Synchrophasors:

Definition, Measurement, and Application

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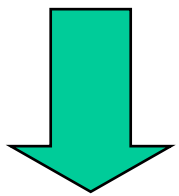
Phasors to Analyze AC Quantities

$$y(t) = M\cos(\omega t + \phi)$$

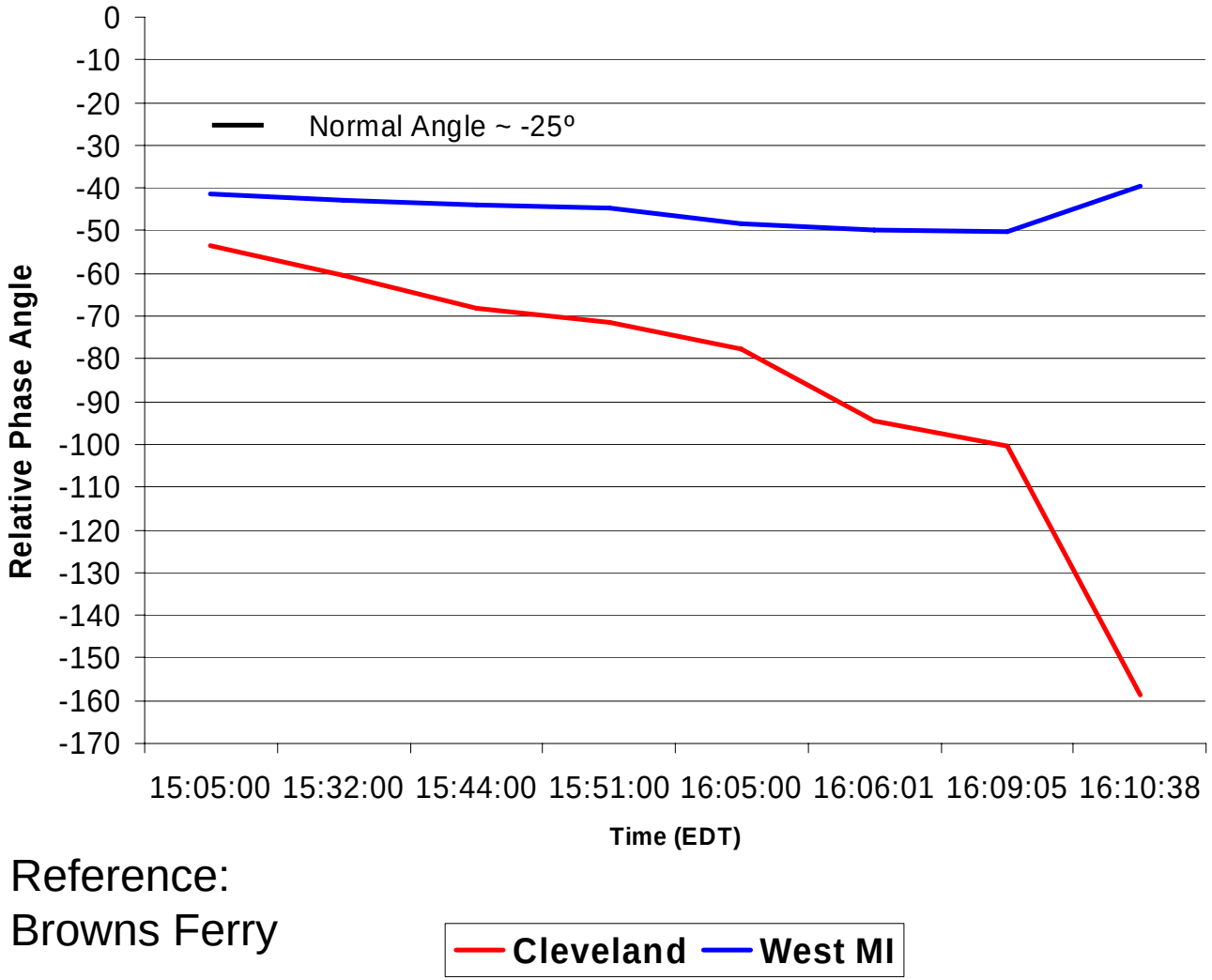


$$M\angle\phi$$

Complex Quantities and their Use in Electrical Engineering; Proceedings of the International Electrical Congress – Chicago; AIEE Proceedings, 1894; pp 33-74.

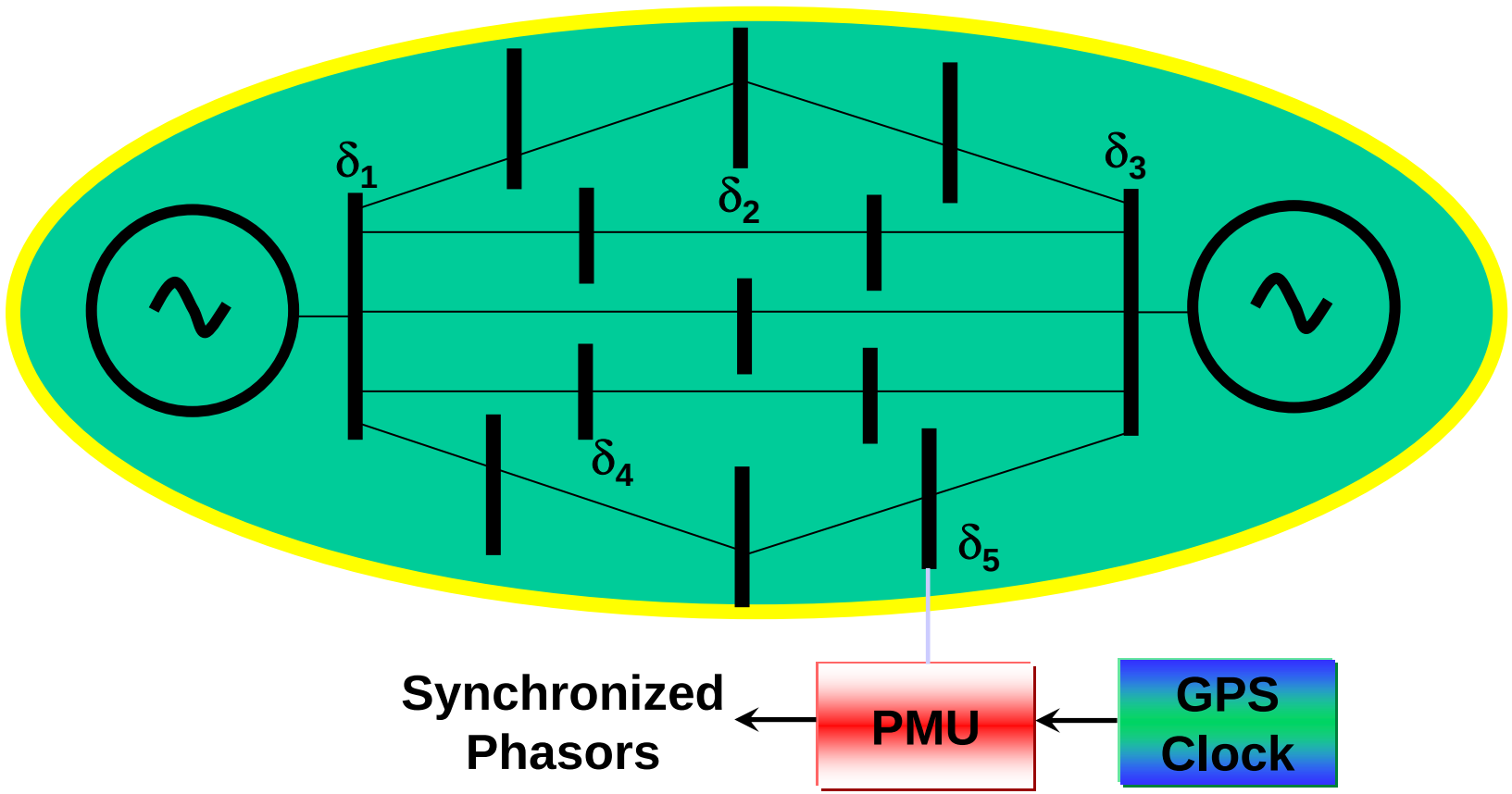
Charles Proteus Steinmetz

Cleveland Separation – Aug 14, 2003

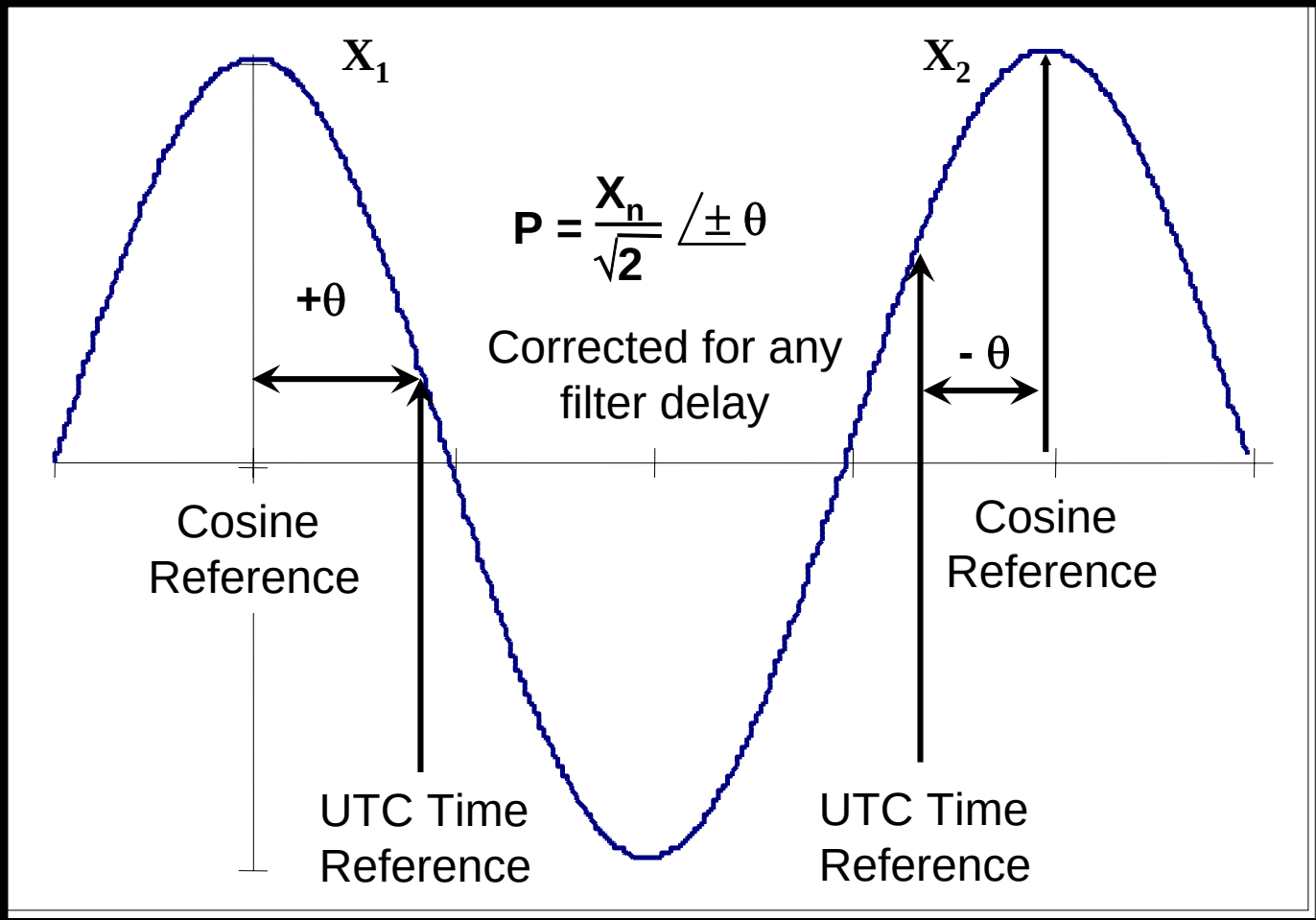


Reference:
Browns Ferry

Phasor Measurement Technology

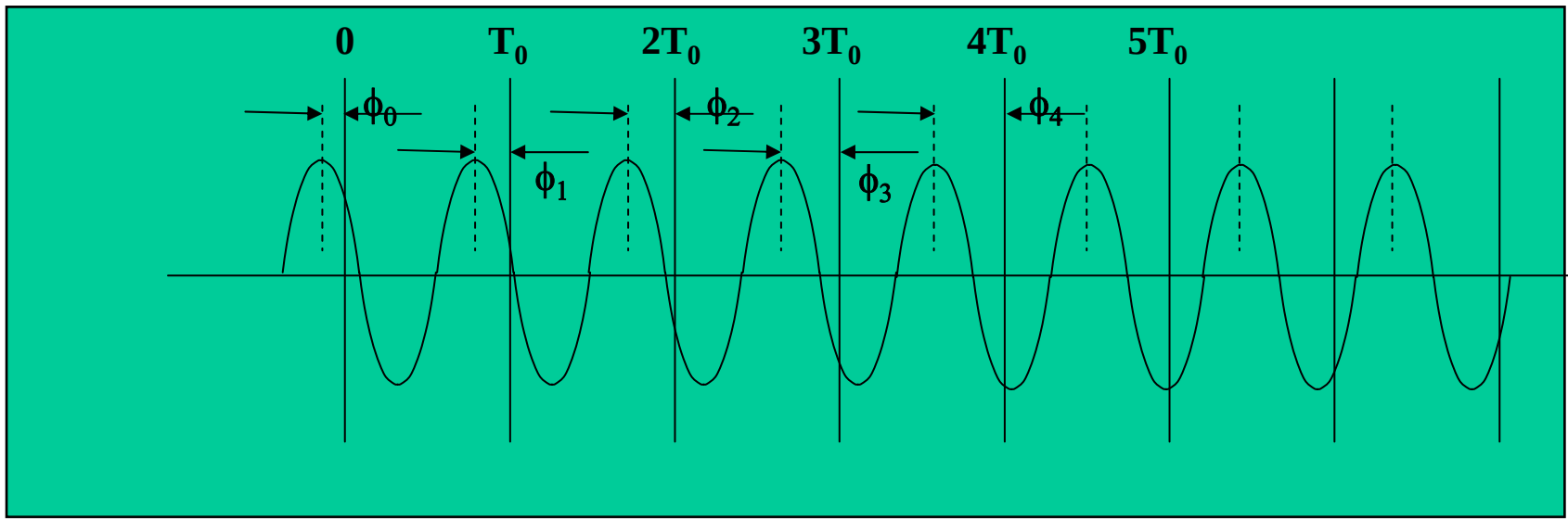


Phasor Definition per PC37.118



UTC Based Synchronized Reporting

Report Rate = 60 Phasors/second



Where: 0 = Top of Second

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

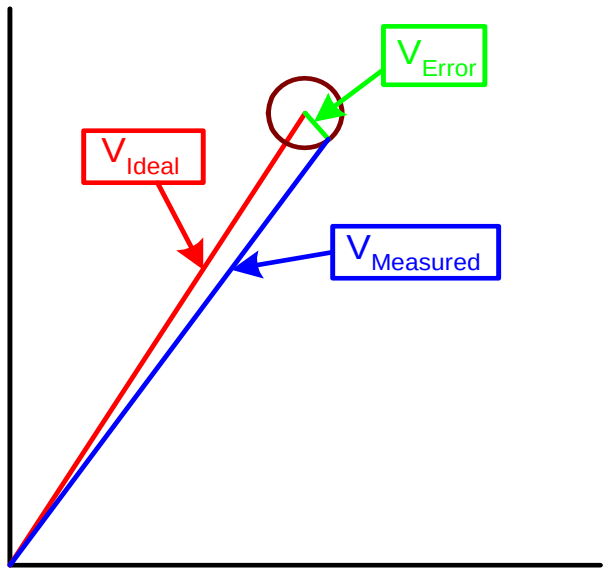
Proposed Synchronous Reporting Rates

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

Optional Phasor Reporting Rates:
50/100 phasors/sec on 50 Hz systems
60/120 phasors/sec on 60 Hz systems

Total Vector Error

$$TVE \equiv \frac{\left|\vec{V}_{Measured} - \vec{V}_{Ideal}\right|}{\left|\vec{V}_{Ideal}\right|}$$



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%

A Classical Centered Fourier Estimator

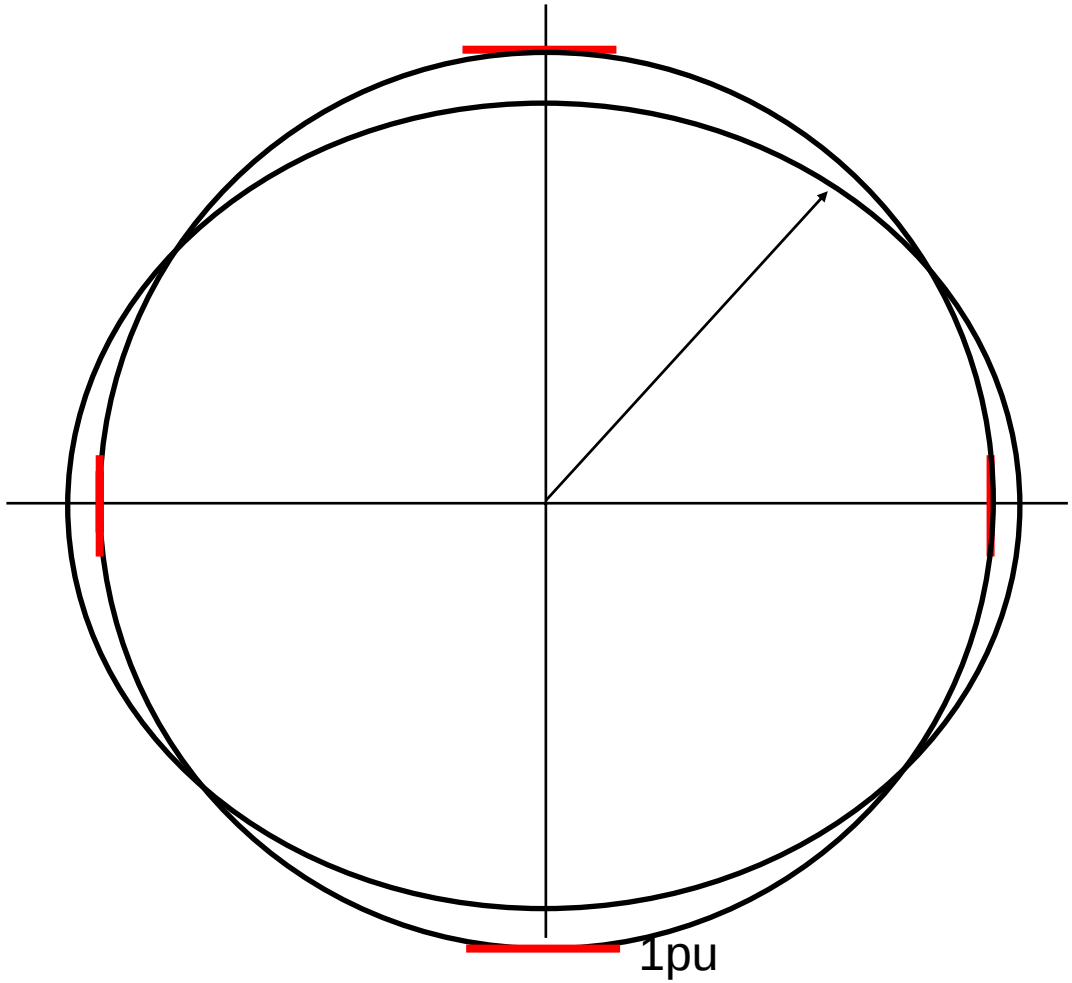
$$\hat{\mathbf{X}} = \frac{\sqrt{2}}{N} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x\left[\Delta t\left(k+1/2\right)\right] \cdot e^{-j(k+1/2)\frac{2\pi}{N}}$$

$$\hat{\mathbf{X}} = \text{one - cycle phasor estimate}$$

$$\Delta t = \frac{1}{N \cdot f_{nominal}}$$

$$x\left[\Delta t\left(k+1/2\right)\right] = \text{current or voltage sample taken at t} = \Delta t\left(k+1/2\right)$$

Classic Fourier Response to off-nominal Frequency



Wide Area Monitoring and Control: A New Concept?

- **Hardly…. wide area monitoring is an integral part of power system operation today:**
  - **Telemetry**
  - **Alarming and status**
  - **State estimation**
- **What is new?**
  - **High-speed, reliable & affordable digital communication means**
  - **Coverage through broad deployment of IEDs**
  - **Real-time metering and communication capabilities of modern IEDs**
  - **Affordable time-synchronized measurements**
  - **Processing and visualization capabilities**

Time-synch measurements and response time are key

Drivers

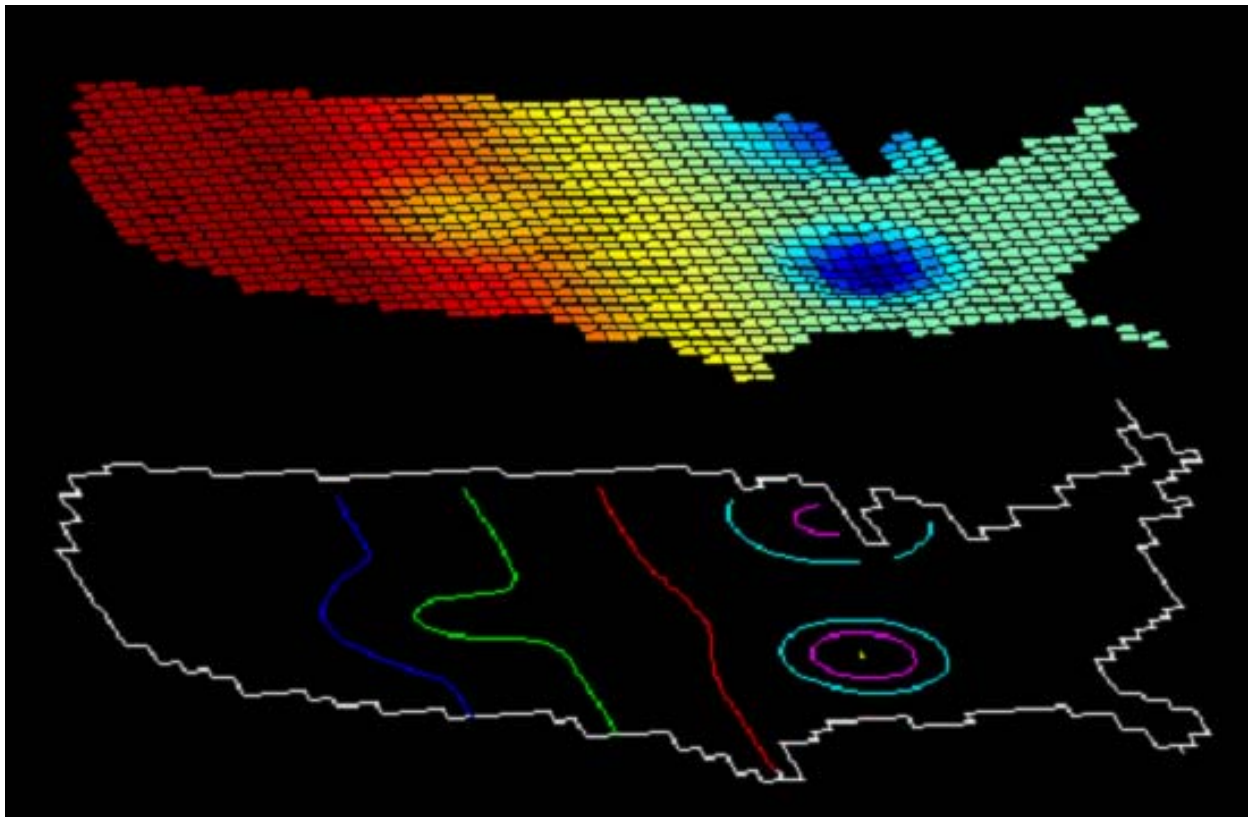
- **Operating the grid is not going to get easier:**
  - » **Insufficient stability margins**
  - » **Generation and load centers displaced even more**
  - » **Environmental and cost constraints on new transmission**
  - » **Deregulations and pressure on asset utilization**
  - » **No recognition for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

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

New View of the Grid

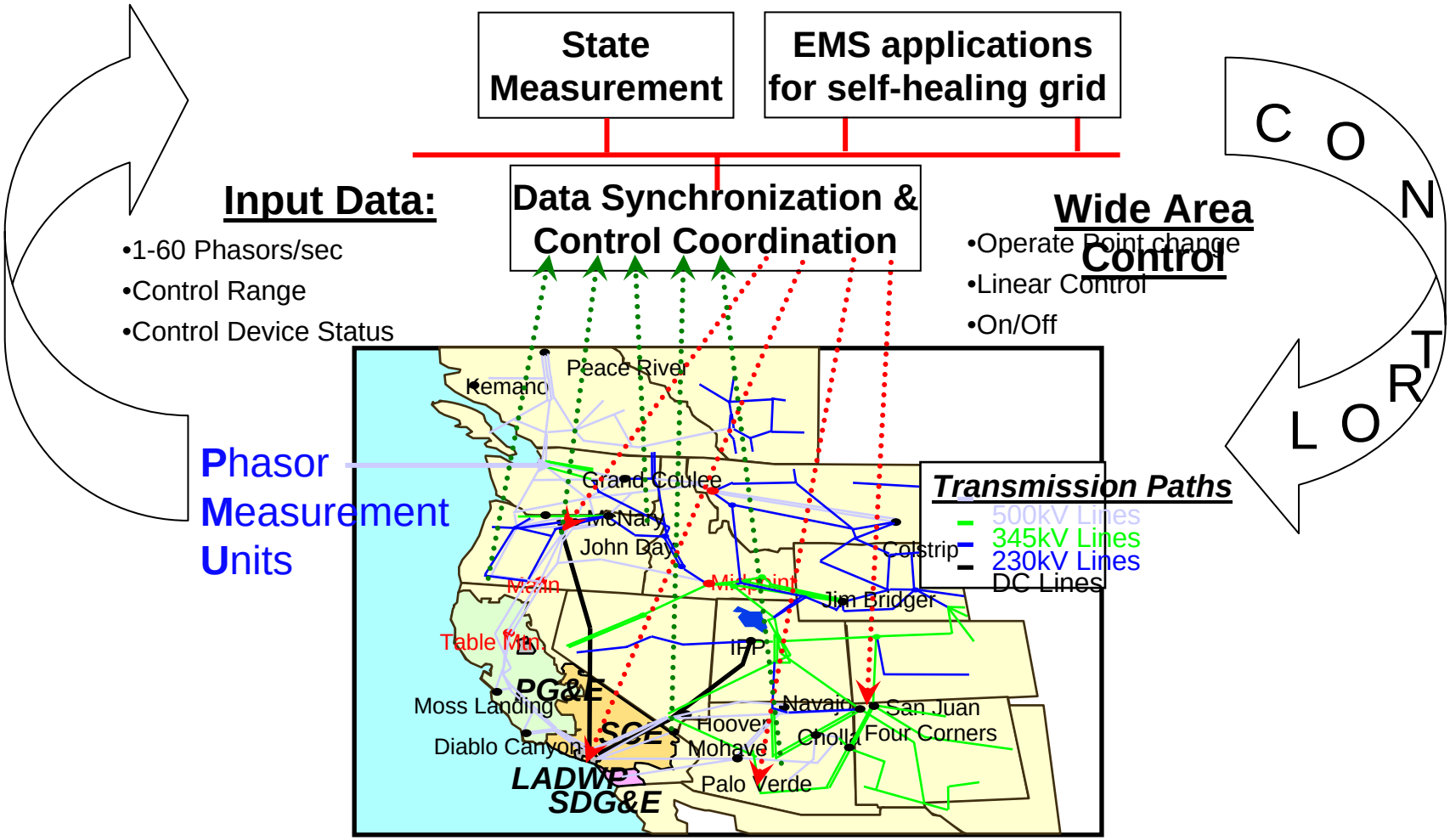


Need for “Situational Awareness”

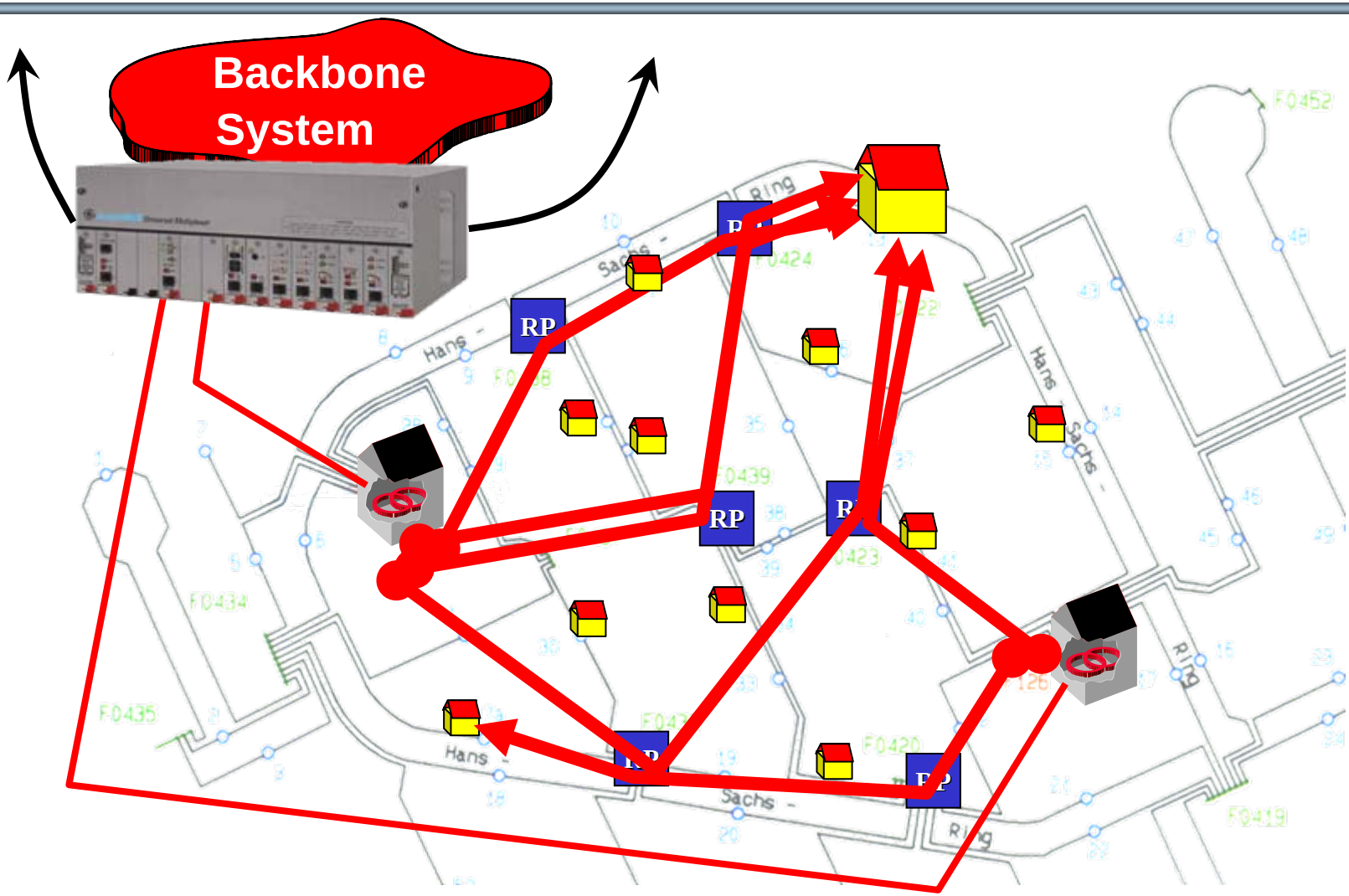
Other Visualization Applications

- 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

Wide Area Monitoring and Control

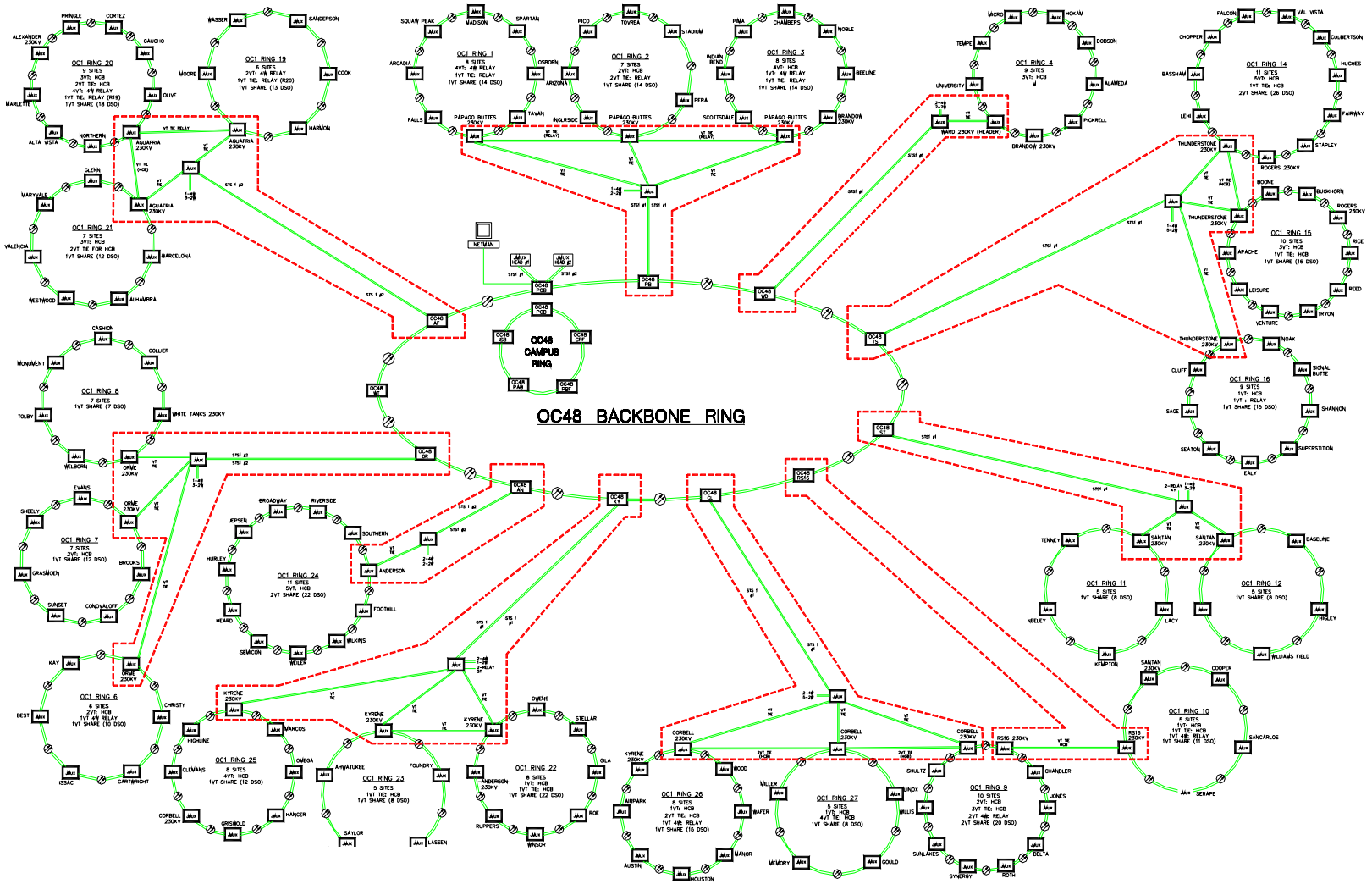


Wide Area Fiber as Backbone for Consumer Load Control



Option: Direct Load Control into the Home

LARGE ELECTRIC UTILITY APPLICATION



Conclusions

- **A wider view of the power system will require synchronized phasor measurements**
- **The need and potential applications are emerging for synchronized measurements to enhance the stability of the operation of the electric power grid**
- **Technology and standards are becoming available**
- **Additional communications bandwidth is needed**