SYNCHROPHASOR BASICS

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A BIT OF HISTORY

- Late-1800's
  - Earliest mathematical models of Power Systems using Phasors.
  - Charles Proteus Steinmetz's 1893 paper analyzed AC networks.
- 1980's
  - First introduction of synchrophasor measuring devices.
- 1990's
  - Deployment of experimental devices.
  - First IEEE standard (C37.118.1) for PMU's and synchrophasors.

WHAT IS A SYNCHROPHASOR?

What is a Phasor?

– A phasor is a representation of a sinusoidal function using its magnitude and phase angle.

We have an AC waveform:

$$x(t) = A \times \cos(\omega t + \varphi) \qquad \omega = 2\pi f$$

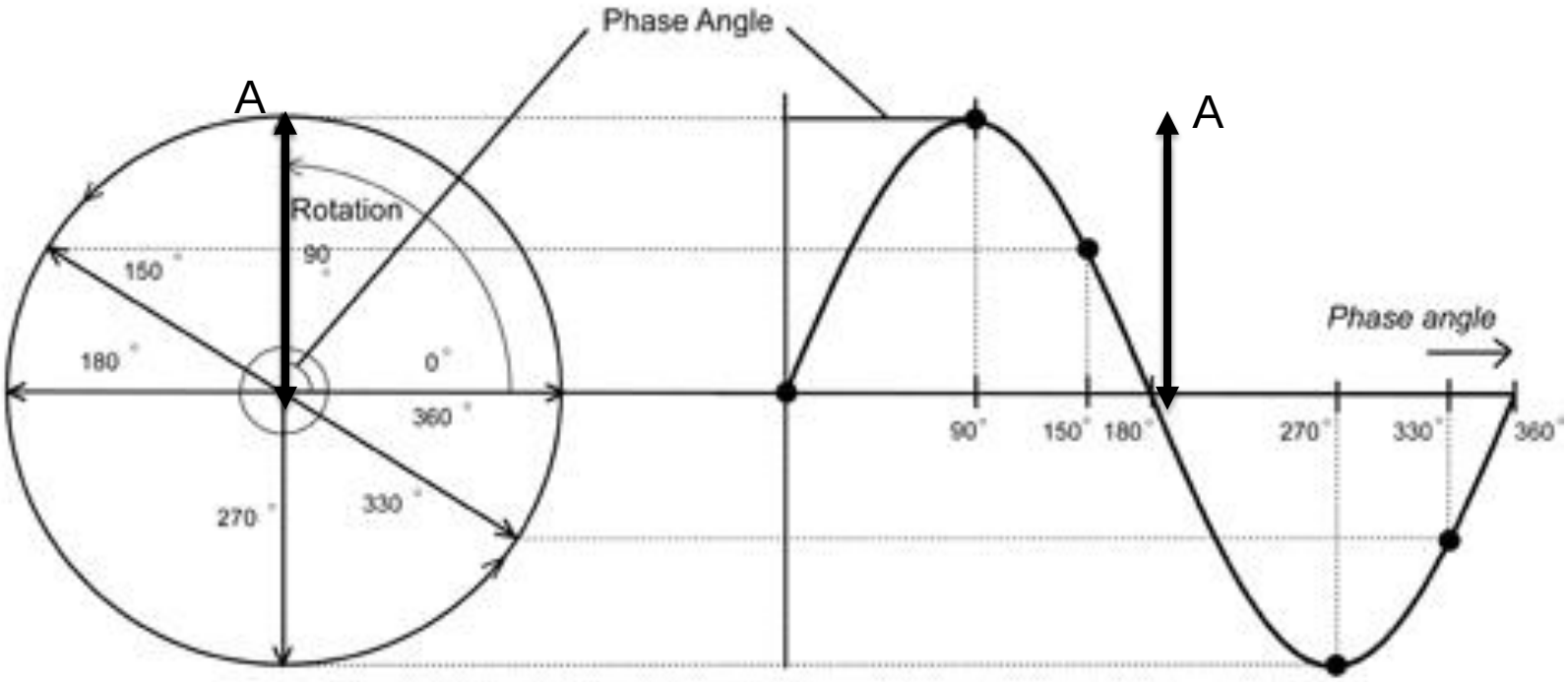
This can be represented by:

$$\bar{X} = A\angle\varphi$$

or as an RMS value:

$$\bar{X} = \frac{A}{\sqrt{2}}\angle\varphi$$

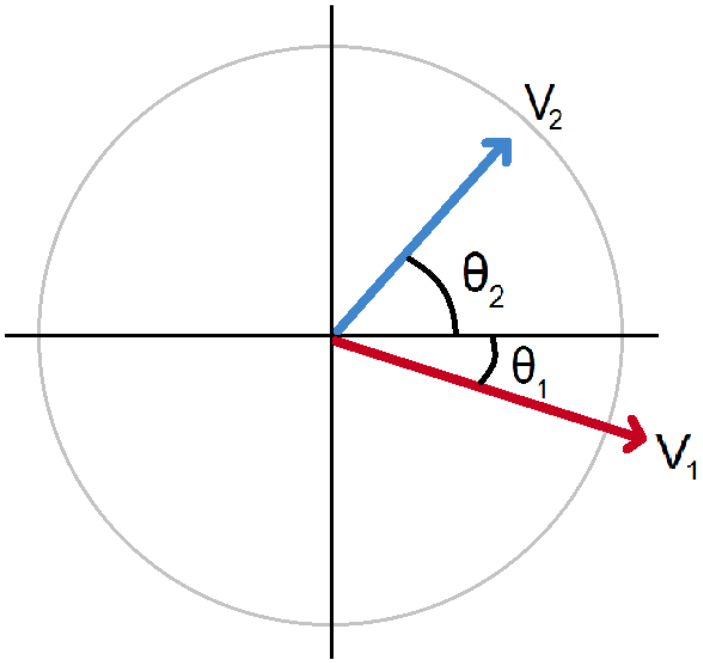
PHASE ANGLE REPRESENTATION

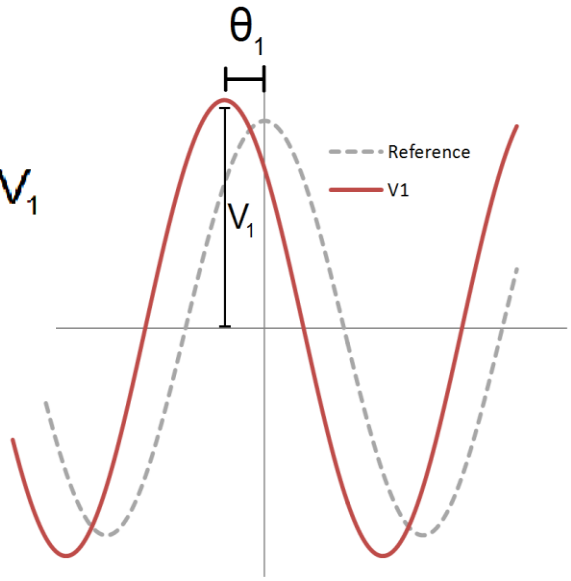


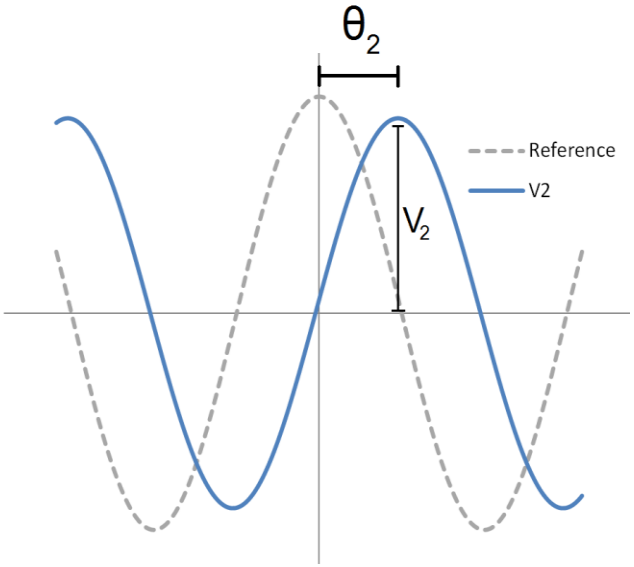
$$\bar{X} = A\angle\varphi \quad \leftrightarrow \quad x(t) = A * \cos(\omega t + \varphi)$$

WHAT IS A SYNCHROPHASOR?

Two voltage waveforms (Red and Blue):







WHY SYNCHROPHASORS?

-Phasors are useful, but comparisons required estimations

-SCADA does not synchronized time keeping capabilities.

-This led to a technique that:

"synchronizes the calculation of a phasor to absolute time, known as a synchronized phasor measurement or [just] synchrophasors." - Mark Adamiak

-A gps-based time stamp was introduced to allow for a reference wave.

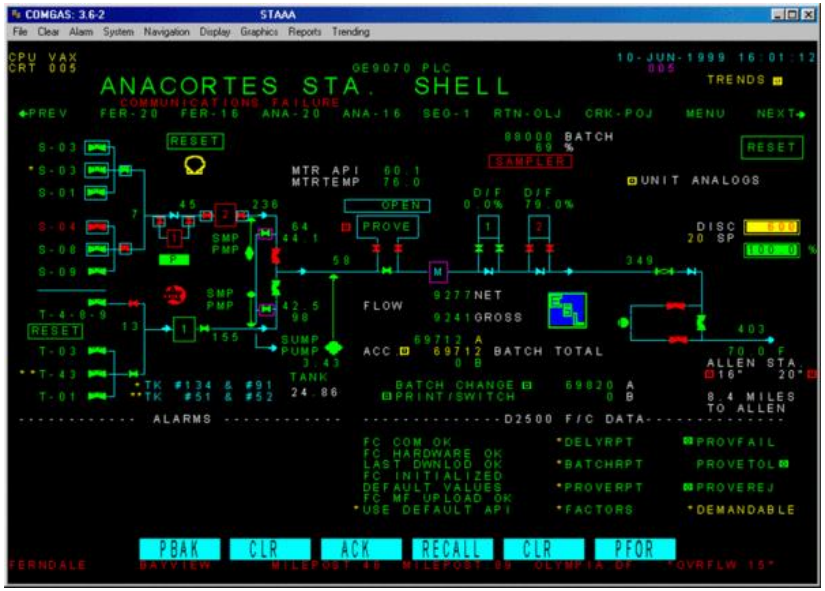
APPROACH, SCADA VS PMU

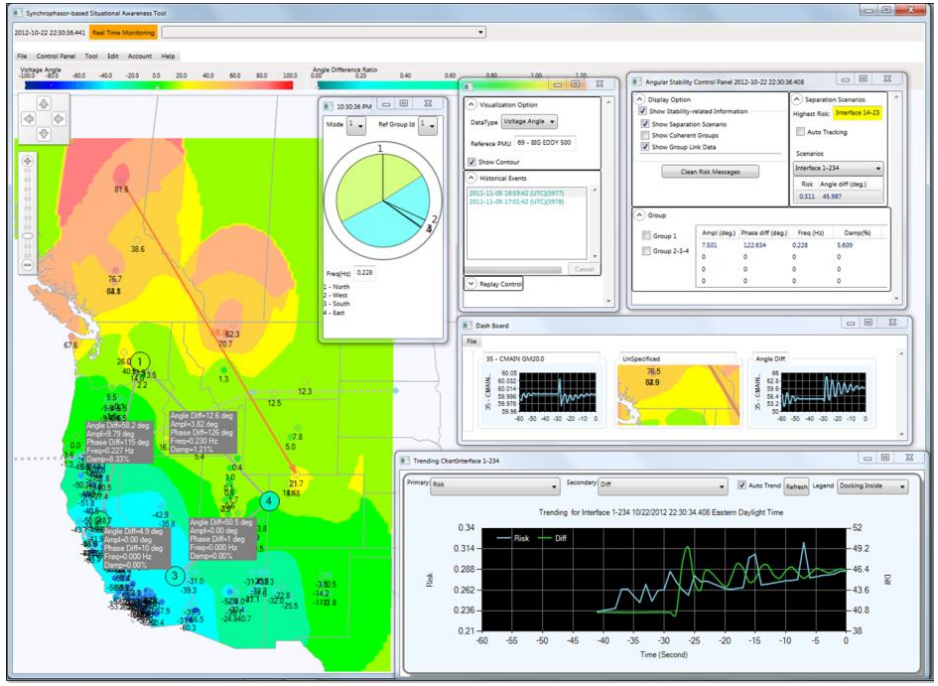
SCADA has no timing synchronization

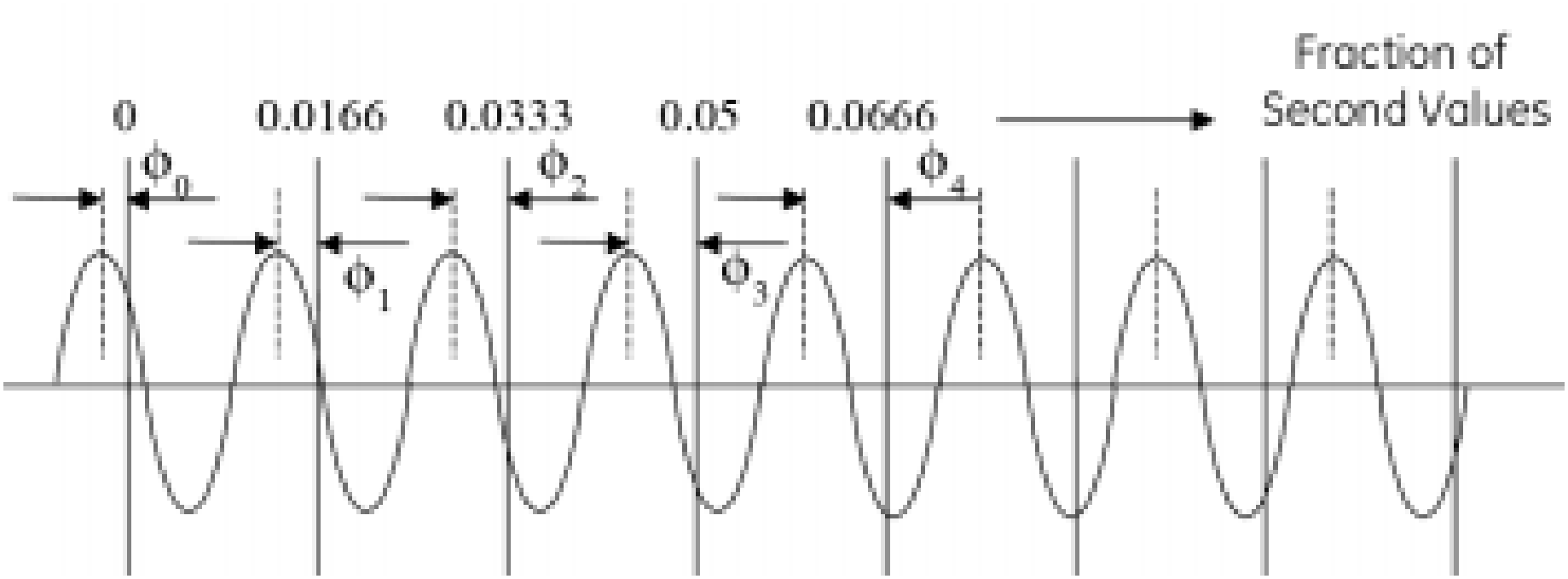
- No time synchronization
- Slow report rates
- Unable to see fast events

PMUs

- More detailed/higher resolution
- “Real” time

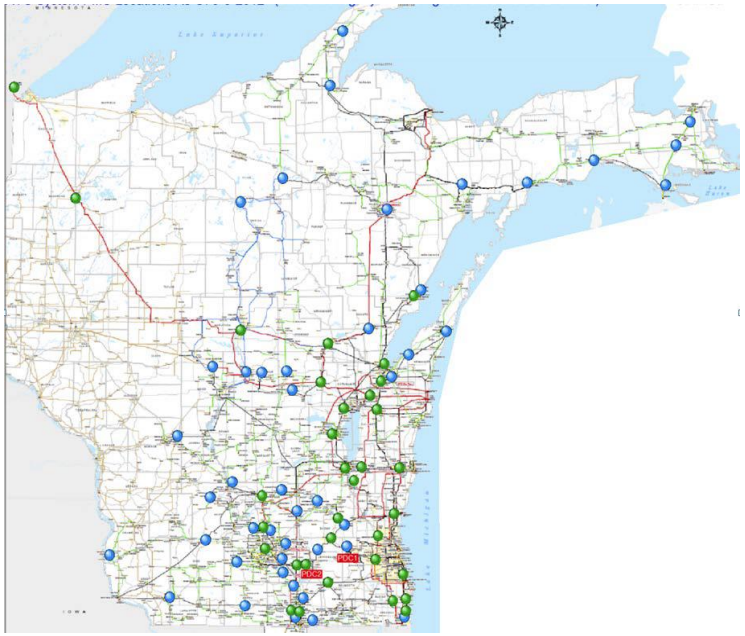





0
0.0166
0.0333
0.05
0.0666
Fraction of Second Values
Φ0
Φ1
Φ2
Φ3
Φ4

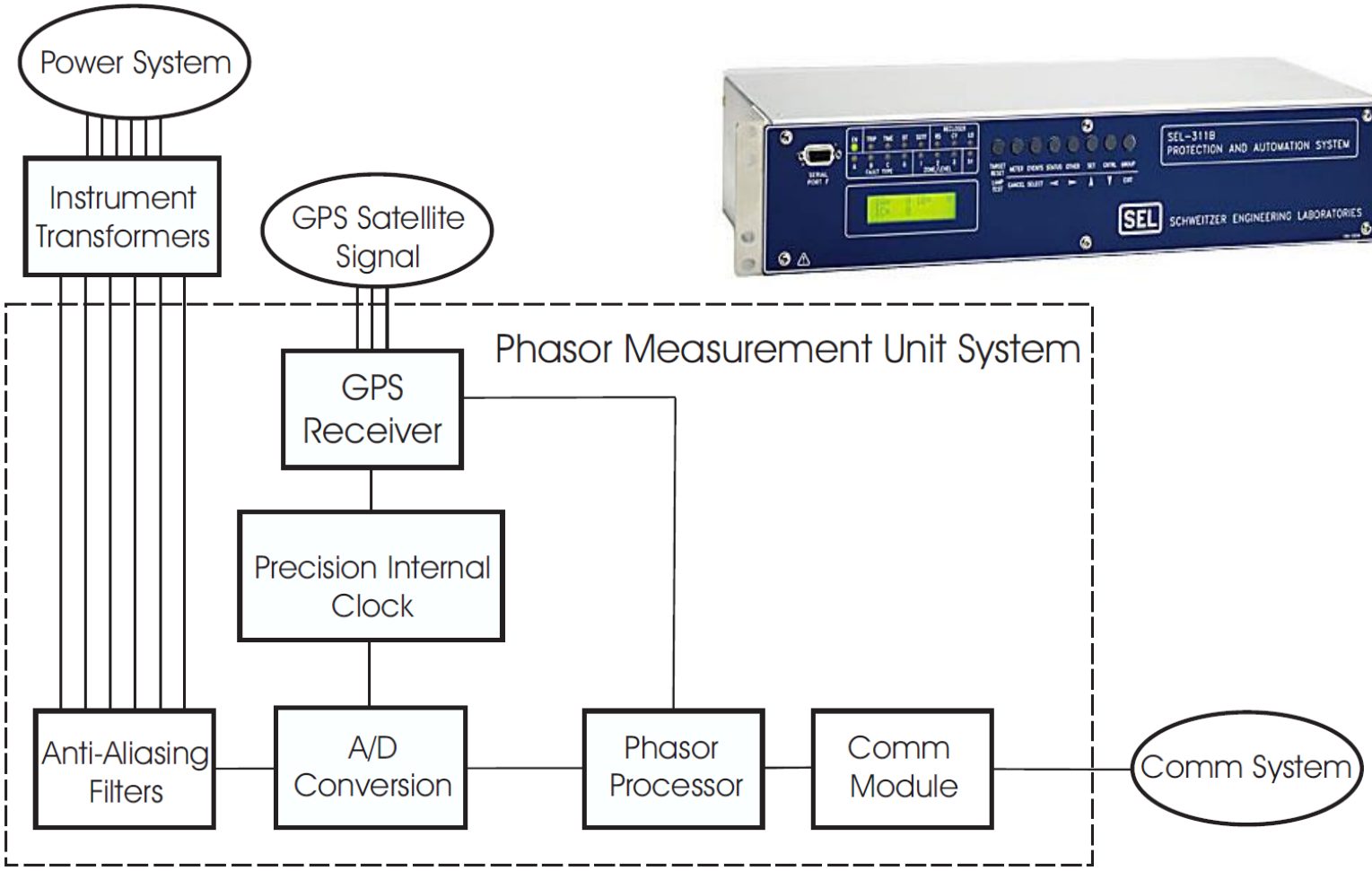
APPLICATIONS

- Wide area measurement/control
- Event Analysis
- Grid Automation/Optimization
  - Load Shedding
  - Detecting faults
  - System isolation



Wisconsin PMU distribution

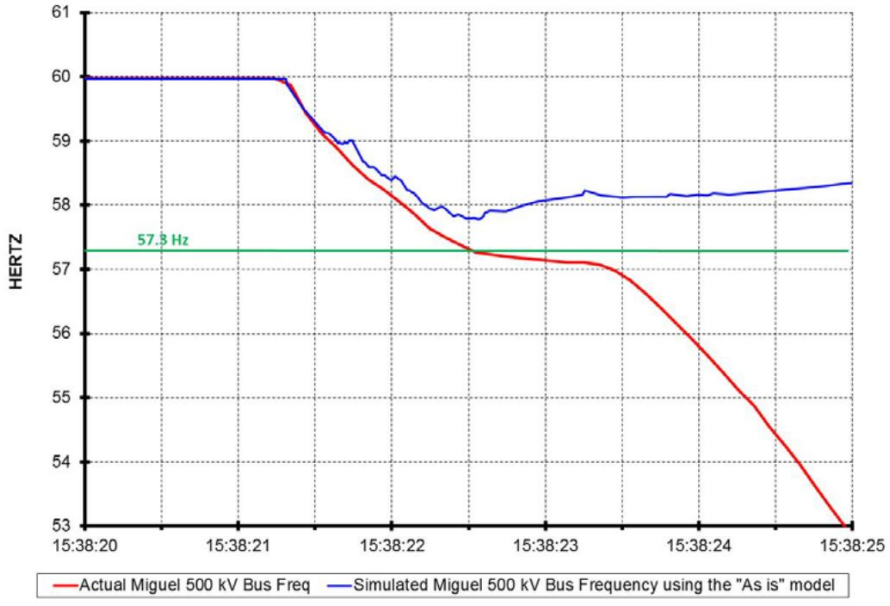
PHASOR MEASUREMENT UNITS



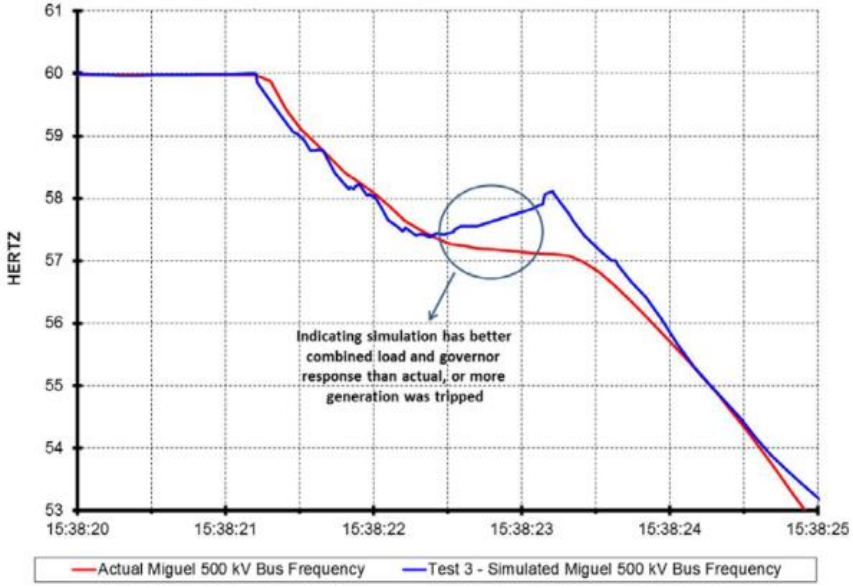
PMU CONTINUED

- Used to investigate system response to an atypical event
- Observe behavior over very large area
- Validate and improve models (California - Arizona Line)

Previous model



New model incorporating PMU data



IEEE AND ITS LIMITATIONS

- 1% Total vector error (TVE) allowed
- Frequency error of 0.005 Hz
- Not many PMUs meet requirements
- 2014 IEEE Std relieved some of the requirements

PSERC

Conformance Test Results

PMU	Class	Steady State Test									Dynamic State Test								
		Magnitude Variation			Phase Angle Variation			Frequency Variation			Measurement Bandwidth			Frequency Ramp			Step Change		
		TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	RT	DT	MO
A	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	F	F
A-1*	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
B	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	F	S
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	S
C	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	S
	M	S	S	S	S	S	S	S	S	S	S	S	S	F	F	F	S	S	S
D	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	F
E	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	F	S	F	F	F	S	S	F	F	S	S	F
F	P	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	S	S
	M	S	S	S	S	S	S	F	S	S	F	F	S	F	F	F	S	S	S
G	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
H	P	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S
	M	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S

*PMU A-1 is an upgraded firmware of PMU A. P: Class P; M: Class M.
TVE: total vector error; FE: frequency error; RFE: rate of change of frequency error;
RT: response time; DT: delay time; MO: maximum over/under shoot
S stands for "Satisfied"; F stands for "Failed".

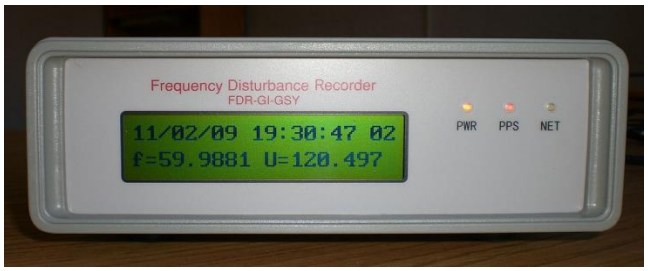
TEXAS A&M UNIVERSITY

Northeastern

FNET

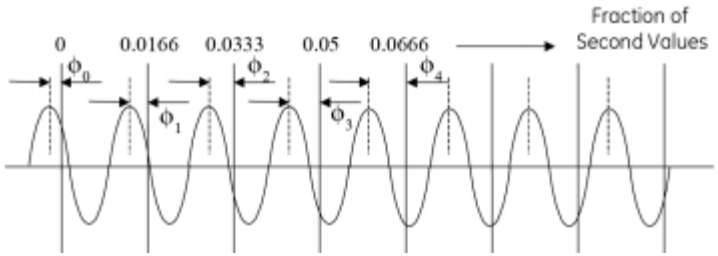
- 120 V, Single Phase PMU
- Samples at 1440 Hz and generates phasors at 10 Hz
- Over 80 installed units, monitoring wide area

- Oscillation detection
- Event detection/location
- Event visualization



QUINLAN! WHAT WE STILL NEED:

- Something showing the time stamps possibly?



- Practical uses
  - Limitations
  - PMU's/Fnet's?
- Future efforts
- Comparison to Scada maybe?
- Anything else? This seems short..