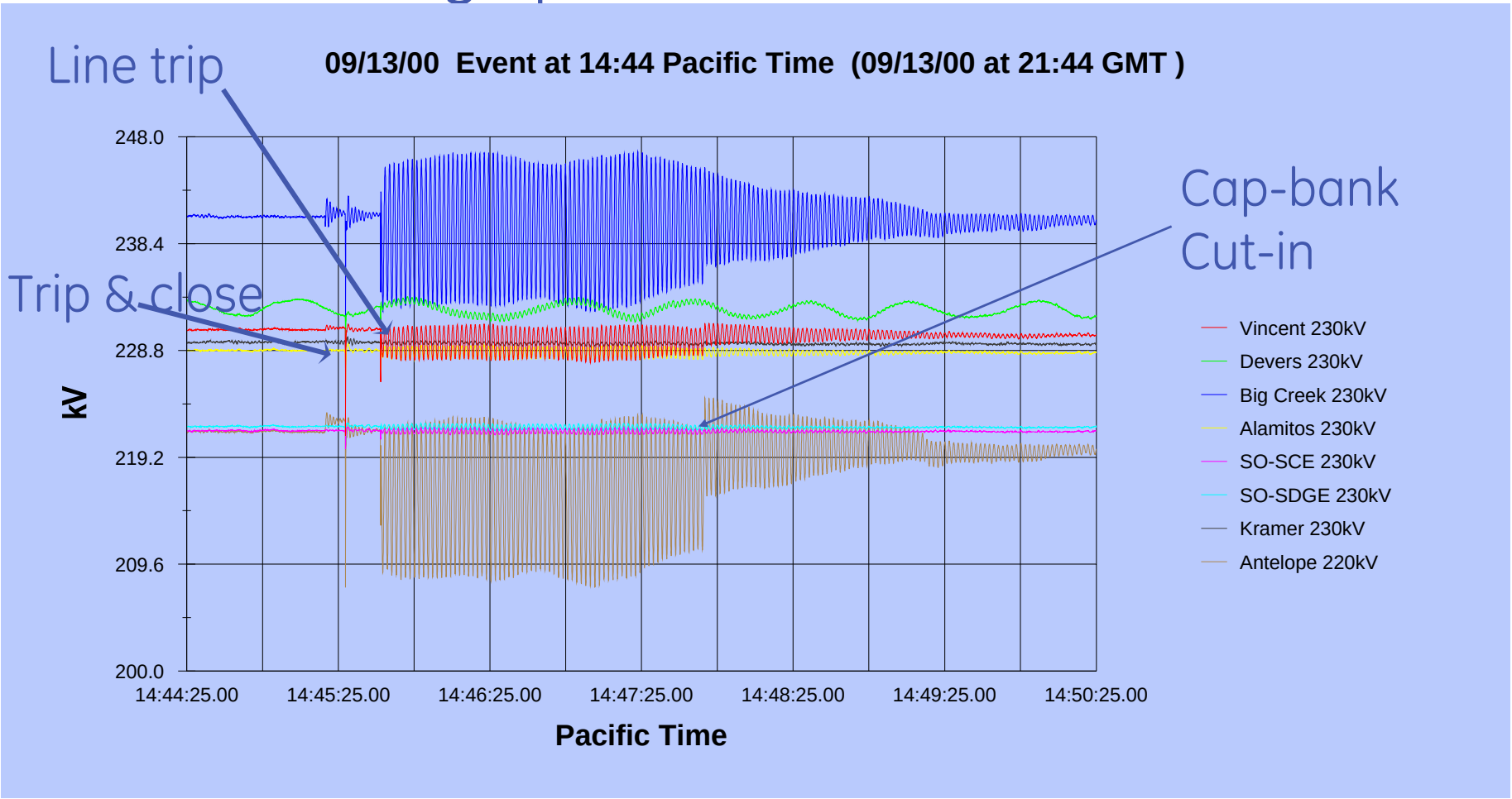
+30
+20
+10
+00
-10
-20
-30



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