Higher Speed Measurements on the Grid

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Outline

- Faster phenomena, sample functions needing higher speed measurements
- Ideal sensor features
- Sensing technologies
- Bandwidth and measurement speed
- Examples of actual measurements in the field
- Path Forward

Faster Phenomena

- Traditional grid switching events such as TRV (Transient Recovery Voltage) measurements* (up to a few 10's of kHz)
- Fast switching and lightning phenomena detection (a few MHz)
- Basic harmonics up to 3 kHz (up to 50th harmonic, IEC 61000-4-7)
- Inverter and power electronics measurements up to 10 kHz
- Advanced inverter and EV charging systems, signals up to 100 kHz
- Supra-harmonic measurement 2-150 kHz (IEC 61000-4-30)

* For example see IEEE PES Tutorial on TRV and its measurement https://resourcecenter.ieee-pes.org/education/tutorials/PES_Ed_TUT_TRV4_100620.html

Desired Features of Sensors

- Non-intrusive – the presence of the sensor doesn't affect the circuit/signal being measured
- Linear – accuracy over wide signal ranges (voltage or current)
- Wide Bandwidth – useable over wide frequency range
- Safe – use in high and medium voltage system
- Light and portable – economical and easy to use

V & I Sensing Technologies

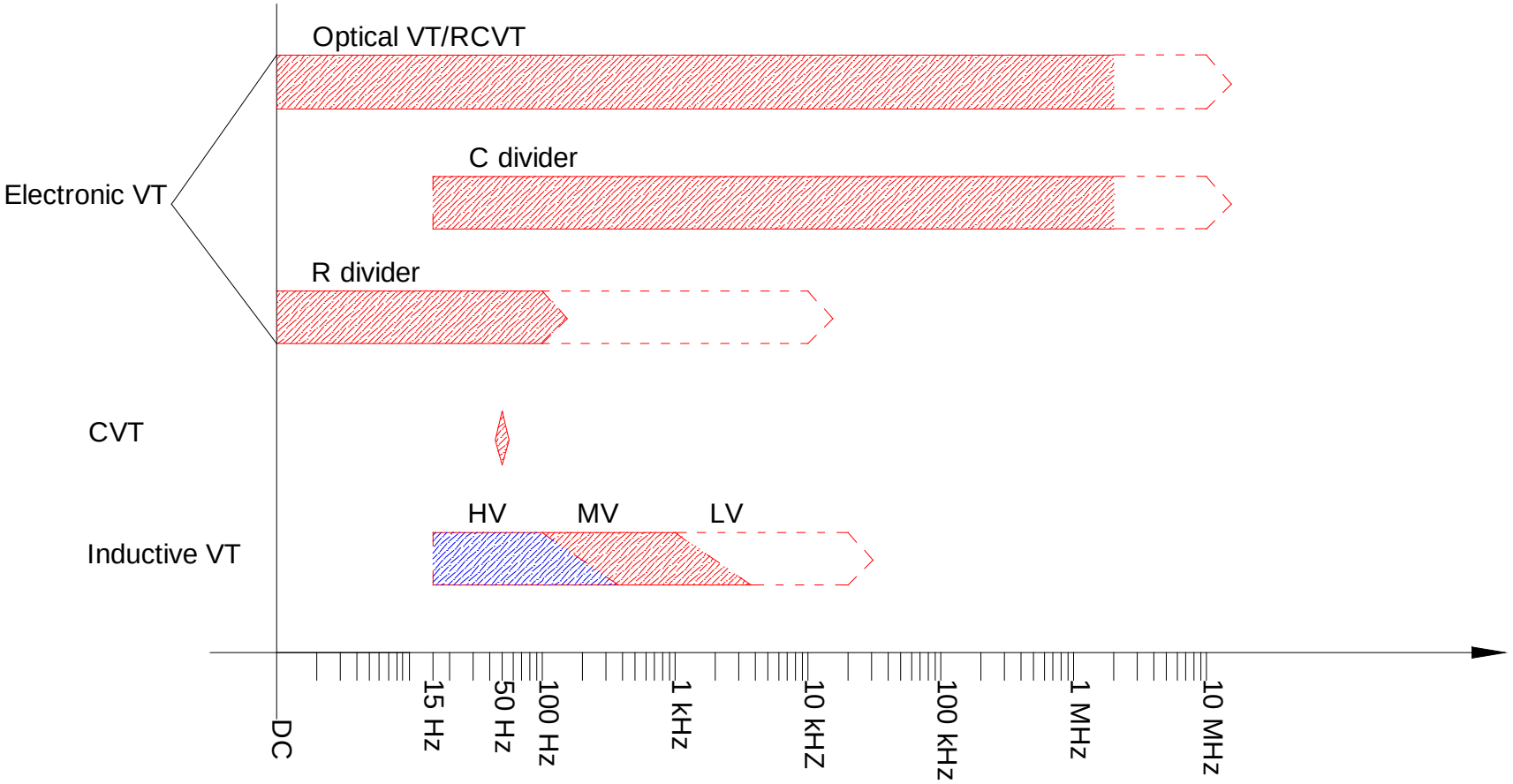
Voltage

- Magnetic-core wire-wound transformers
- Capacitive voltage transformers
- Resistive and capacitive dividers
- Optical sensors
  - Electro-optic effect
  - Lightly deflection & intensity modulation
  - Other
- Hybrid sensors
  - Using a combination of sensing and communication solutions

Current

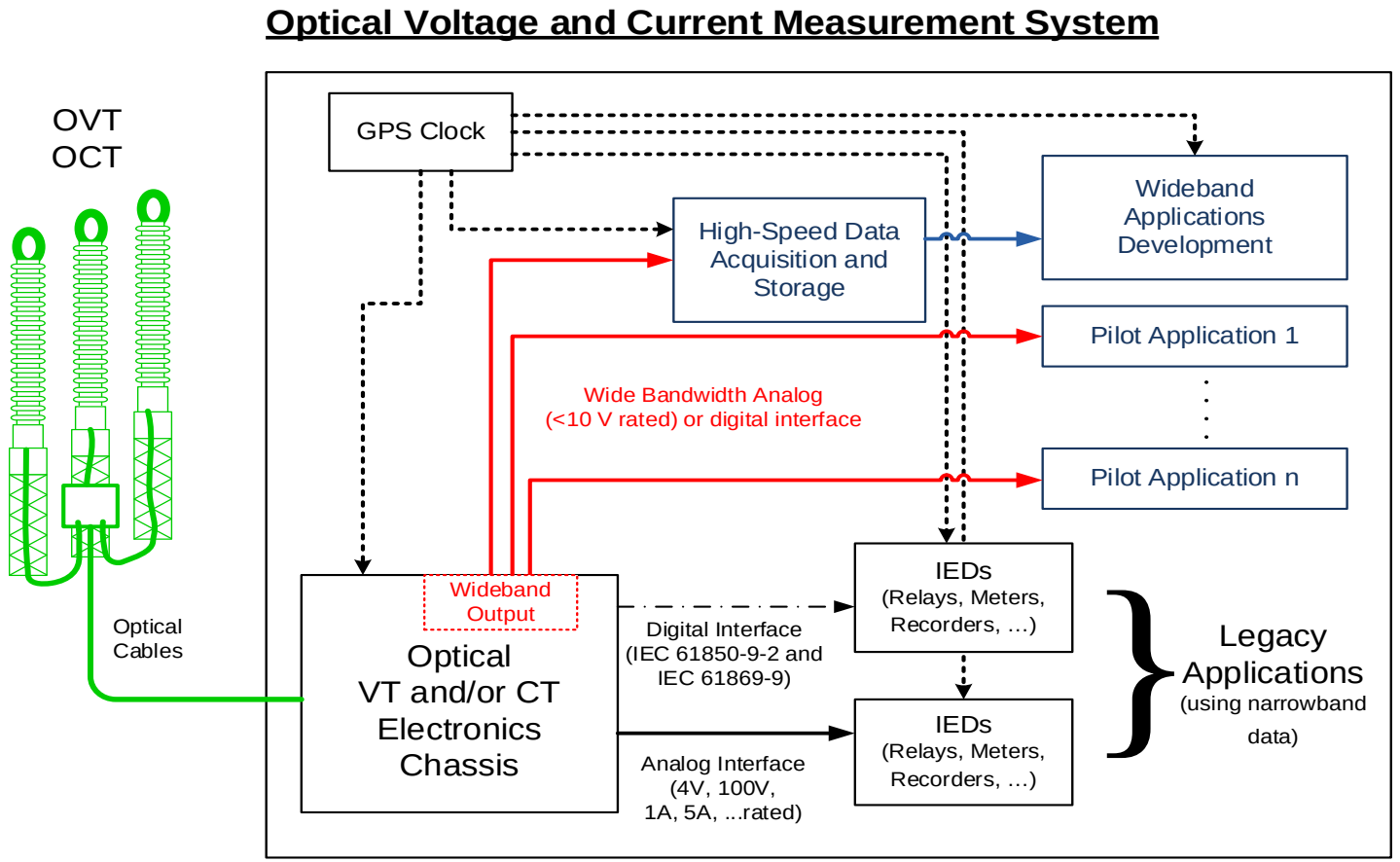
- Magnetic-core wire-wound transformers
- Air-core (Rogowski) coils
- Resistive shunts
- Optical Current sensors
  - Bulk glass vs. fiber magneto optic
  - Polarimetric vs. interferometric
  - Light deflection & intensity modulation
  - Other
- Hybrid sensors
  - Using a combination of sensing and communication solutions

Bandwidth



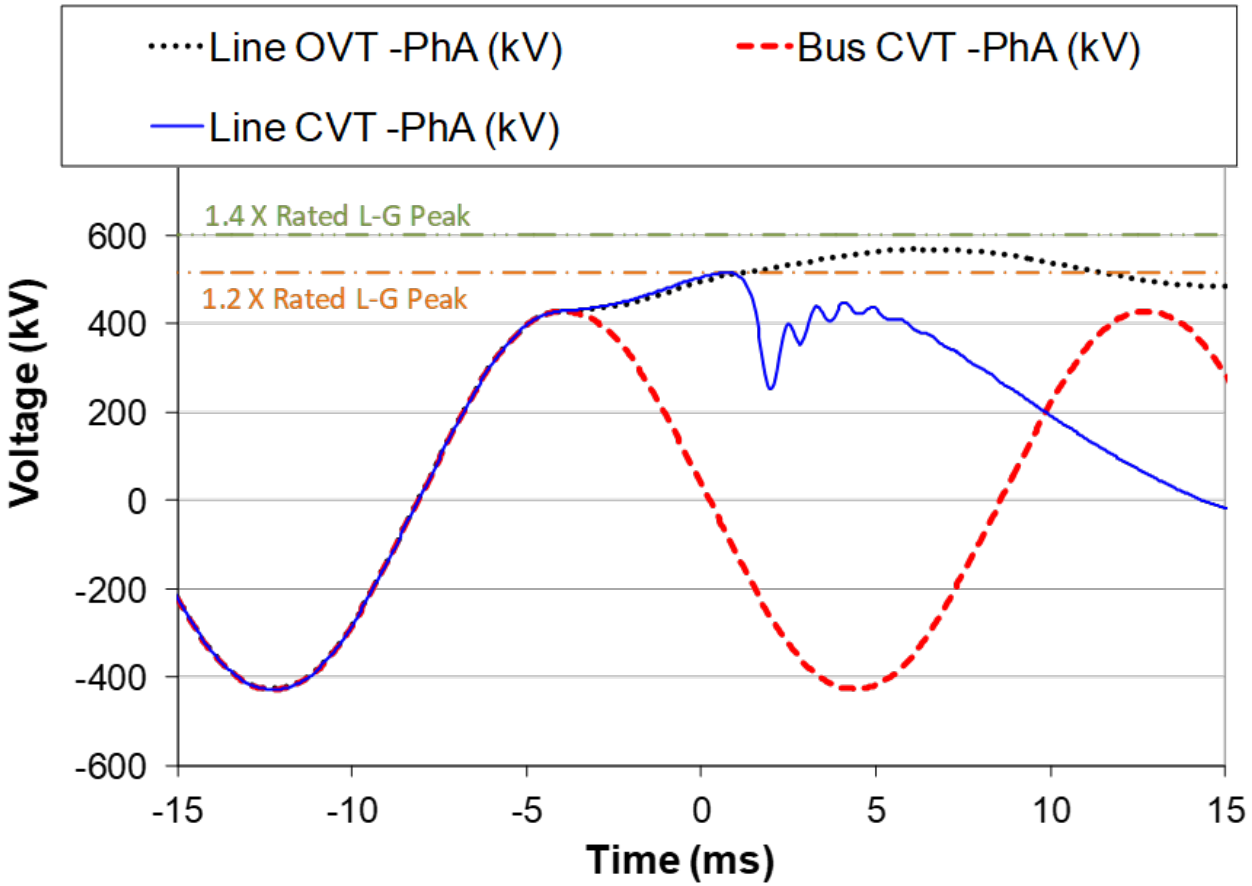
IEC 61869-103:2012, Figure 9 – Voltage Transformer technologies' frequency range according to present experience.

Example - an Optical Sensing System Architecture to Serve Multiple Applications



"Real-time Monitoring and Capture of Power System Transients." D.F. Peelo, F Rahmatian et. al. CIGRE Paper No. B3-101 CIGRE 2012 Session.

Example - Near-DC Non-Intrusive Performance

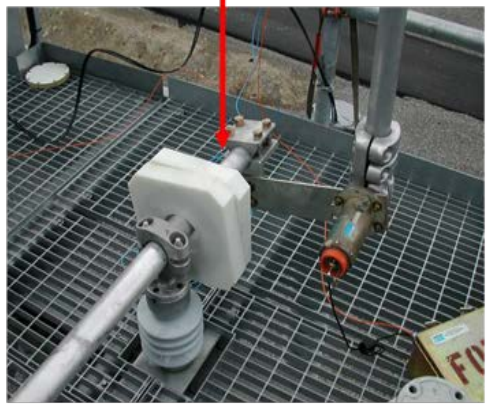


Waveform recording during line de-energization switching at a 525 kV substation in 2011. The data were recorded at 24,000 Samples/s (with OVT bandwidth 40 kHz).

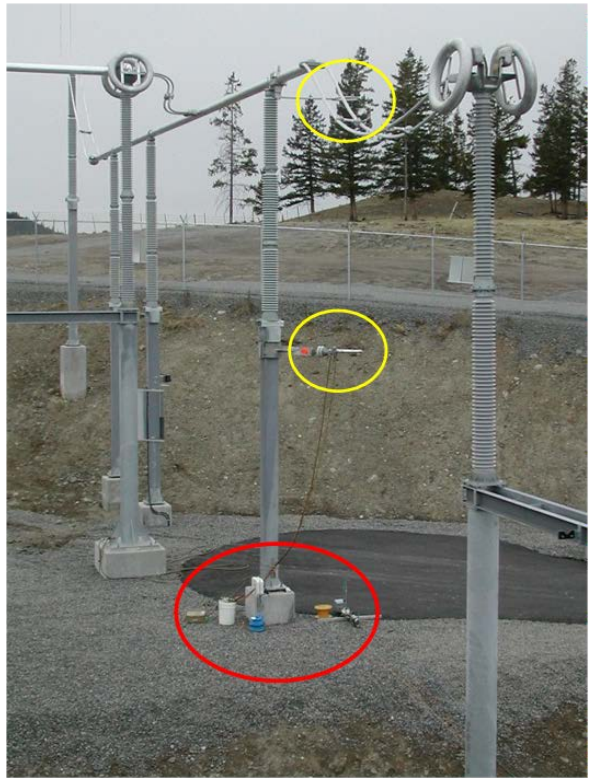
500 kV Series Capacitor Bank Staged Fault Testing

MOV Voltage Measurement

MOV Current Measurement

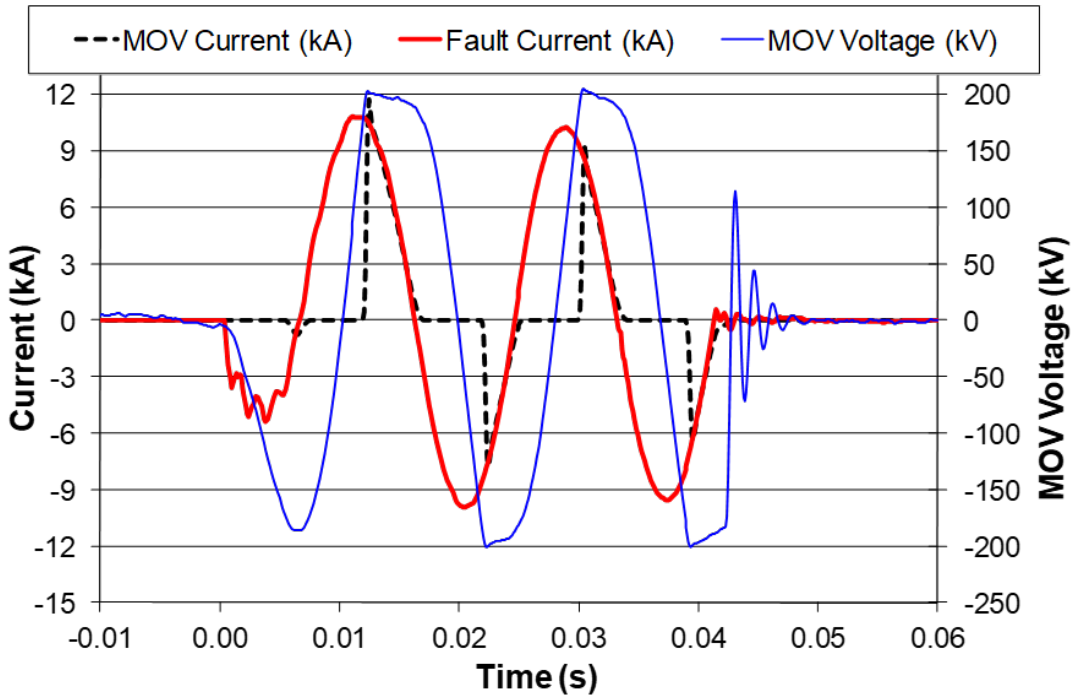


- Ref VT-138kv class, Bandwidth ~ 40 kHz, Ratio = 201,250:10
- Ref. optical CT for MOV current, Bandwidth ~ 6 kHz, Ratio = 12,000 A : 10 V
- Window optical CT for fault current, Bandwidth ~ 6 kHz
  - ✓ Ratio 1 = 12,000 A : 10 V
  - ✓ Ratio 2 = 750 A : 10 V
- Time delay ~ 43 μs

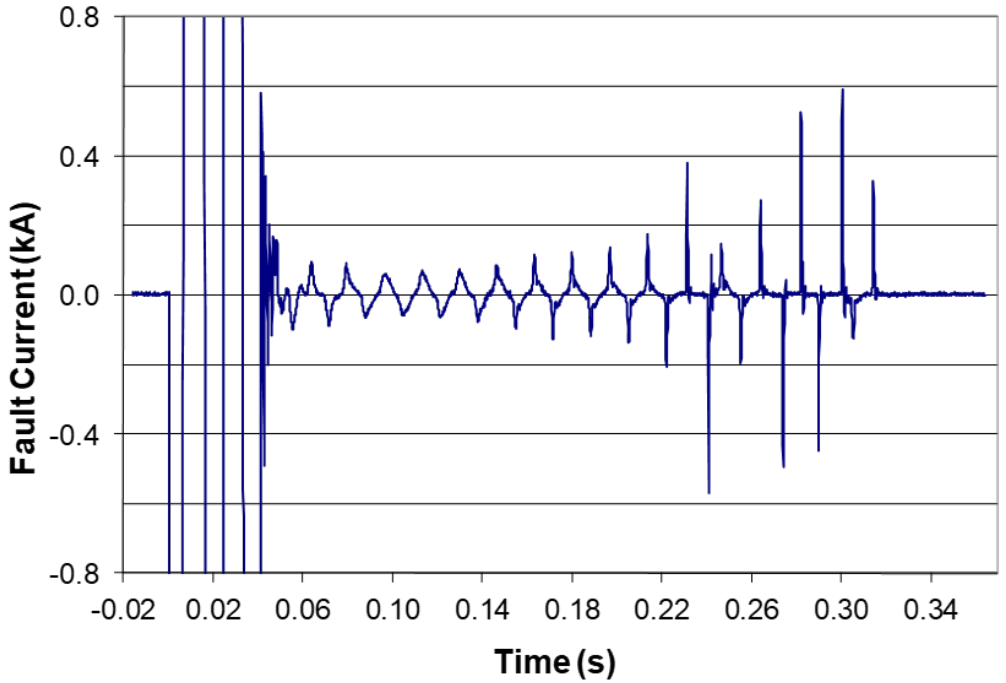


500 kV Series Capacitor Bank Staged Fault Testing

An example where wide dynamic range (low and high currents/voltages) and wide bandwidth (low and high frequencies) are required

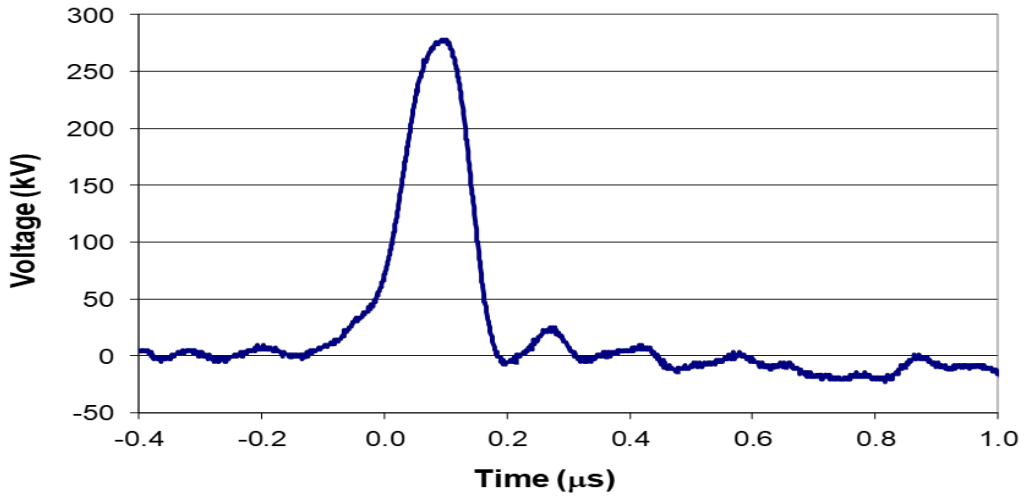


MOV voltage and current and fault current traces;

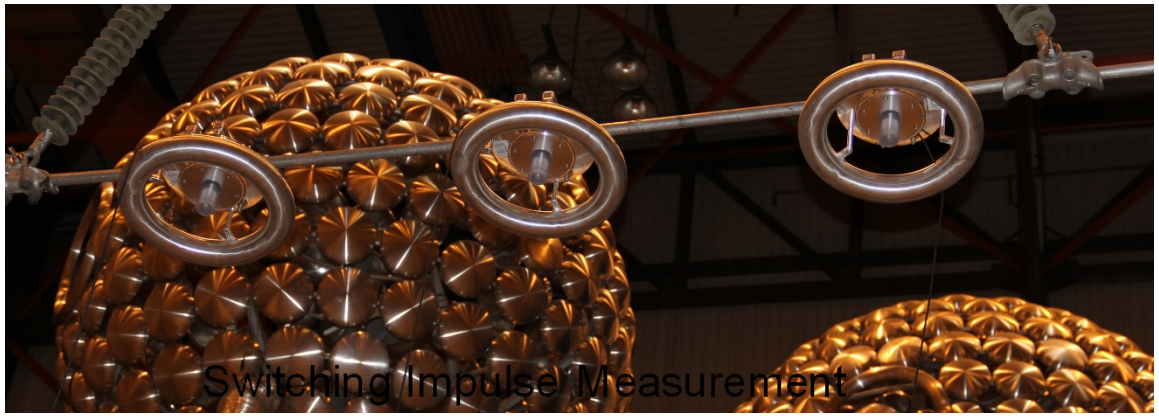


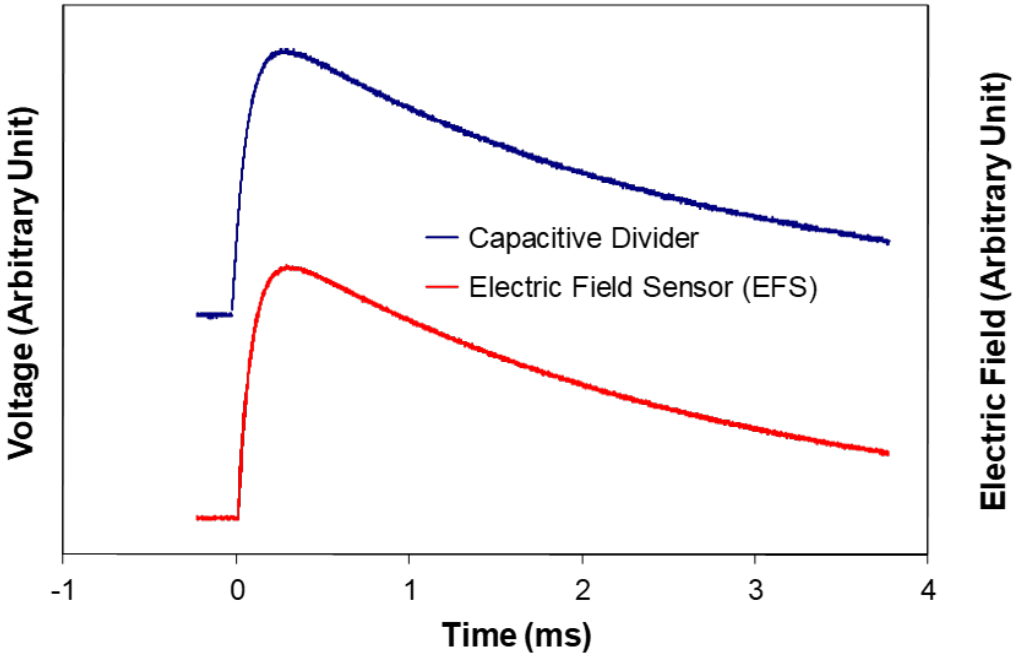
Primary fault and secondary arc currents

Impulse Measurement with Optical Electric Field Sensors



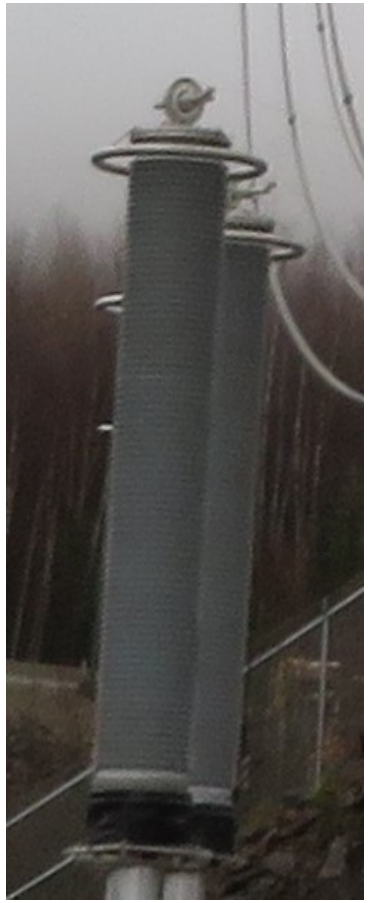
Fast impulse measurement (~0.1 μs rise time)



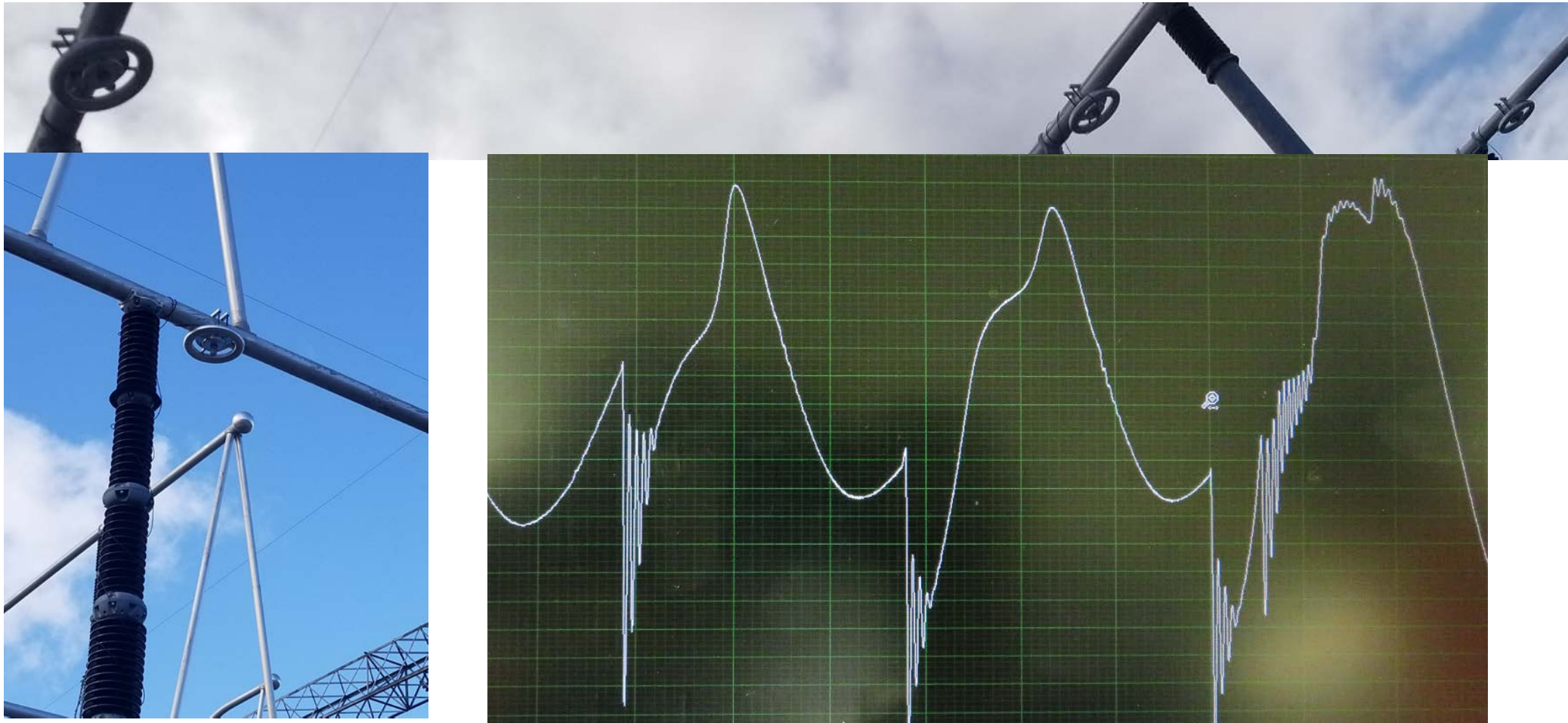


Switching Impulse measurement in HV lab

Switching Transient Measurement in the Field with Optical Sensors



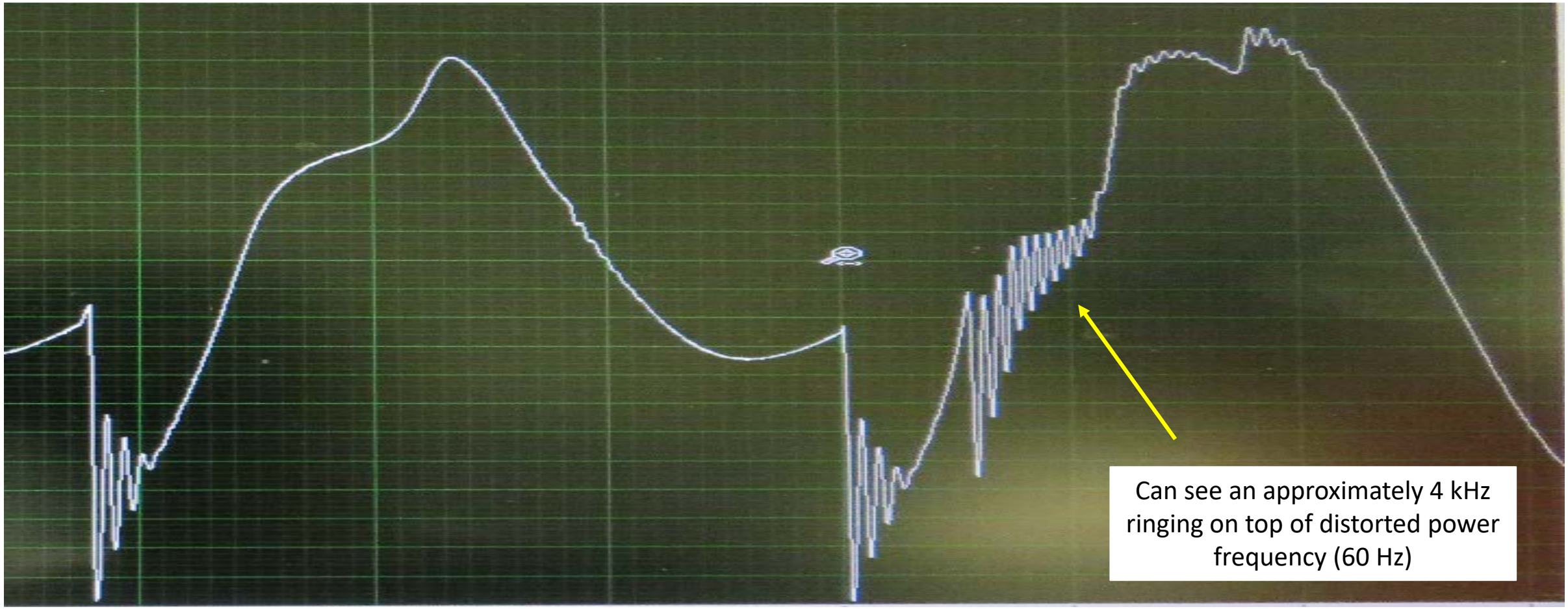
550 kV Optical VT



Floating Optical
Electric Field Sensors (EFS)

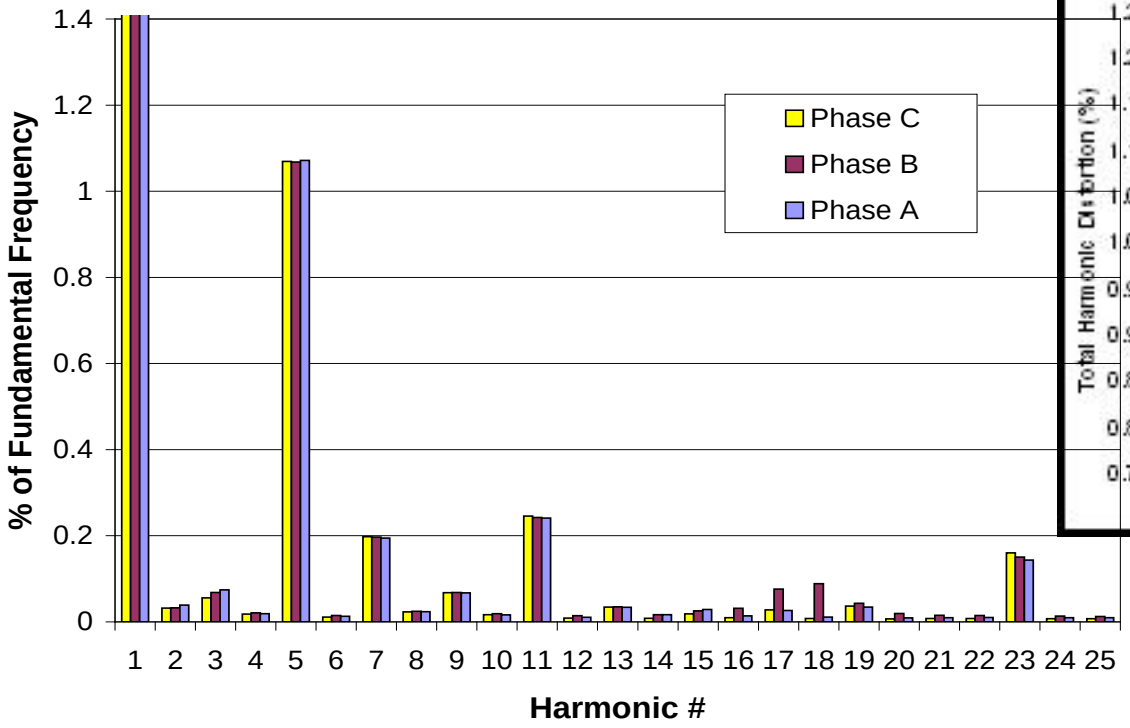
Placed at the right location, EFS can provide an accurate approximation of voltage waveform

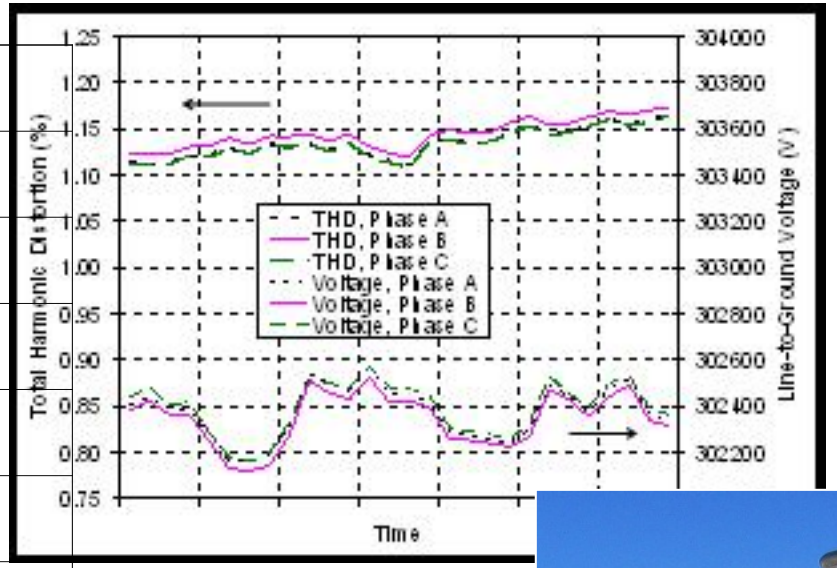
Feature-Rich Switching Transient



Time duration of recording shown ~ 34 ms

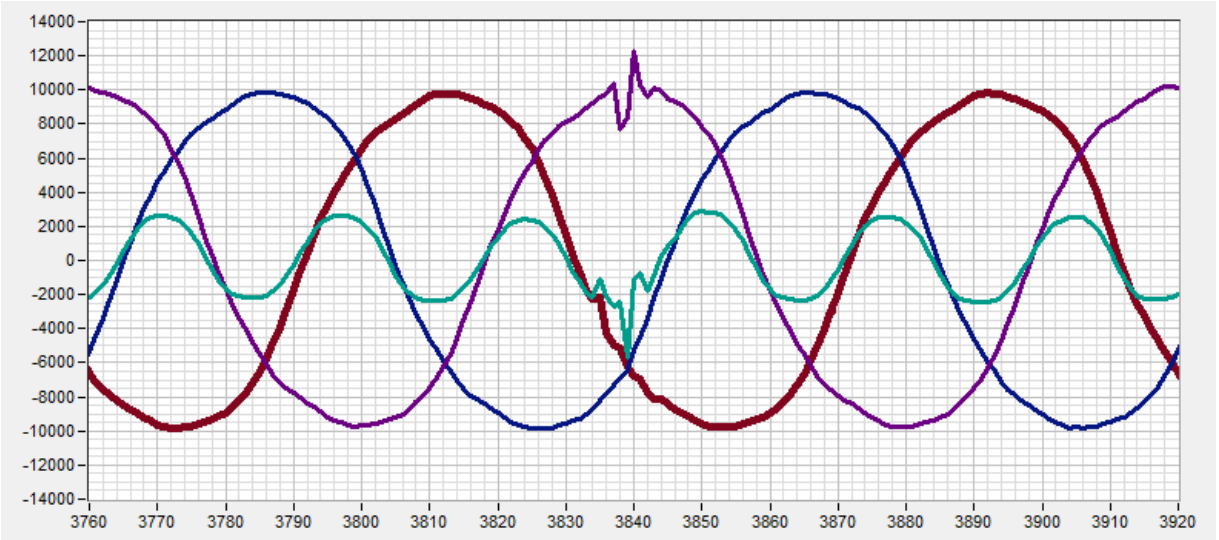
SVC Substations – Harmonics Measurement





- Combination of Optical VT (on the right) and capacitive dividers (middle and left) for an on-site 3-phase 550 kV harmonics and transient measurement during an SVC commissioning exercise.
- The OVT was used to calibrate the capacitive dividers in the field prior to testing.

Distribution Monitoring – Capacitor Switching and Disturbance Monitoring



3 phase voltages and summation (zero-sequence) waveform sampled at IEC 61859-9 preferred rate of 4800 samples/s {& 14,400 Samples/s}

Path Forward

- Non-intrusive high-speed sensors to be able to observe
  - Fast switching and lightning phenomena
  - Inverter and power electronic issues
  - Harmonics and supra harmonics (and harmonic synchrophasors)
- Importance of data management architecture
  - Edge computing and distributed storage versus central storage and computing
  - A hybrid model is most practical
- Sensor quality and data quality measures can help each other
  - A careful mix of sensor technologies can improve data quality too
- Importance of automated or semi-automated analysis and pattern recognition