Deep Data from Optical Sensors

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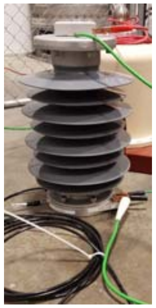
Outline

- What is a "deep-data" sensor?
- Optical Voltage/Current Sensors
- Value Stack
- Impact of function requirements
- Data Extraction - examples
- Life-cycle value



Definition

"DEEP-DATA Sensor"

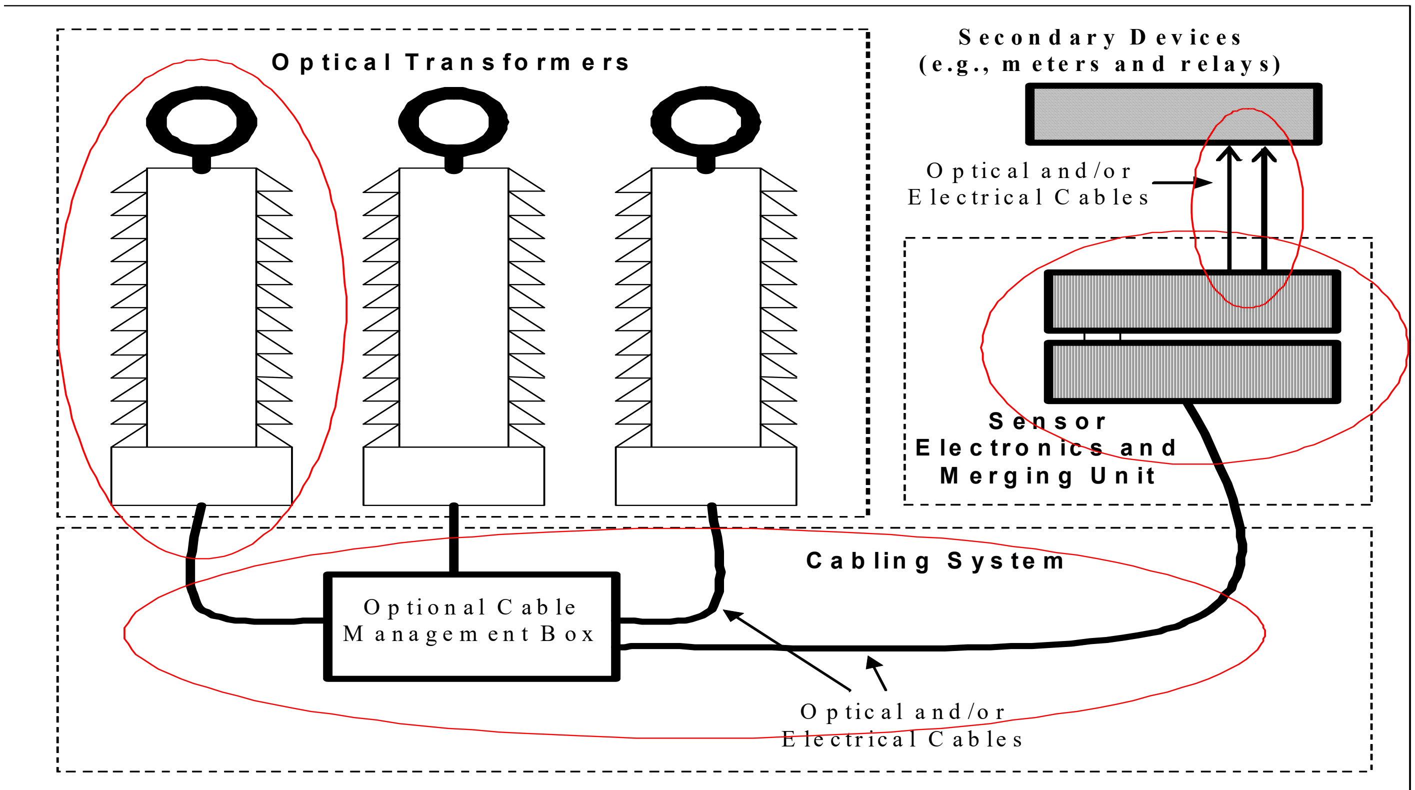
A sensor that has the linearity, accuracy, and bandwidth to provide source data for various filtering/optimization to serve a wide variety of applications with different data requirements.

~ multi-function sensor

Value Proposition for V & I Sensors

- Voltage and Current Sensors are our "eyes" and "ears" into the power system
  - Can you see far enough?
  - Can you hear deep enough?
- To maximize value from the grid, we need to see it and hear it "well"
  - Accuracy
  - Dynamic range
  - Frequency range

Optical Voltage and Current Sensor Systems

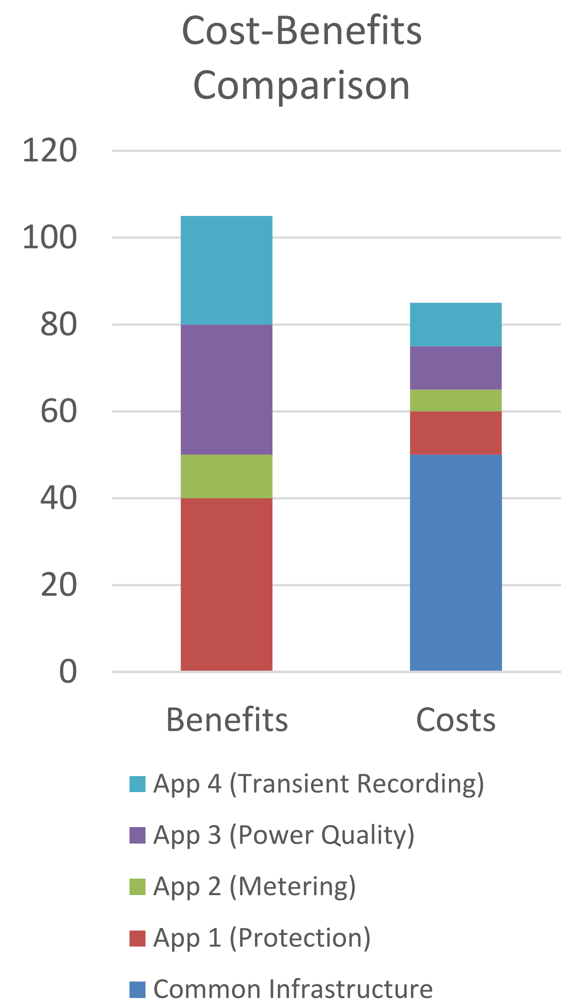


Schematic of a typical optical sensor system

IEEE Std 1601

Stacking Values

- Importance of stacking up values/benefits with shared cost
  - Serving multiple applications with one measurement system
- Importance of suitable architecture
  - Expandable and modular
  - Maintainable (design for maintainability)
- Value of using “**deep-data**” sensors
  - Wide Dynamic range
  - Wide frequency response
  - Accuracy and linearity



Data Optimization and Impact on Sensor Requirements

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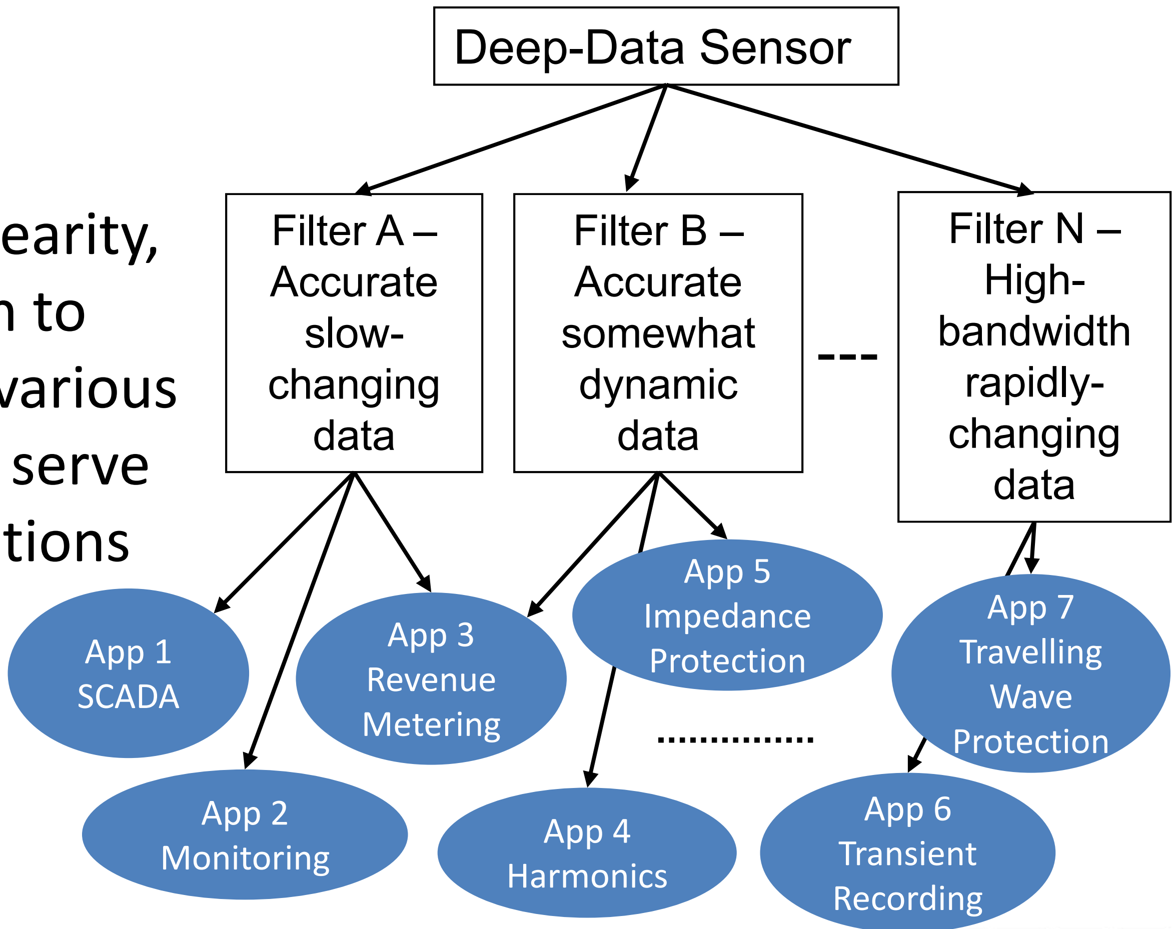
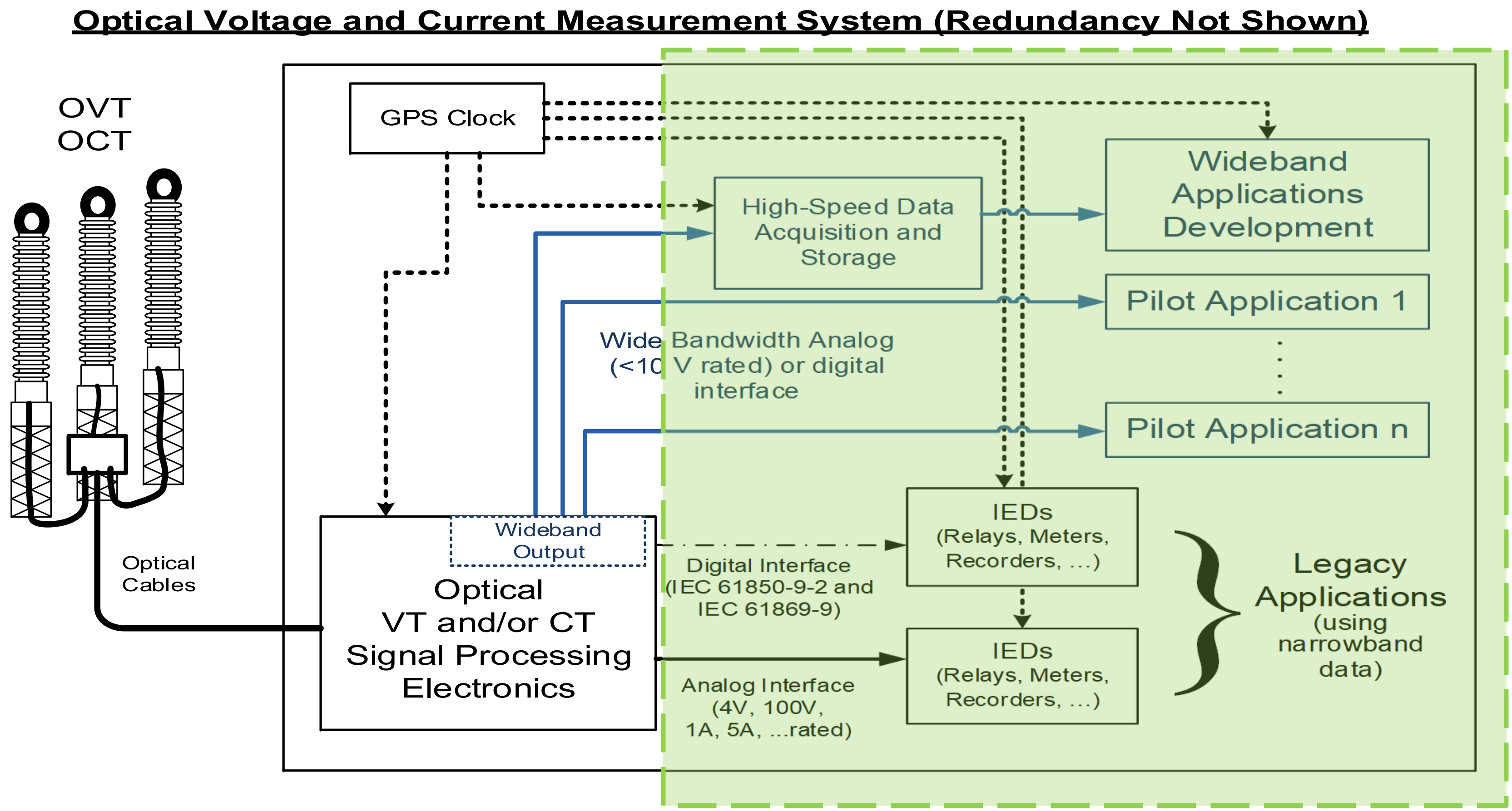


Example of a "DEEP-DATA Sensor" system design:



* D. F. Peelo, F. Rahmatian, M. Nagpal, and D. Sydor, "Real-time Monitoring and Capture of Power System Transients," *CIGRE General Session 44*, Aug. 26 - 31, 2012, paper B3-101.

Function Requirements – Impact on Sensor Requirements

Linearity Example:

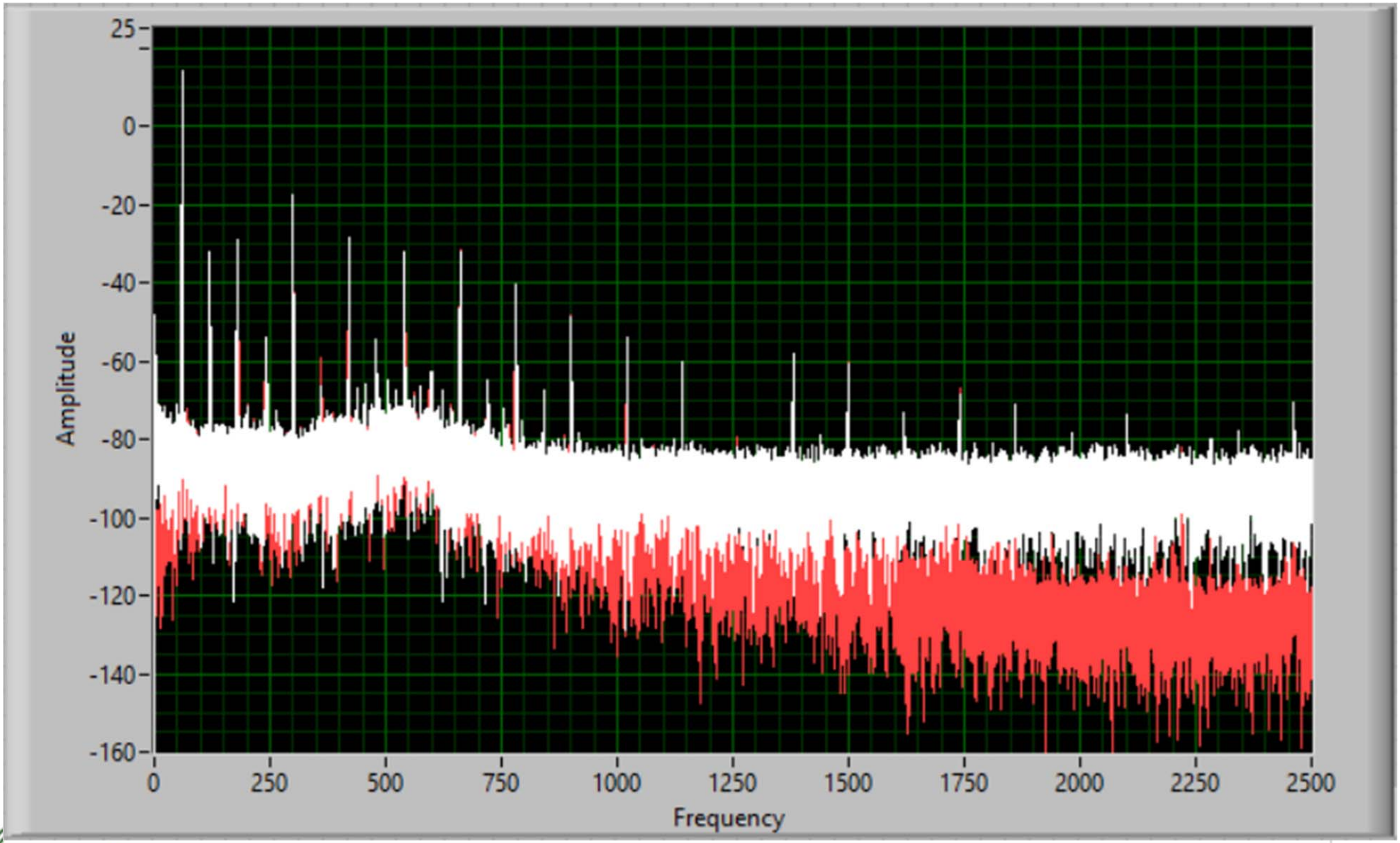
- Capacitor bank unbalance protection
  - Detect 0.25 to 5 A in a few seconds
- Situational awareness
  - 50 A to 4000 A in every second
- Over current protection
  - 2000 A to 100,000A in a few milliseconds

Function Requirements – Impact on Sensor Requirements

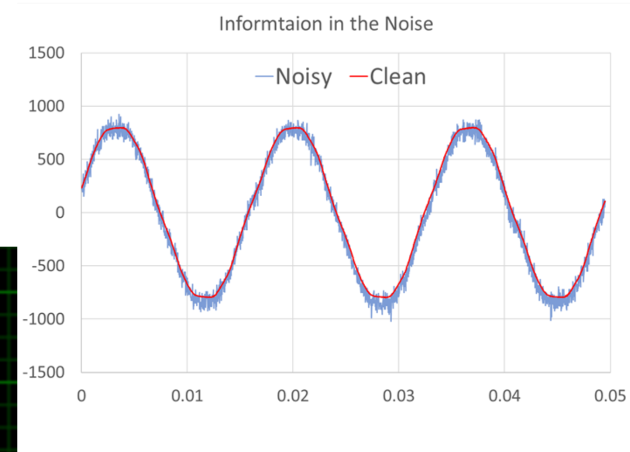
Bandwidth Examples:

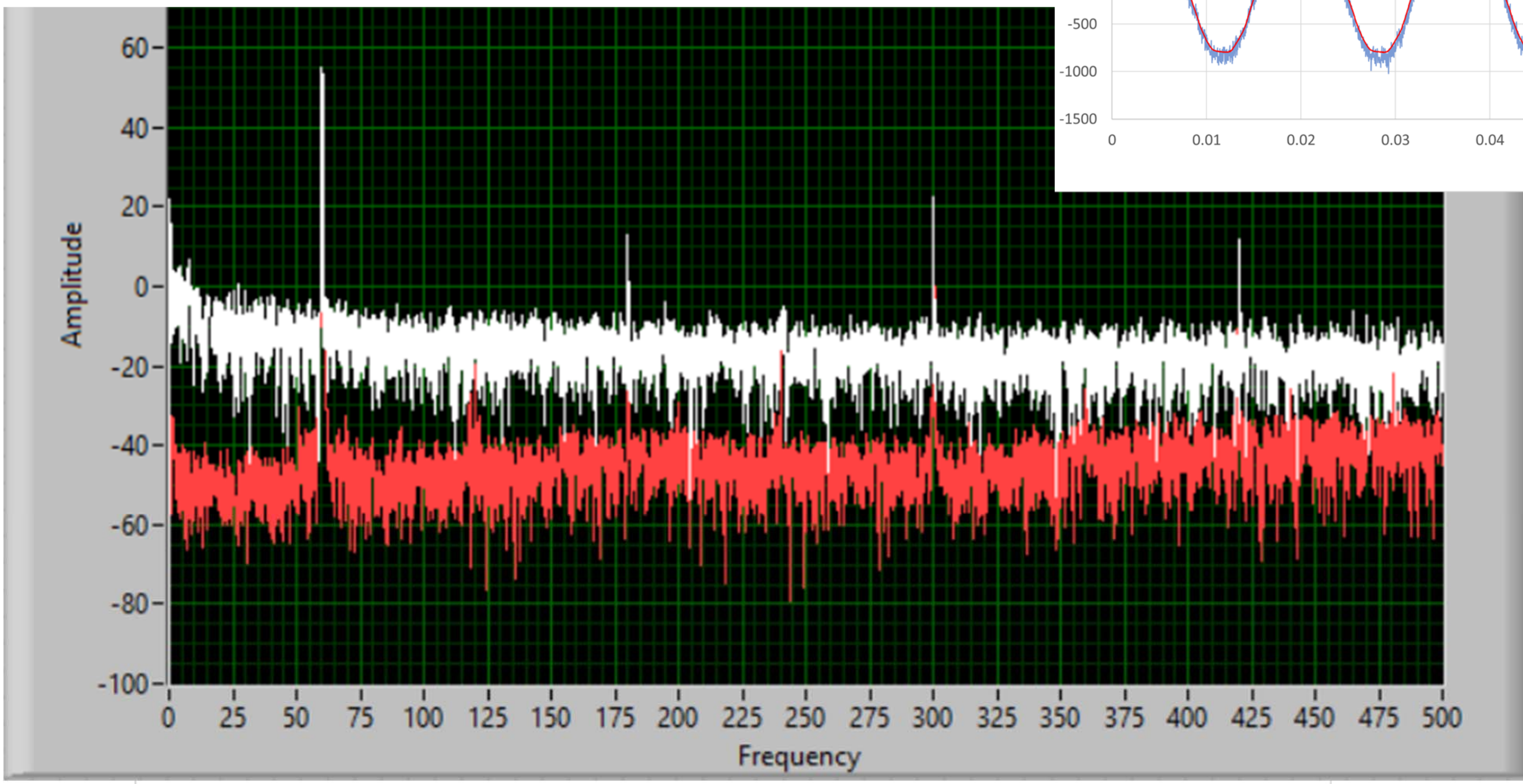
- Synchrophasors and traditional over current protection
  - 50 or 60 Hz components, every cycle or so, 1% to 10% accuracy
- Power quality metering to 50^{th} Harmonic (3 kHz)
  - 5% accuracy, 50 A to 2000 A primary, every 6 to 10 cycles
- HVDC or Static VAR Compensators
  - 20 kHz to 100 kHz bandwidth, < 10 µs latency for control
- Fast transient recording
  - >1 MHz bandwidth, niche application, special sensors and wiring

Time vs. Frequency Domain

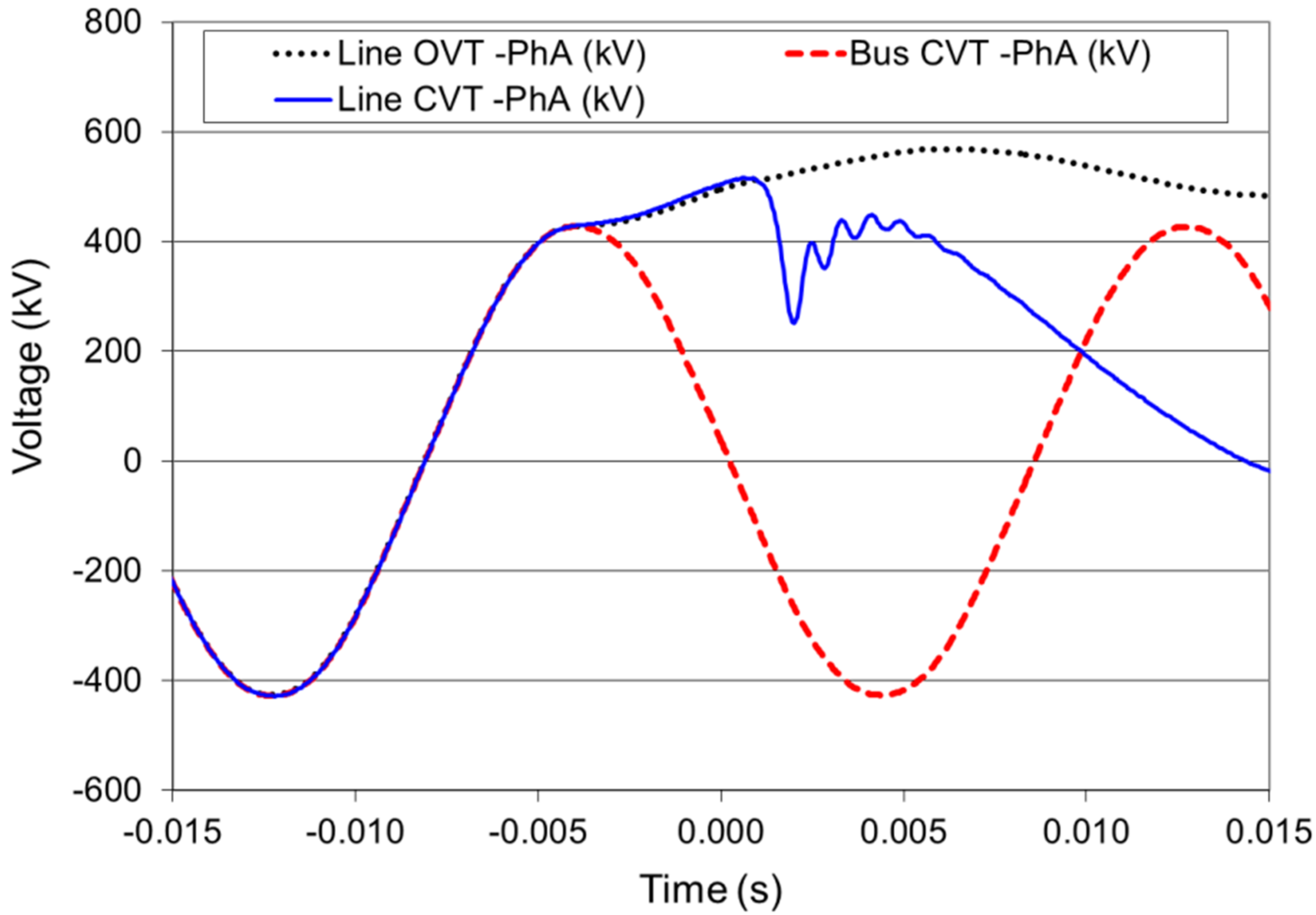


Time vs Frequency Domain



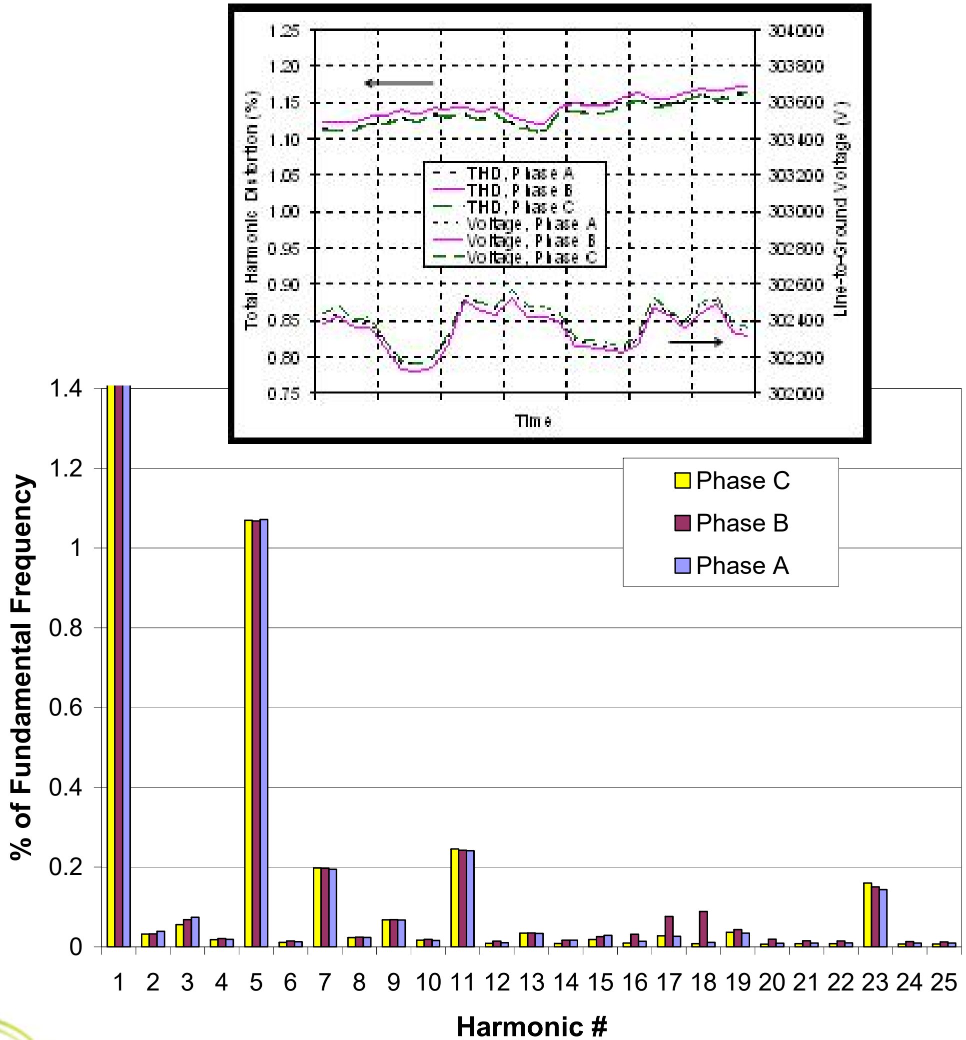


Switching & Transients



IEEE Std C37.241-2017 - Guide for Application of Optical Instrument Transformers for Protective Relaying

SVC Substation Harmonics Measurement



550 kV class testing for harmonics (Bandwidth 20 kHz)

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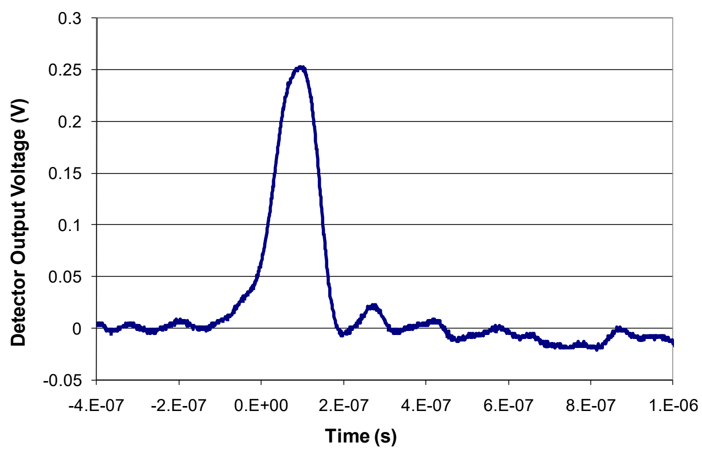
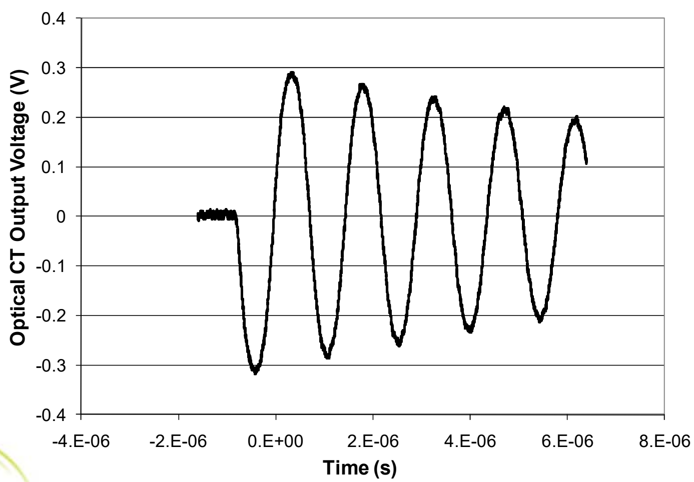
High-Frequency Measurements

Impulse and fast transient voltage and current measurements, e.g., for reactive switching test (in laboratory and on site)

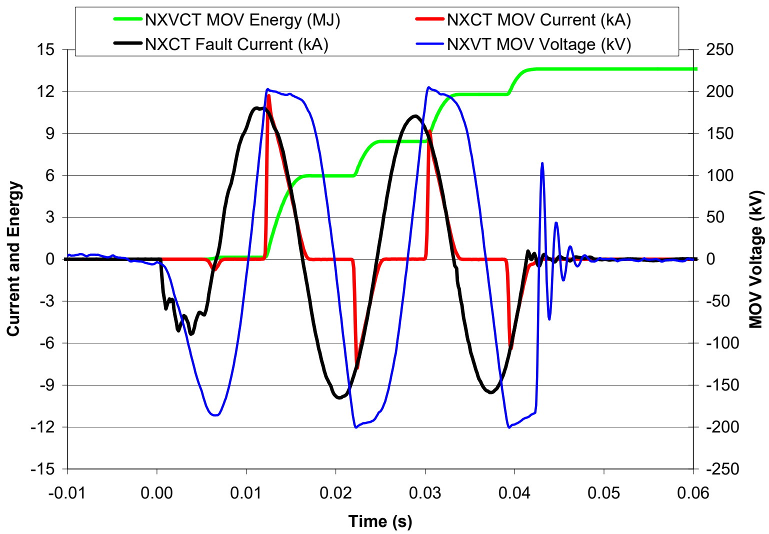


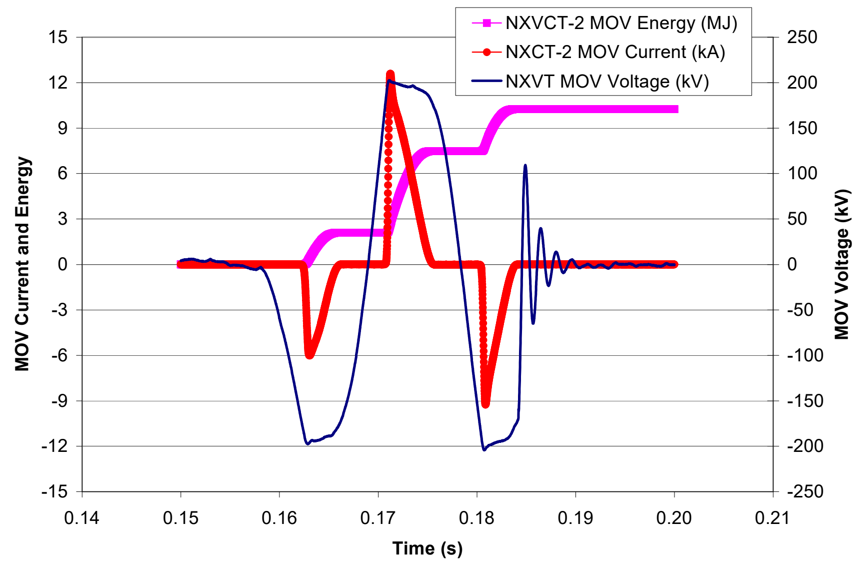
Sample Voltage Measurement Waveform: 283 kV peak with <100 ns rise-time



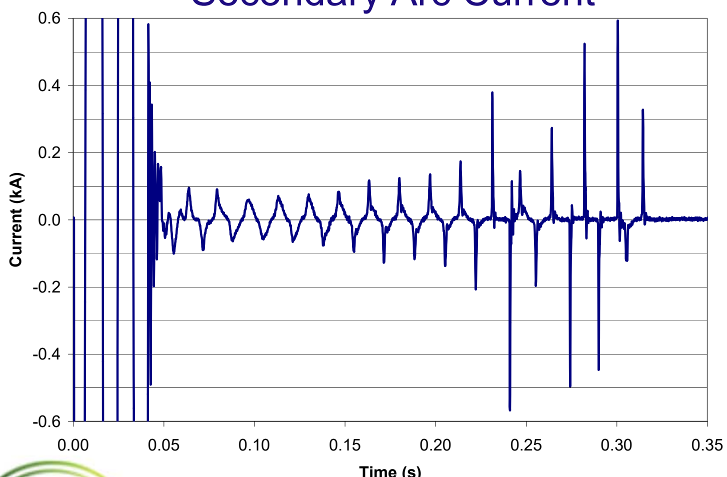
Sample Current Measurement Waveform: 26 kA peak at 0.7 MHz

Series Capacitor Staged Fault Testing





Secondary Arc Current



Summary Results

	Units					
Fault number		**1**	**2**	**3**	**4**	**5**
Primary arcing time	ms	**36**	**36**	**36**	**36**	**42**
Secondary arcing time	ms	425	863	606	290	276
Number of voltage peaks clipped by MOV		1	3	3	2	5
MOV energy absorbed	MJ	2.39	10.7	10.2	3.42	13.6
MOV Voltage Peak (absolute value)	kV	196	204	204	202	205
MOV Current Peak (absolute value)	kA	6.4	12	12	12.8	13
Approx. MOV Voltage ringing frequency	Hz	610	610	620	620	620
Primary Fault Current Peak (absolute value)	kA	11	11	11	11	11
Approximate secondary fault current (peak-to-peak)	A	120	160	120	160	160

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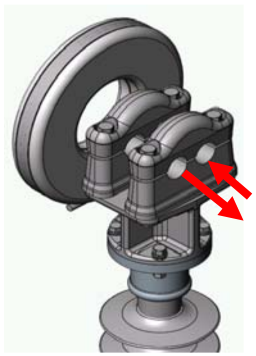
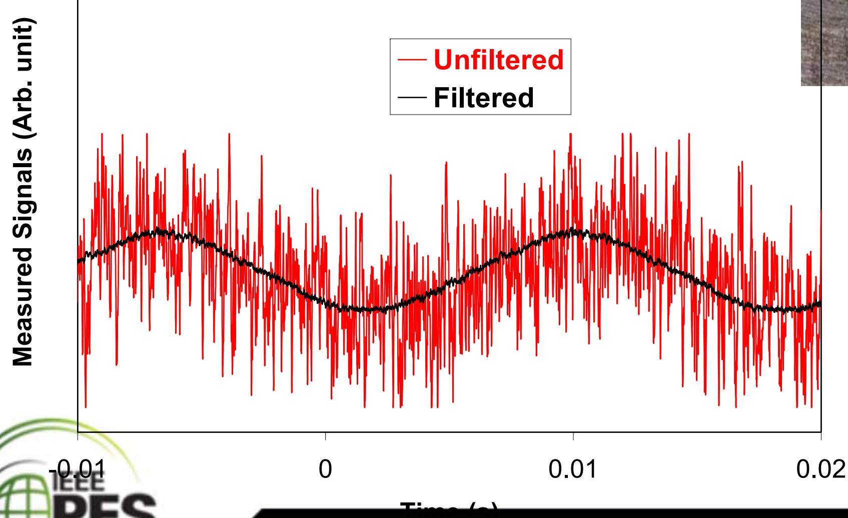
Shunt Capacitor Banks



Showing Primary Current of 0.5 A



Staged Approach to Extracting Value

- Pick technologies that have wide-scale use to maximize value
- Expect (and plan for) progression in use-cases
- Target high-value applications first, while
  - Architecting for application expansion (without blocking future foreseen applications)
  - Modularizing system components to allow evolution of modules (to minimize future cost)
- Deployment in stages
  - Allow for changing electronics while keeping passive long-life optics/high-voltage parts
  - Consider life-cycle cost (not just product cost)

Questions