

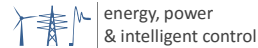


OpenPMU

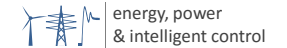
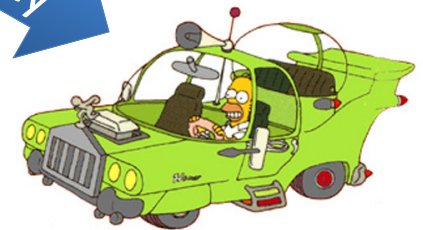
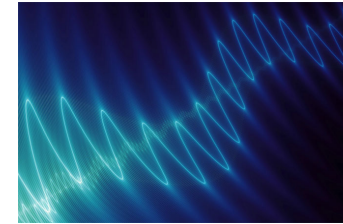
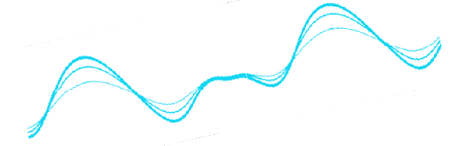
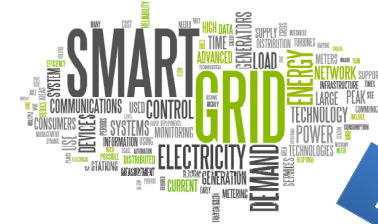
Open Source Phasor Measurement Unit

March 2017

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Why build your own PMU?



Why build your own PMU?



The reality of PMU ownership

Bad hardware

Like, really bad! Really, really bad!

Bad software

You'll wish it ran Windows ME

Mystery algorithms

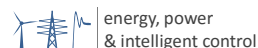
Who needs to know where the data comes from, so long as it does...

Awful reliability

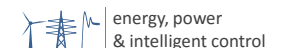
Oh yeah, except good luck with getting the data



"But the cost isn't the \$30 of hardware we used, it's the development we did in the 1980s!"



Why build your own PMU?



Phasor Representation

Phasor representation in AC power systems is a useful tool for analysis and design (first proposed in 1893 by Charles Steinmetz).

Phasor representation greatly simplifies the mathematical complexity of analysing complex networks with sinusoidal voltages.

A phasor describes the amplitude and phase angle of a **time invariant** waveform.

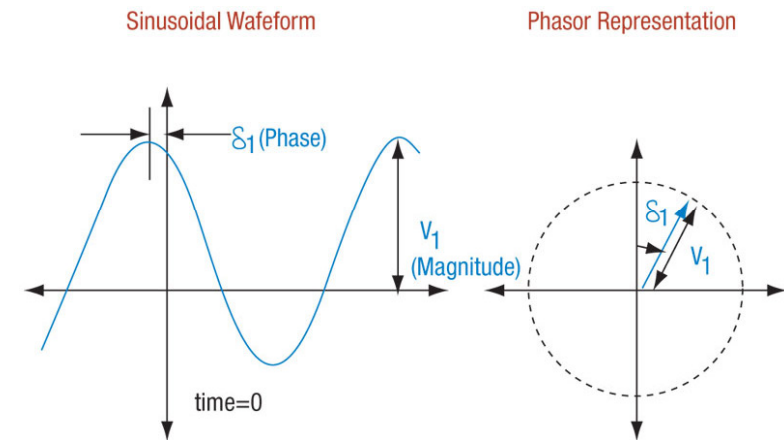
That is to say, that a phasor is only valid when the frequency of the AC power system is constant.

But we want to use PMUs to understand faults and stuff! <<< ????

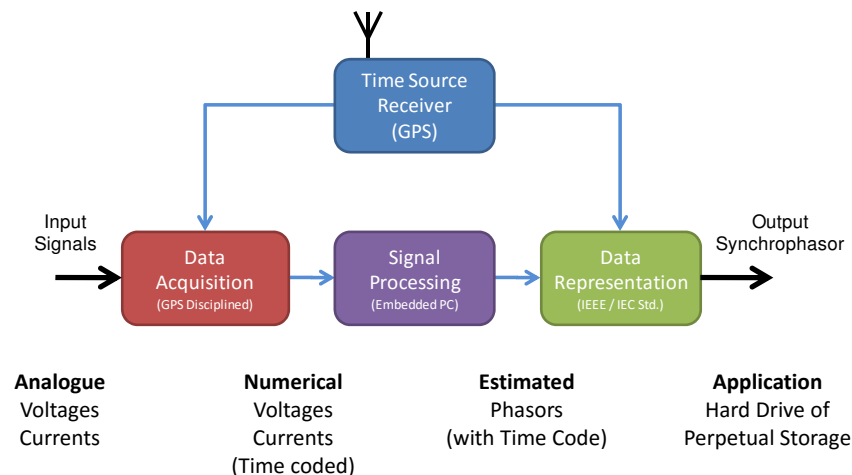


Charles Proteus Steinmetz

Phasor Representation



PMU Basics



Synchrophasors

What PMUs do

Estimate time synchronised phasors...

- Amplitude
- Phase Angle
- Frequency
- ROCOF

What some people think PMUs do

Record oscillography
Estimate power quality
Become an RTU
Control wind farms
Predict the future
Do your taxes
Perpetual motion
Make toast

DFR / Multifunction devices

Synchrophasors

Time synchronised phasors...

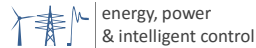
- Amplitude
- Phase Angle
- Frequency
- ROCOF

The only function a PMU has is to take the sampled values from its ADC and estimate a phasor which represents them.

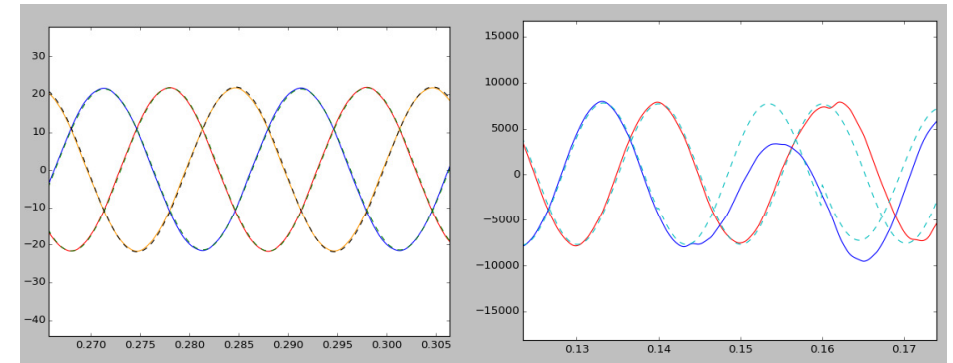
$$x(t) = X_m \cos(2\pi ft + \varphi)$$

Measurement requirements:
IEEE C37.118.1-2014

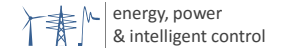
Data format:
IEEE C37.118.2-2014



Synchrophasors



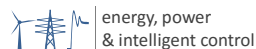
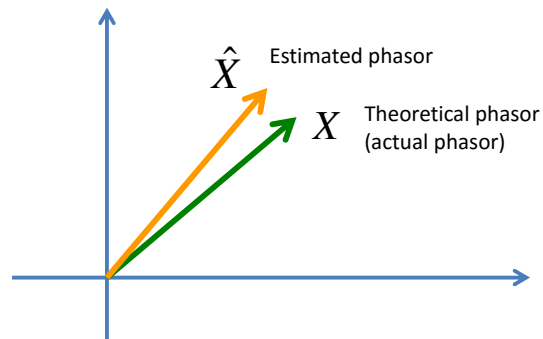
Remember, we can only fit a cosine to the sampled data that we have, nothing else!



Total Vector Error (TVE)

The error in estimating a phasor is comprised of

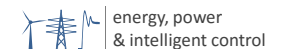
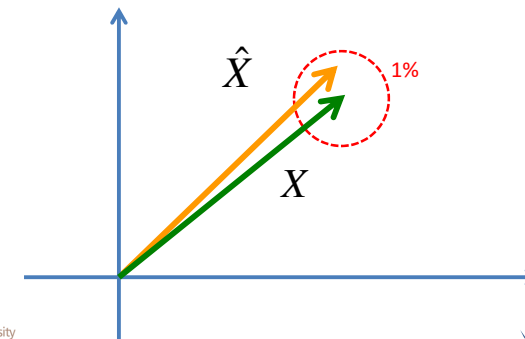
- 1) magnitude error, and
- 2) phase error



Total Vector Error (TVE)

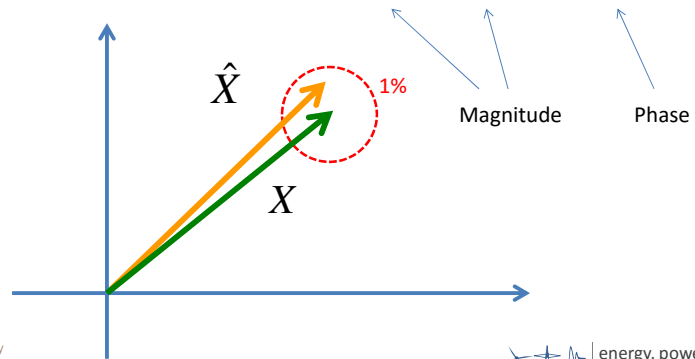
The IEEE Standard allows a TVE of 1% under normal conditions

We can think of TVE as a “bubble of uncertainty” in our estimation



Total Vector Error (TVE)

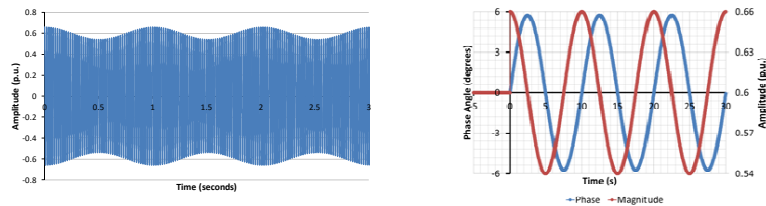
Mathematically...
$$TVE^2 = 1 + \left(\frac{\hat{X}}{X} \right)^2 - 2 \left(\frac{\hat{X}}{X} \right) \cos(d\phi)$$



Performance Tests in IEEE C37.118.1

1. Steady-state (subclause 5.5.5)
2. Measurement bandwidth (subclause 5.5.6)
3. Ramp in frequency (subclause 5.5.7)
4. Step change in phase / magnitude (subclause 5.5.8)

Measurement Bandwidth

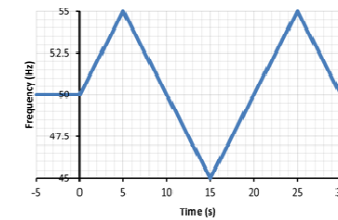


$$X_1 = X_m [1 + k_x \cos(\omega t)] \times \cos[\omega_0 t + k_a \cos(\omega t - \pi)]$$

where,

X_1 is the positive sequence component
 X_m is the amplitude of the input signal
 ω_0 is the nominal frequency of the power system
 ω is the modulation frequency in radians/s
 k_x is the amplitude modulation factor
 k_a is the phase angle modulation factor

Ramp in Frequency

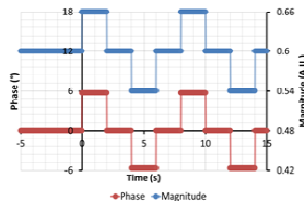


$$X_1 = X_m \cos[\omega_0 t + \pi R_f t^2]$$

where,

X_1 is the positive sequence component
 X_m is the amplitude of the input signal
 ω_0 is the nominal frequency of the power system
 R_f is the frequency ramp in Hz/s (df/dt)

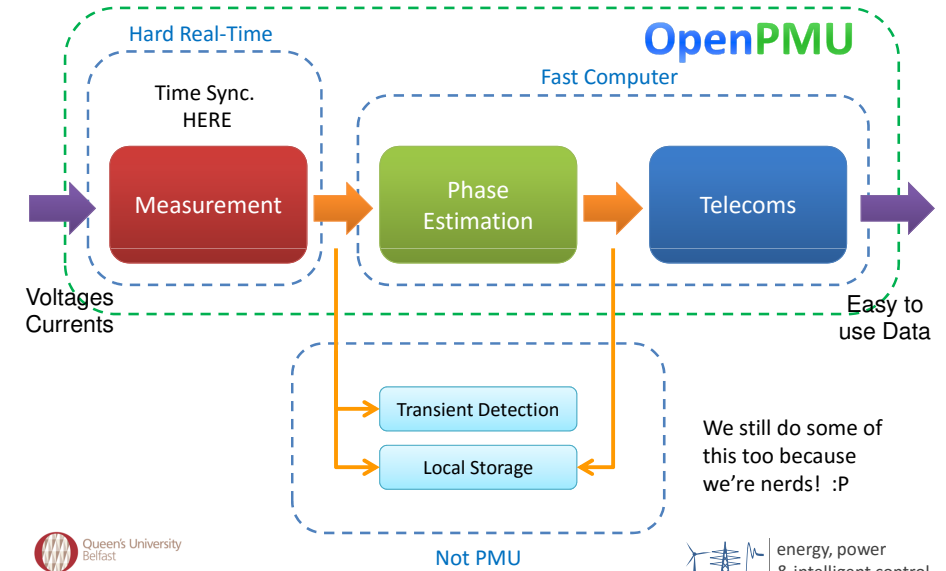
Step Change in Phase / Magnitude



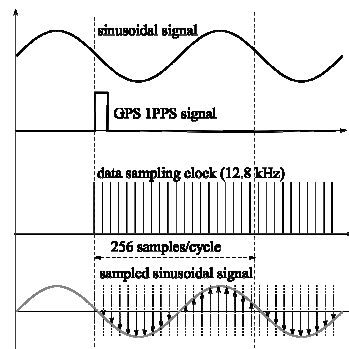
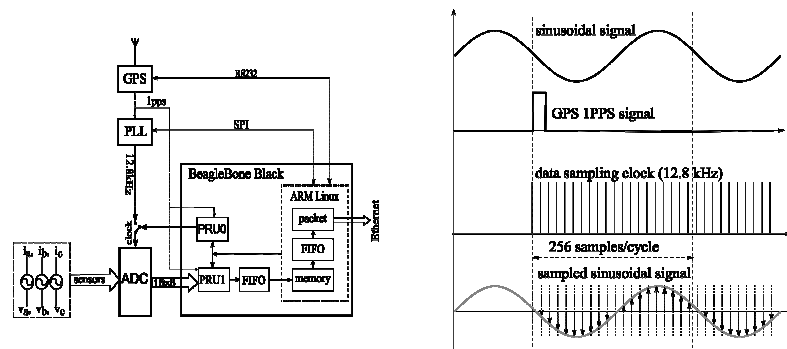
$$X_1 = X_m [1 + k_x f_1(t)] \times \cos[\omega_0 t + k_a f_1(t)]$$

where,
 X_1 is the positive sequence component
 X_m is the amplitude of the input signal
 ω_0 is the nominal frequency of the power system
 k_x is the magnitude step size
 k_a is the phase step size
 $f_1(t)$ is a unit step function

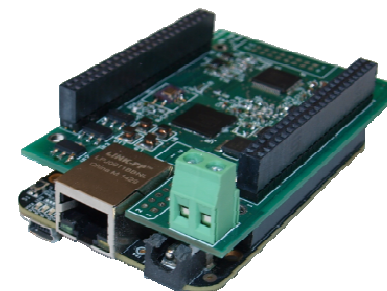
Making it better...



GPS Disciplined ADC



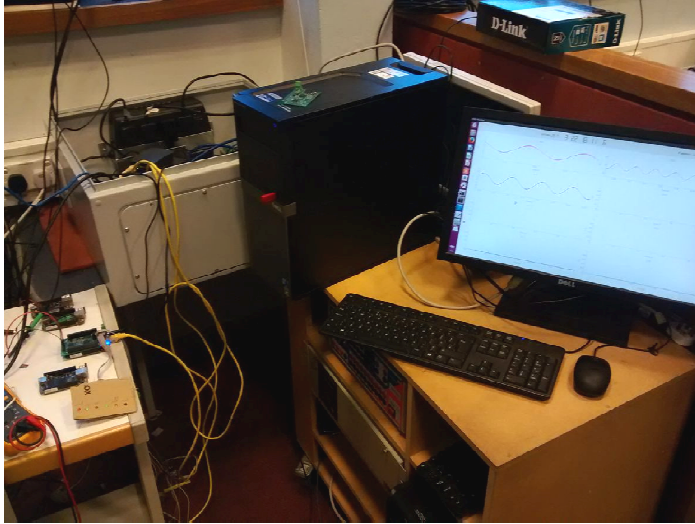
GPS Disciplined ADC



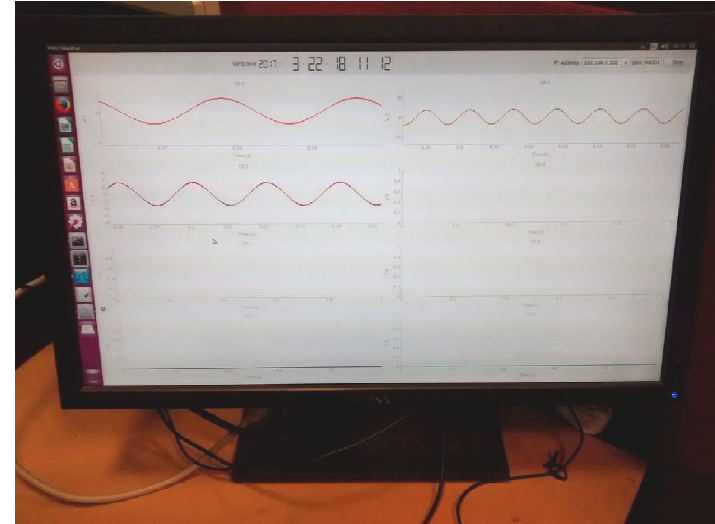
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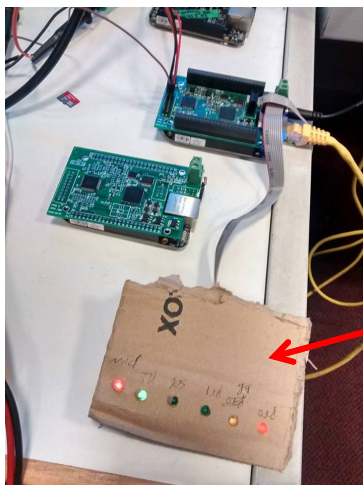

GPS Disciplined ADC



GPS Disciplined ADC



GPS Disciplined ADC



At late stage of
development,
hardware / software
but we include some

cardware!

Phasor Estimation

