Point-on-Wave Measurements Introduction

April 16, 2019

Farnoosh Rahmatian
NuGrid Power Corp

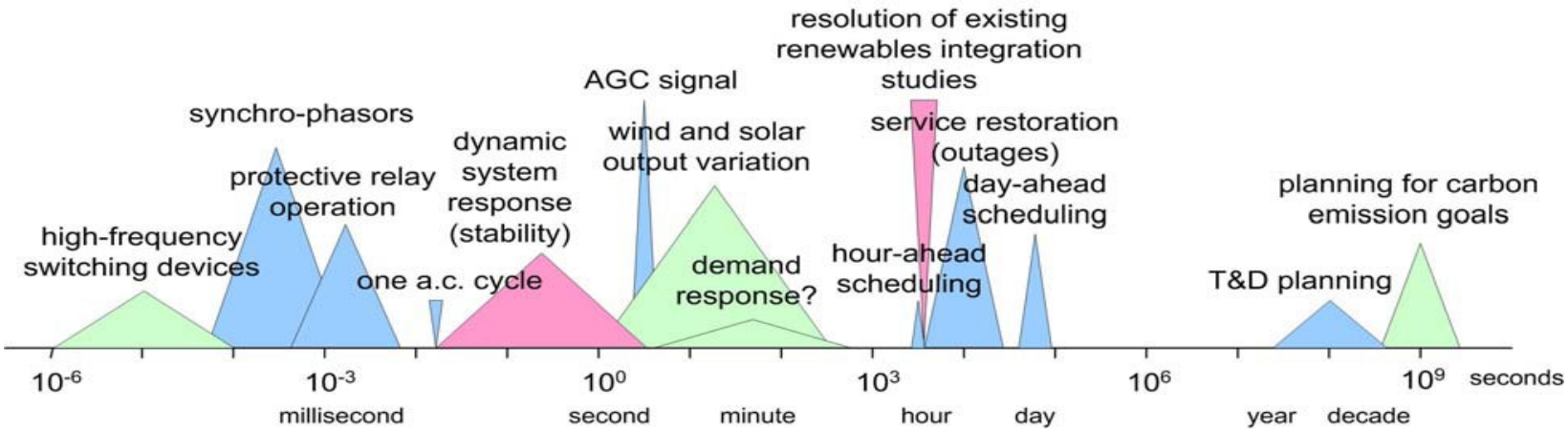
NuGrid

Outline:

- Time scale of measurements
- Mostly sinusoidal waveforms
- Standards for digital point on wave measurements
  - Digital measurement streaming
  - Digital measurements storage
- Measurement chain performance
- Presentation topics

Time Scale of Measurements

- Load profiles
- SCADA
- Synchrophasors / RMS
- Instantaneous measurements
- Harmonics
- Slow transients
- Fast Transients
- Partial Discharge



Time Scales for Power System Planning and Operation*

*A. von Meier, "Challenges to the Integration of Renewable Resources at High System Penetration," California Energy Commission, May 2014

Electrical Measurement in the Utilities

	Meters & PQ & Recorders	Relays	Merging Units (61850 SV)	PMUs	RTUs and SCADA
Signals sampled	V and I from VTs and CTs	V and I from VTs and CTs	V and I from VTs and CTs	V and I from VTs and CTs	Phase-to-phase voltage
Typical sampling rates	960 to 50,000 Hz	960 to 8,000 Hz	4,800 to 14,400 Hz	960 to 8,000 Hz	Typically under 1,000 Hz
Output data intervals	0.2s (PQ) to 5 minutes	By exception	0.4 ms	8 ms to 33 ms	2s to 10s
Output data rate	12 per hour (0.003 per second)	Irregular	2400 per second	30 to 120 per second	0.1 to 0.5 per second
Number of input channels	6 (3V and 3I)	6 (3V and 3I)	6 (3V and 3I)	6 (3V and 3I)	1 (V_{AB})
Number of parameters measured per device	1 to 20	1 to 6 +	3 to 8	5 to 20 (Vs, Is, f, etc.)	1 (V_{AB}) +
Number of devices acting	1 local	1 to 2 local	1 to 5 per relay 1-200 in substation	100s to 1000s Wide Area	1000s Wide Area

Pure Sinusoid

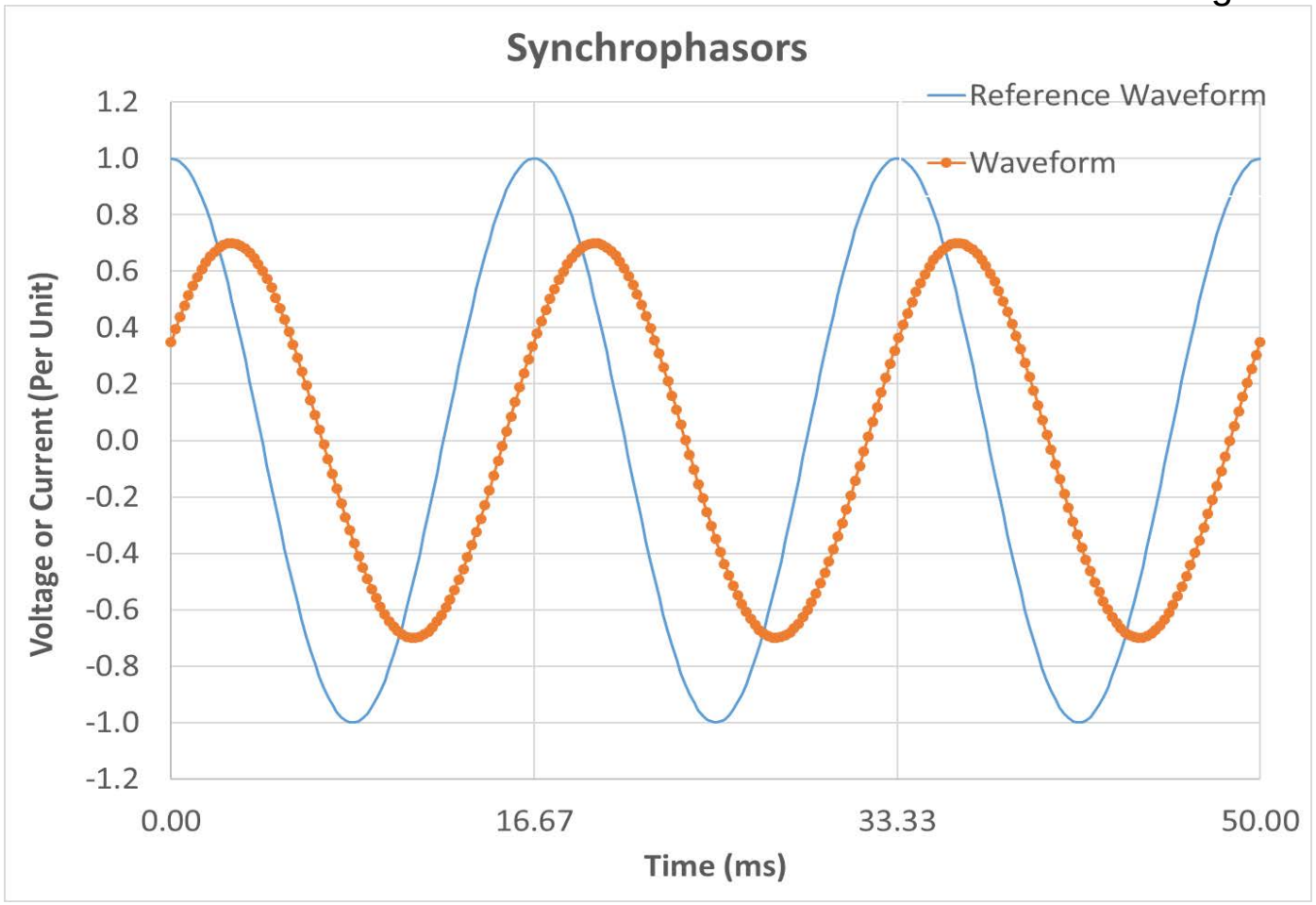
Steady State Conditions

$$x(t) = A\cos(\omega t + \varphi)$$

magnitude

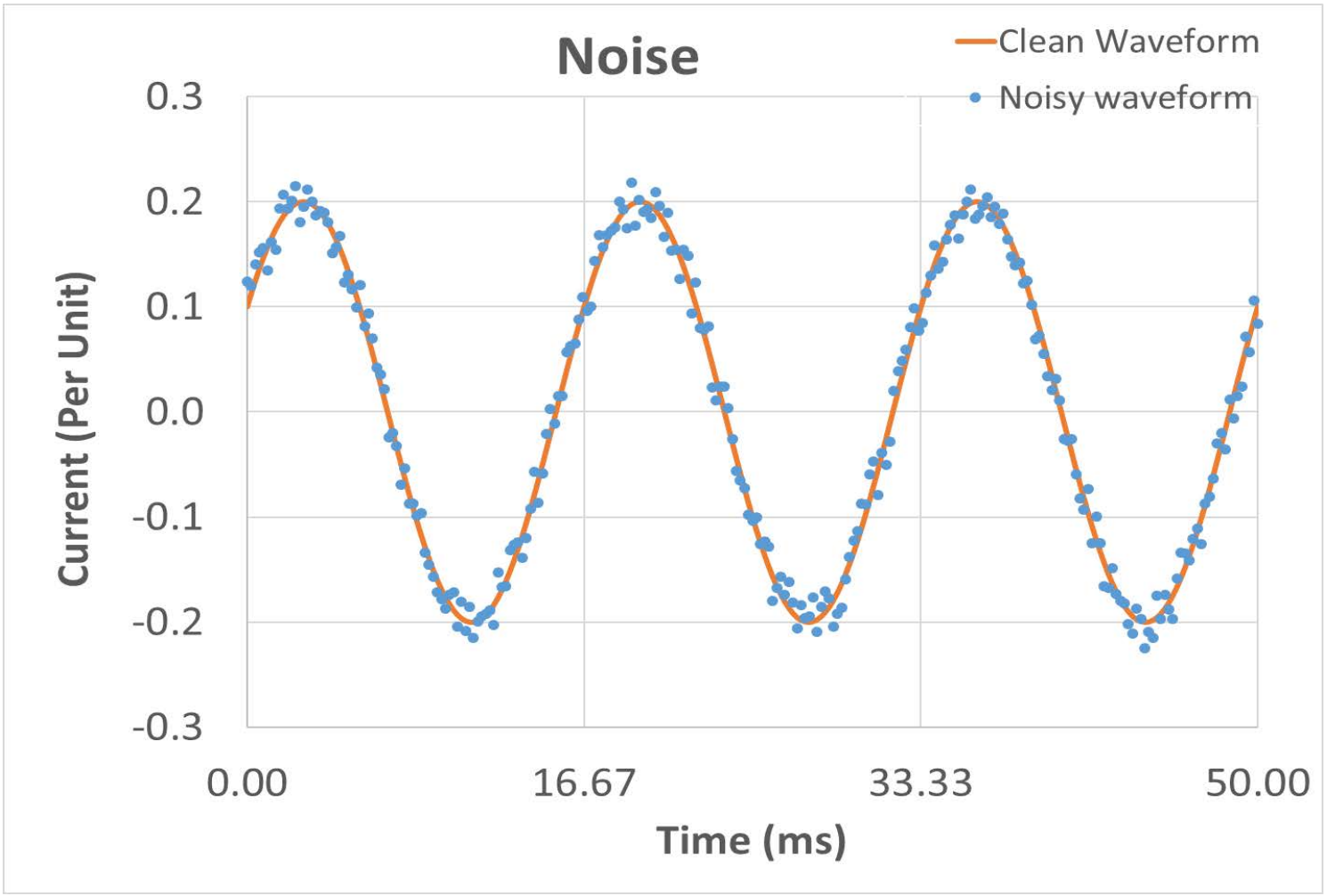
frequency

phase



Noisy Sinusoid

$$\mathrm{SNR} = 20\,log\frac{A}{\sqrt{\frac{1}{N}\sum_{k=1}^{N}(u_k - v_k)^2}}$$



Showing an example with Signal-to-Noise Ratio (SNR) of ~ 23 dB

Synchrophasors Measurement

$$v\,(t) = V\cos(\omega t + \varphi) \qquad i\,(t) = I\cos(\omega t + \theta)$$

- A “Fitting Challenge” can be measured using a Goodness of Fit (GoF) metric

$$\mathrm{GoF} = 20\log\frac{A}{\sqrt{\frac{1}{(N-m)}\sum_{k=1}^{N}(u_k - v_k)^2}}$$

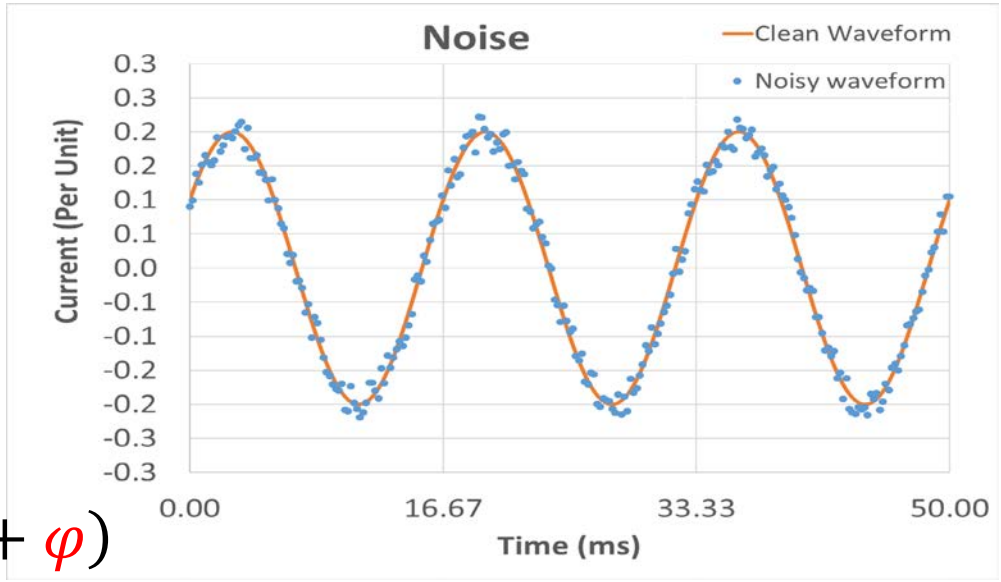
$$\mathrm{SNR} = 20\,log\frac{A}{\sqrt{\frac{1}{N}\sum_{k=1}^{N}(u_k - v_k)^2}}$$

$m = 3$

Actual Sampled Data

Obtained from the Synchrophasor Estimated

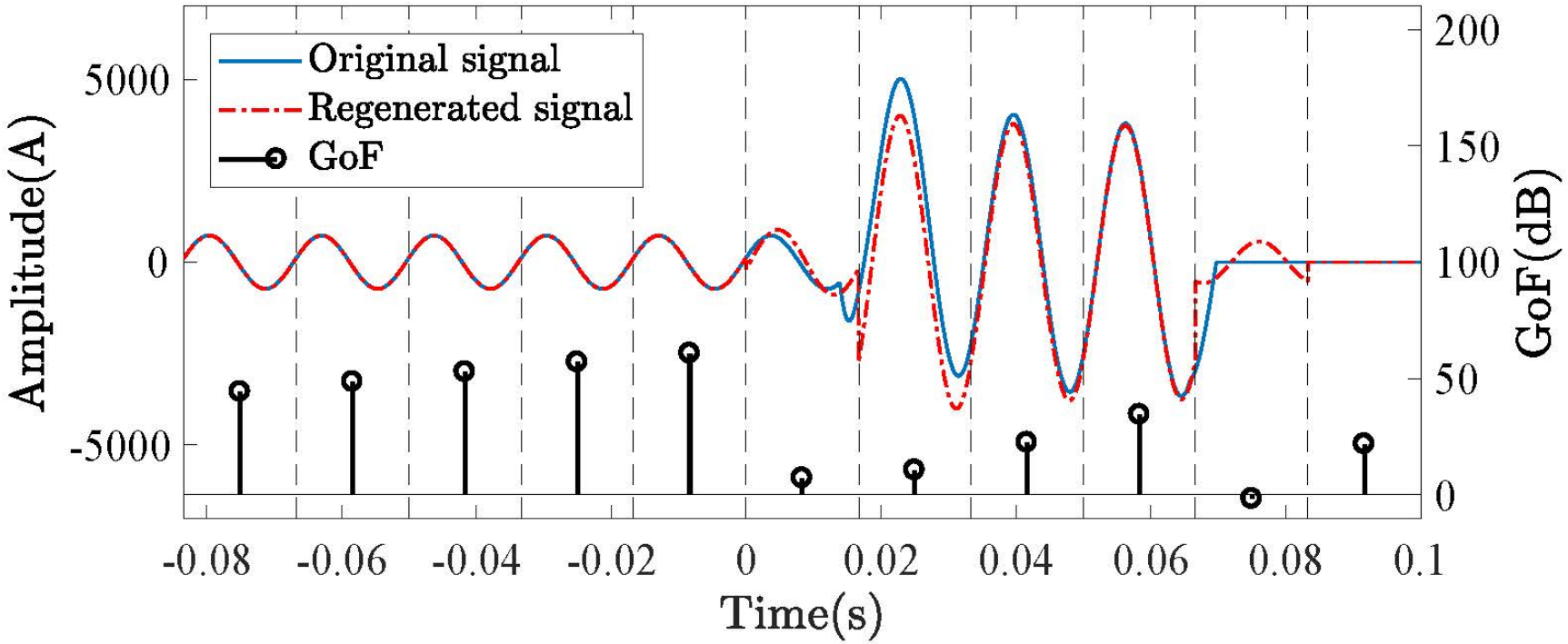
$$v_k = V\cos(\omega t_k + \varphi)$$



A. Riepnieks and H. Kirkham, “An introduction to goodness of fit for PMU parameter estimation,” *IEEE Transactions on Power Delivery*, vol. PP, no. 99, pp. 1–1, 2016.

Goodness of Fit

$$\mathrm{GoF} = 20\log\frac{A}{\sqrt{\frac{1}{(N-m)}\sum_{k=1}^{N}(u_k - v_k)^2}}$$

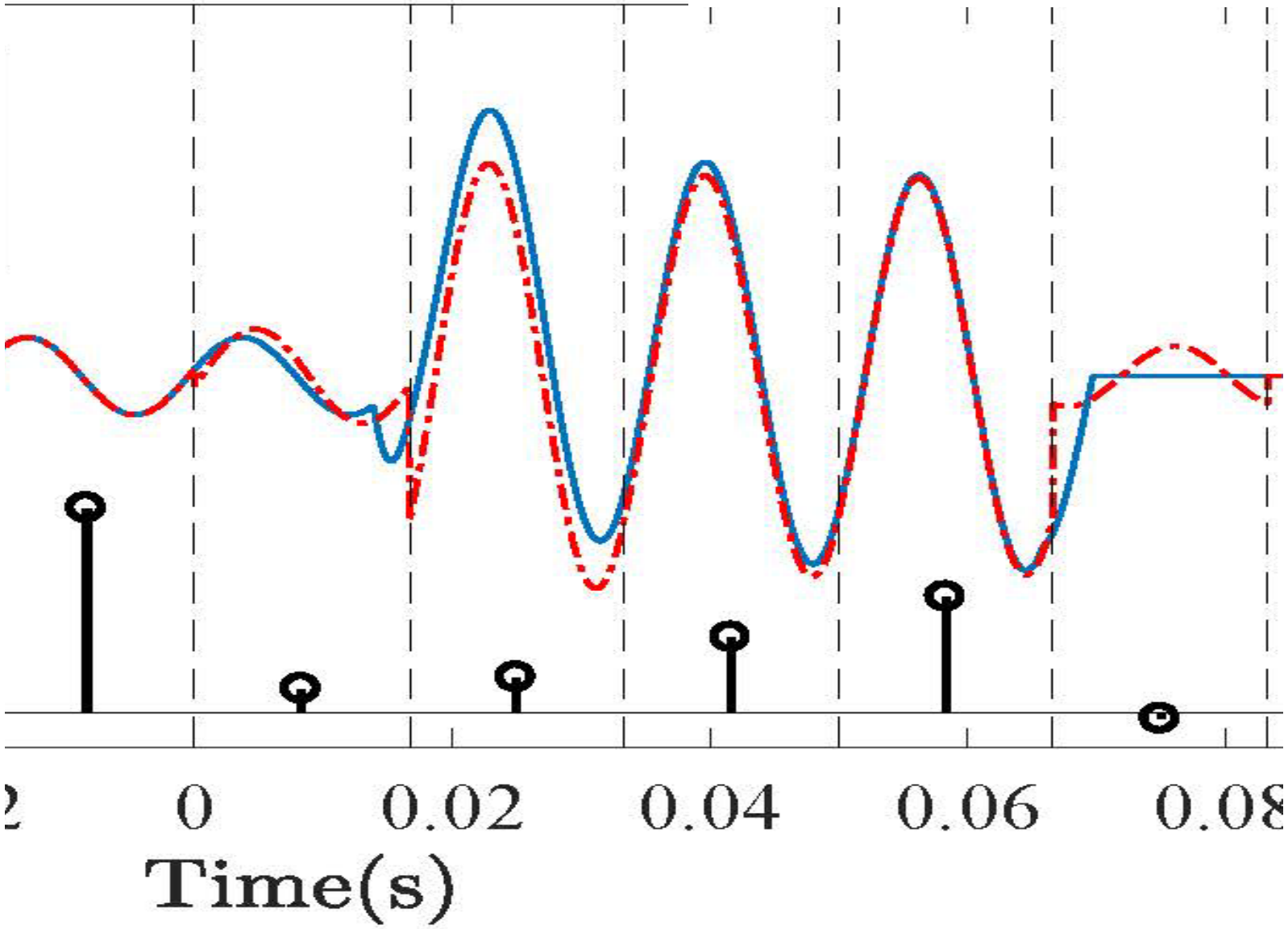


GoF can be low for various reasons:

- Noise in the measured signal, especially at low currents (low SNR)
- Distorted waveforms, particularly during the first or last cycle of faults
- DC offsets (decaying DC) during the early cycles of faults with long time constants
- Distortions due to CT saturation
- Distorted waveforms during high-impedance faults

During Faults

$$\mathrm{GoF} = 20\log\frac{A}{\sqrt{\frac{1}{(N-m)}\sum_{k=1}^{N}(u_k - v_k)^2}}$$

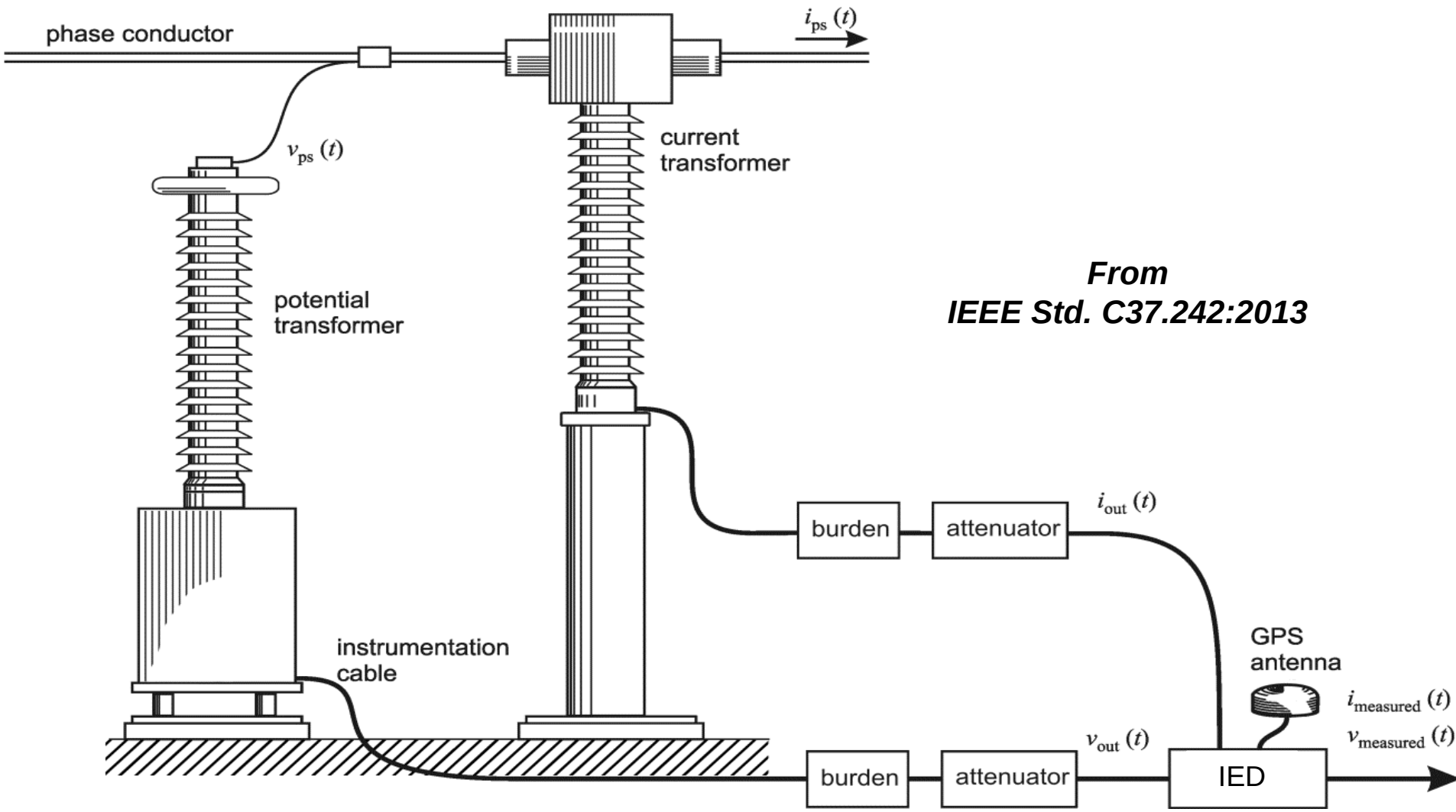


Standards for digital point on wave measurement

- IEC 61850-9-2 with IEC 61869-9 profile:2016
  - Merging Units and real-time streaming of Sampled Values
  - Sampling rates of 4800, 14,400, and 96,000
  - 2 ms max processing delay
  - 2400 Hz communications rate
  - Anti-aliasing and frequency profile
- IEC 61850-9-2 + UCA Guide (92LE):2003
- IEEE C37.111-2013 - IEEE/IEC Measuring relays and protection equipment – Part 24: Common format for transient data exchange (COMTRADE) for power systems

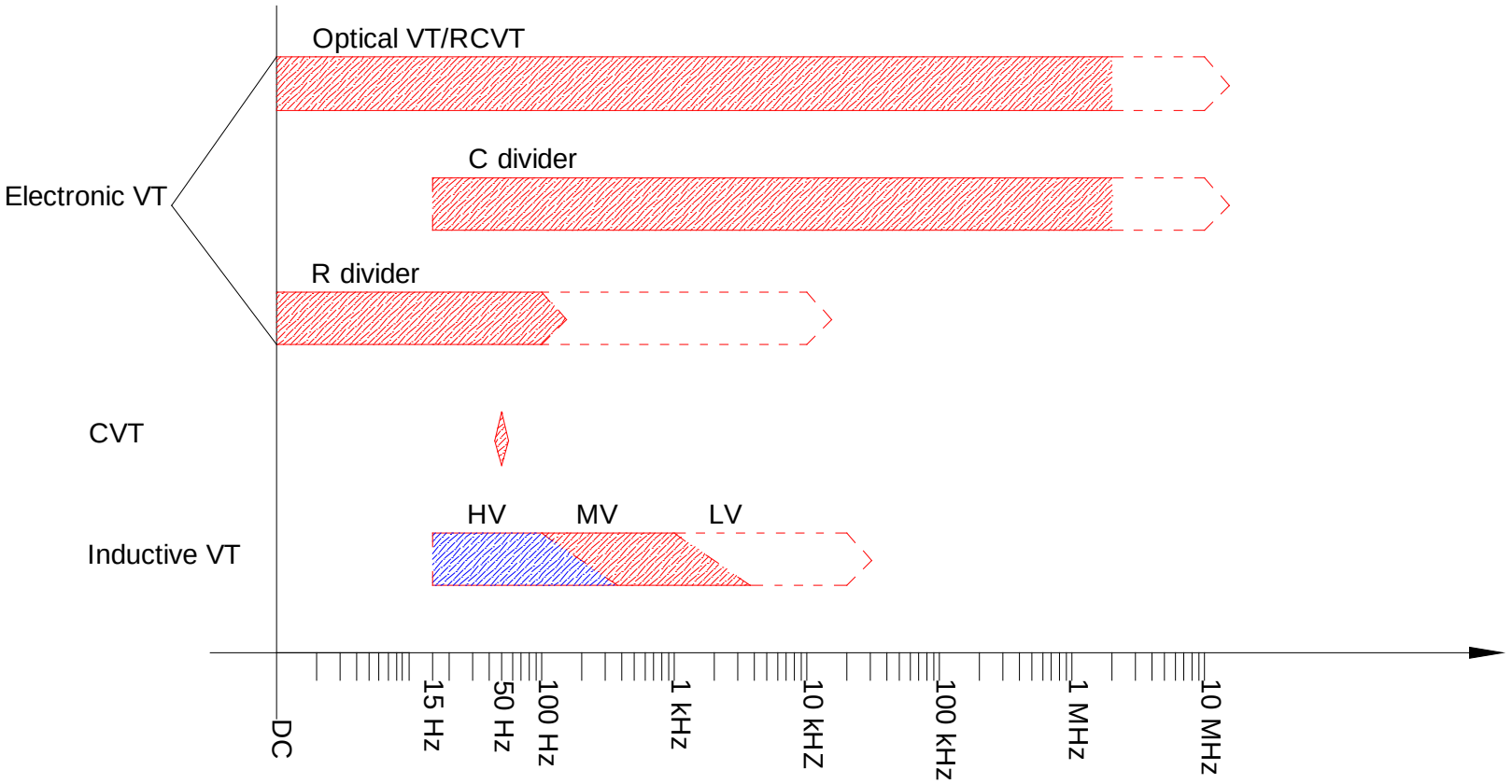
Measurement Chain and Bandwidth

- The IED is only part of the measurement chain



From IEEE Std. C37.242:2013

Sensor Bandwidth



IEC 61869-103:2012, Figure 9 – Voltage Transformer technologies' frequency range according to present experience

Presentation Topics

- Synchronized point-on-wave data recorder
- Frequency measurement under disturbance conditions
- High-speed synchrophasor computation
- Synchrophasors combined with triggered point-on-wave data, and dynamic harmonic phasors
- Software-defined sensors with point on wave Measurements
- Advancements in software technology for processing time-series data
- Open-source data analysis tool to support the use of point-on-wave measurements