Brief Overview of

Optical Current and Voltage Sensors

in the Electric Power Industry

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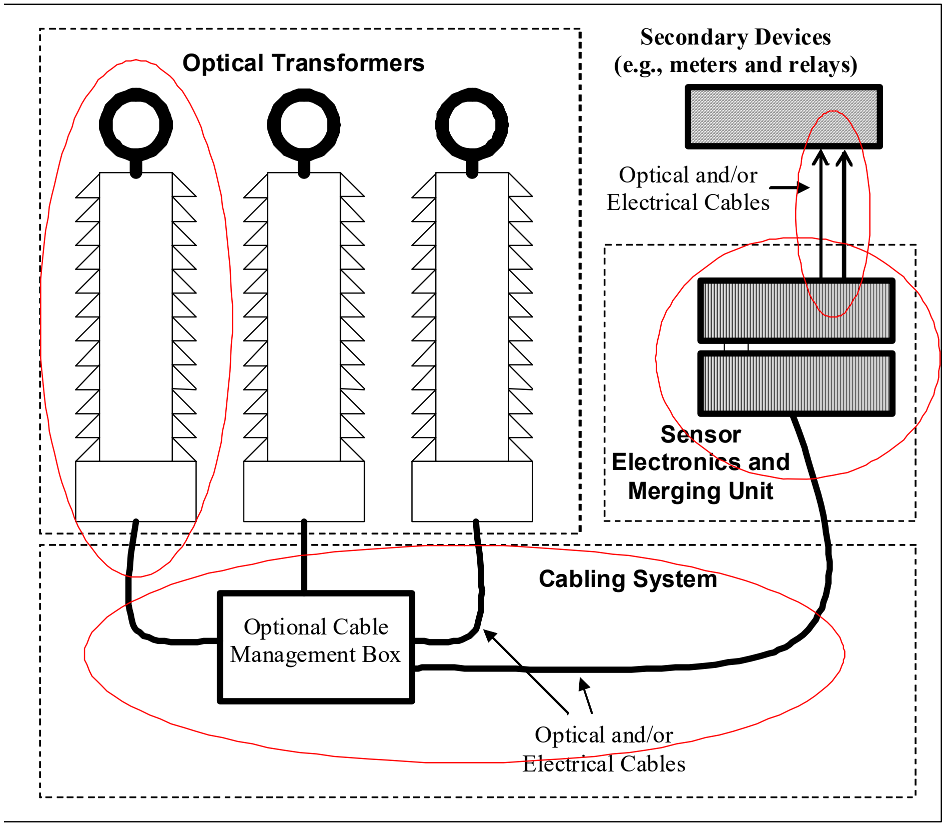
NASPI Distribution Task Team – June 1, 2017

Modern Grid Measurement Needs

- Voltage and current sensors are the eyes and ears of the electric power system
- A smarter grid can benefit from seeing and hearing better
- Measurement needs
  - Safer
  - More accurate
  - More reliable
  - Wider dynamic range
  - Wider bandwidth
  - High speed communication
  - Ease of use
  - Accurate timing

Optical Voltage and Current Sensor Systems



Schematic of a typical optical sensor system

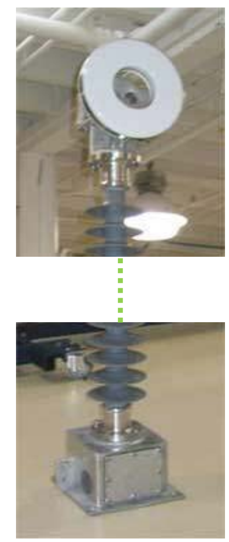
Potential Benefits of Advanced Optical Sensors

- Performance Features
  - Accuracy over a very wide dynamic range
    - Exceptional phase accuracy (e.g., synchrophasor applications)
  - Bandwidth, DC and harmonic
  - Seismic performance
  - User-adjustable sensitivity

- Safety & Environmental Concerns
  - Avoiding insulating oil or SF_6 (depending on design)
  - No open secondaries
  - No ferro-resonance
  - Galvanic isolation from HV line

Potential Benefits of Advanced Optical Sensors

- Installation features
  - Small size and weight
  - Multi-function, e.g.,
    - metering & protection in one device
    - Voltage & current in one device
- Self monitoring
- Simple, linear, and scalable
  - Simplifies substation/feeder design by allowing a simple template design for multiple applications
- Digital communications

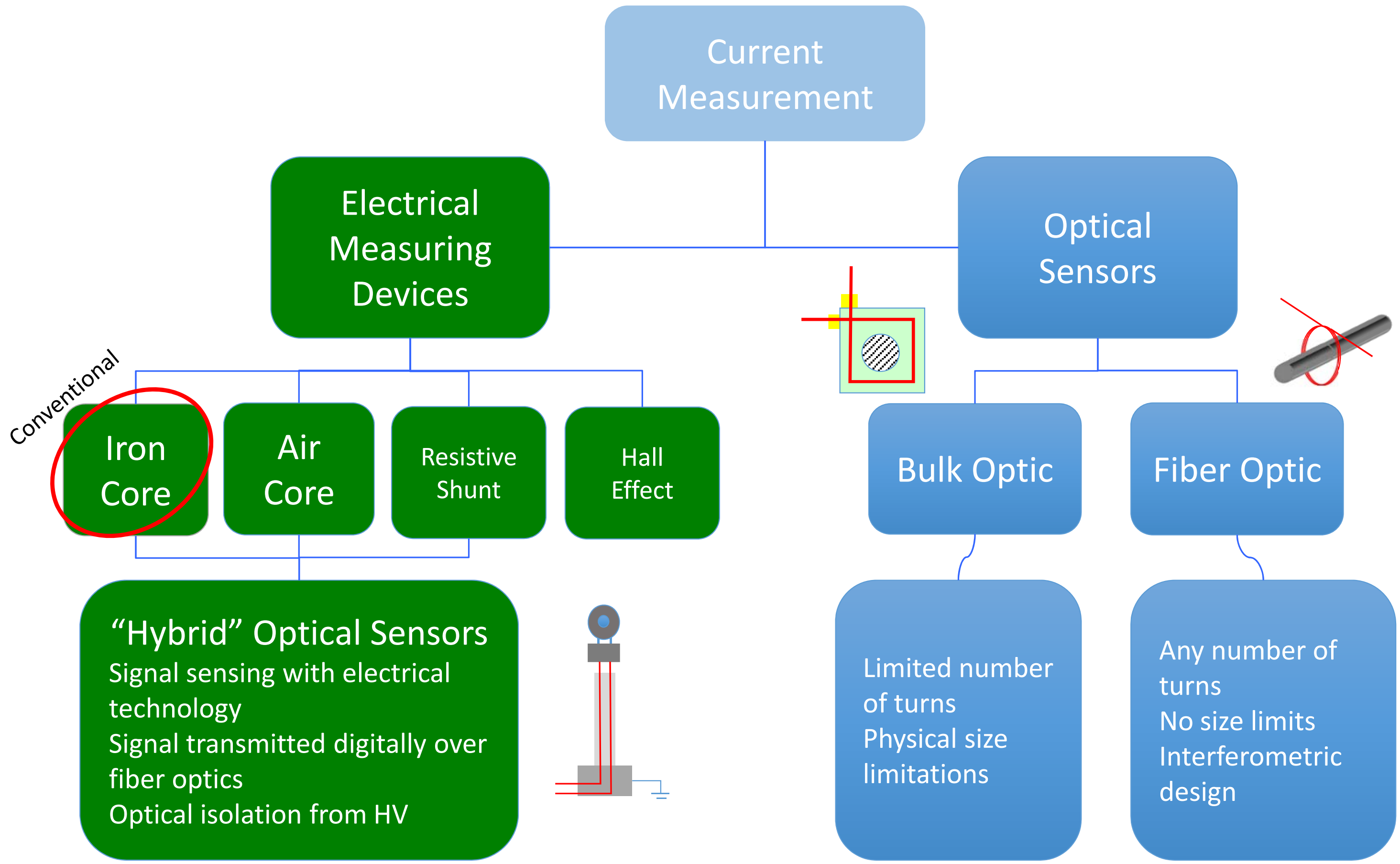


x kV Optical CT

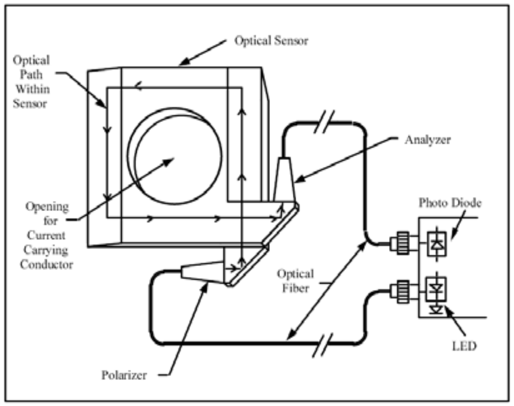
Optical Instrument Transformers – Technology Overview

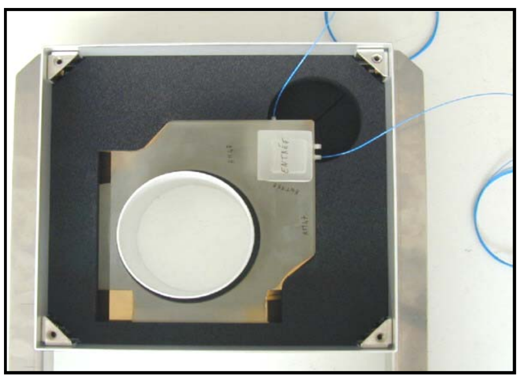
- Faraday and Pockels effects
- Product R&D in 1960s and 1970s
- Field prototypes/products in 1980's and early 1990's
- Cost-effective and high-MTBF optical/electronic components availability in the 1990's
  - Thanks to the telecom boom/evolution.
- Commercial products available since late 1990's

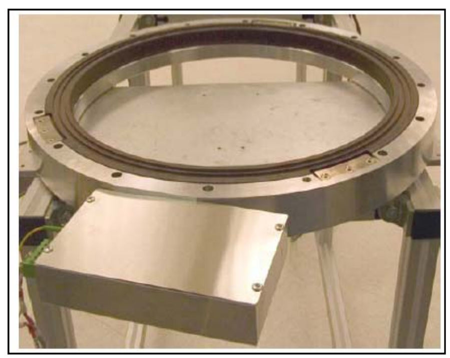
Current Sensors Technology Overview

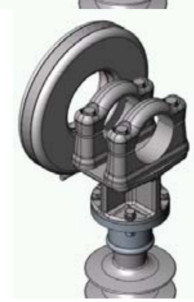


Industrial Optical Current Sensors

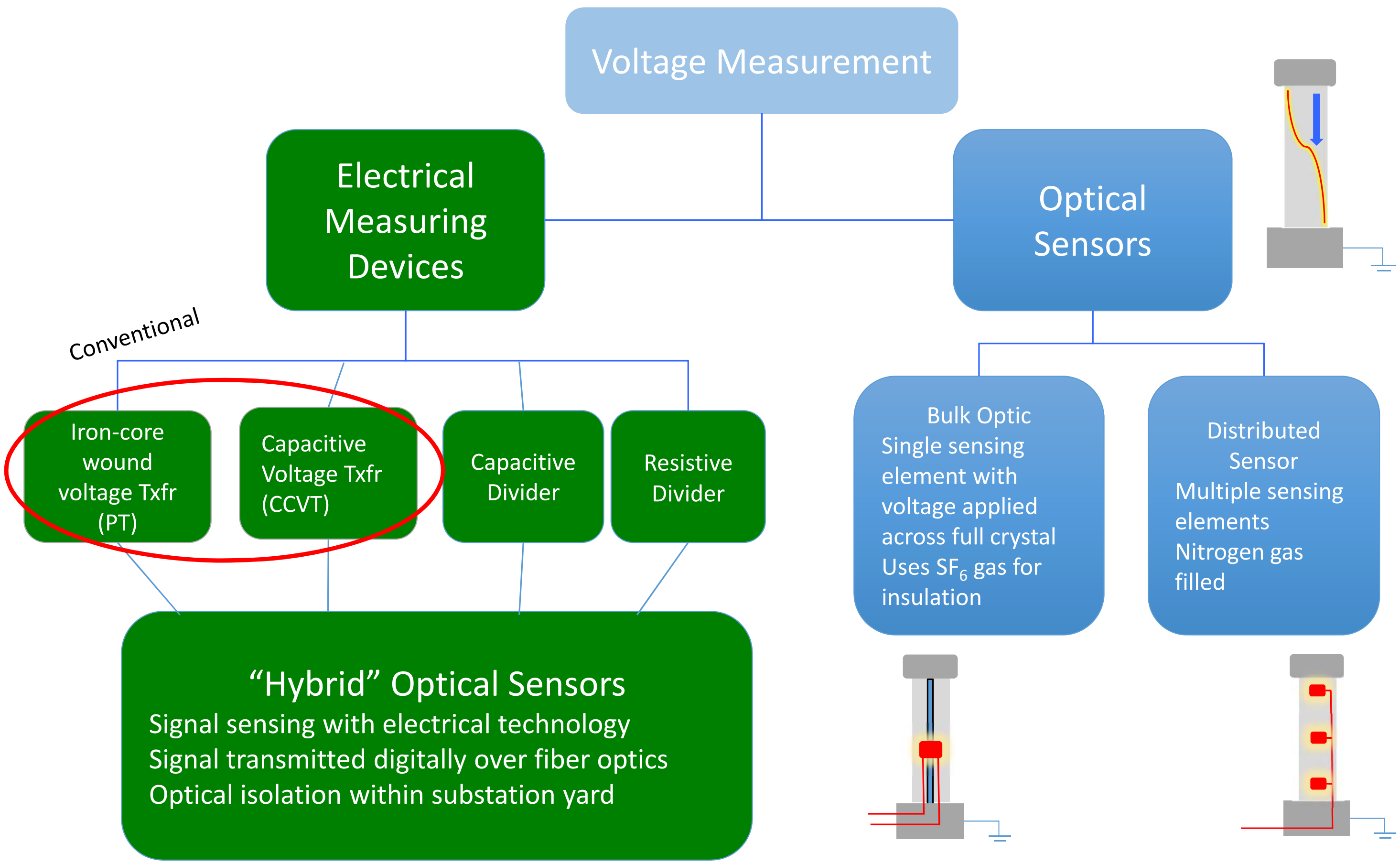








Voltage Sensors Technology Overview



Industrial Optical Voltage Sensors

138 kV class
Combined OVT/OCT
(Mobile)

500 kV class
mobile OVT

230 kV class
Combined OVT/OCT

500 kV class
Combined OVT/OCT

35kV
OVT

Challenges

- Newer technology / products
- User familiarity / comfort
- Standards and Guides
- Regulatory approval and certification
- Maintenance and deployment practices
- …

Standards and Guides

- IEEE/ANSI C57.13
- IEEE C37.92 (low energy analog interface)
- IEEE 1601-2010 (Optical CT VT)
  - Accuracy terminology, e.g., 0.3*DR0.5-150* (RF=1.5)
- IEC 60044 series (-7/8 for non-conventional VT/CT)
  - And associated CSA series C60044-7/8
- IEC 61869 series (new standards – not all published yet)
  - IEC 61869-6:2016
  - IEC 61869-9:2016
- IEC 61850-9-2 (digital interface)
  - UCA Guide – 61850-9-2 light
  - IEC 61869-9 with IEEE 1588 profile for Merging Units (MU)
- IEEE Std. PC 37.241 (IEEE PES PSRC WG I-11)
  - Application of optical sensor systems in Protection – in balloting.

Applications

- General metering & protection
- Synchrophasors
- Grid intertie metering
- Wind farms and Independent Power Producers
- HCDC - high current DC (e.g., aluminum smelters)
- Power cable protection (differential)
- UHV measurements
- HVDC (high voltage DC) and High voltage platforms (series Capacitors)
  - FACTS, SVC, …
- Power quality applications and transient monitoring
- Synchronized switching (lines, capacitors, reactors, transformers, …)
- Cable Monitoring
- Portable Calibration
- Testing (for laboratory and field testing)
  - E.g., field calibration of synchrophasor systems

Synchrophasors using Optical Digital Sensors

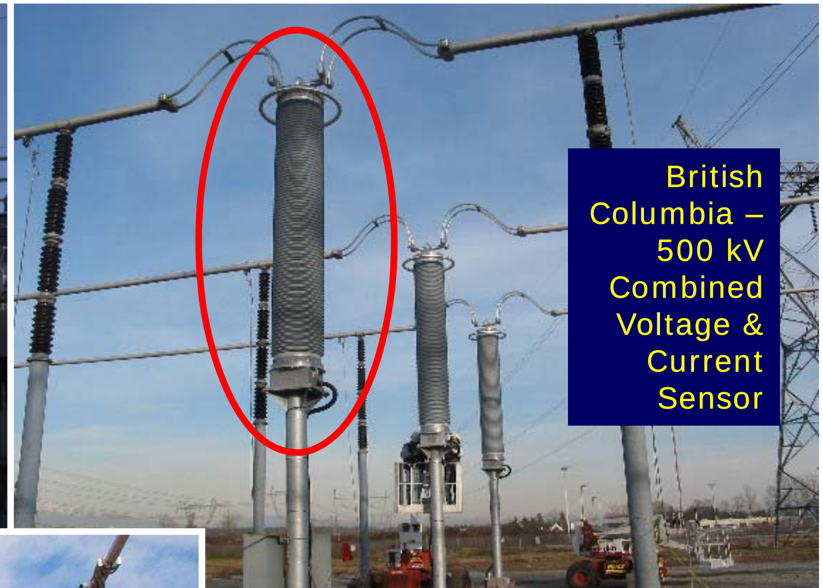
- Similarities of PMUs (Phasor Measurement Units) and MUs (Merging Units)
  - ✓Digital Time-Tagged measurements
  - ✓Precision timing
- Excellent phase accuracy regardless of current/voltage level
- Linearity over wide dynamic range of current/voltage
- Integrated PMU in optical sensor electronics
  - ✓Synchrophasors can be just another digital output format

Questions?

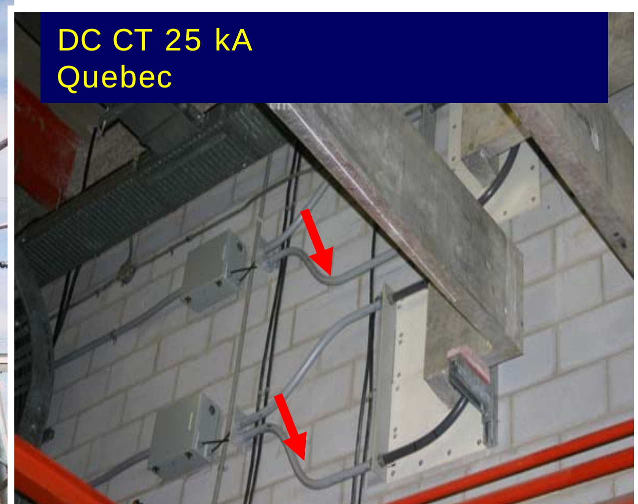
Supplementary Information

See the following slides for various examples of optical sensor applications / installations

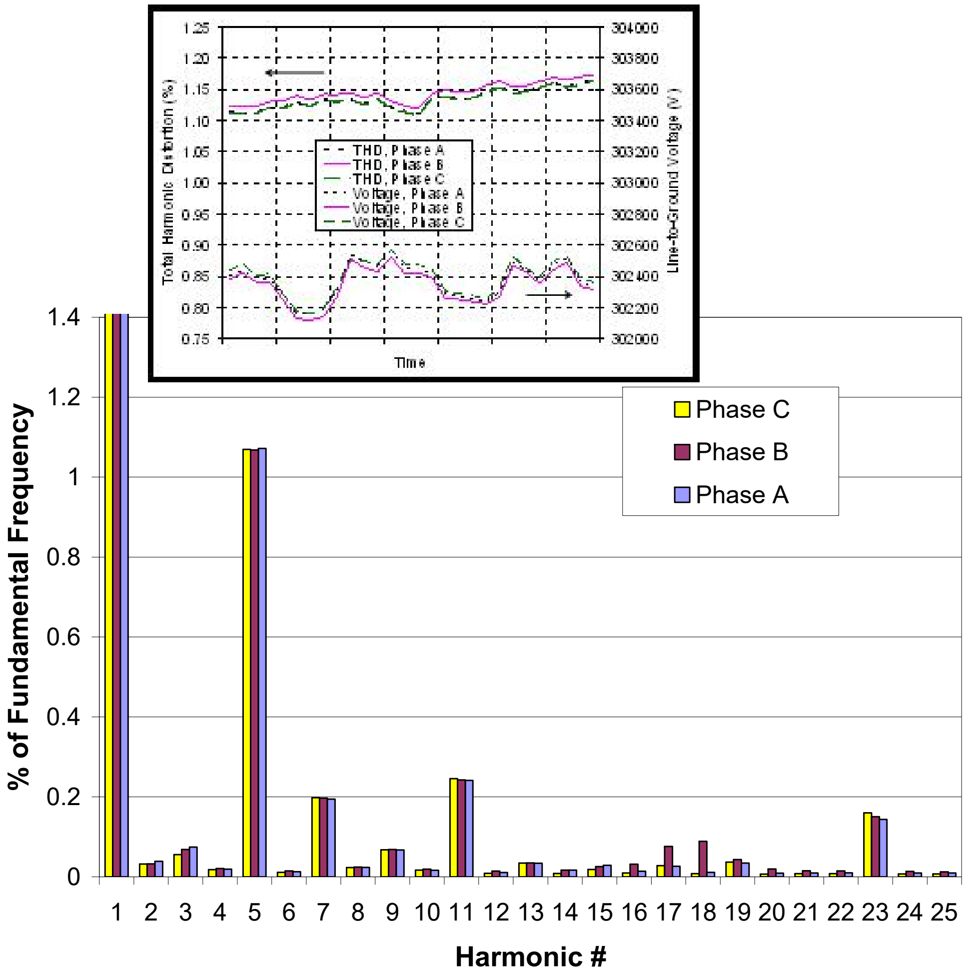

Arizona –
230 kV
Combined
Voltage &
Current
Sensor


British
Columbia –
500 kV
Combined
Voltage &
Current
Sensor


United
Kingdom
420 kV -
OCT


DC CT 25 kA
Quebec

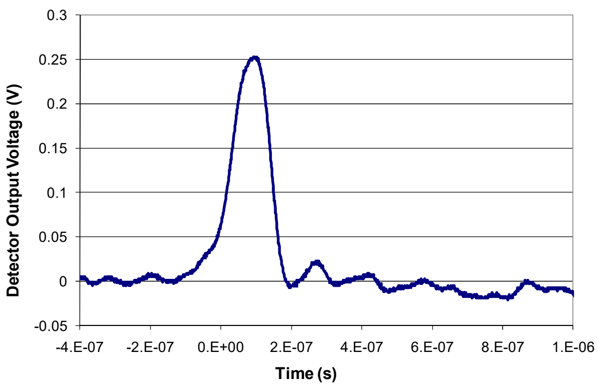
SVC Substation Harmonics Measurement



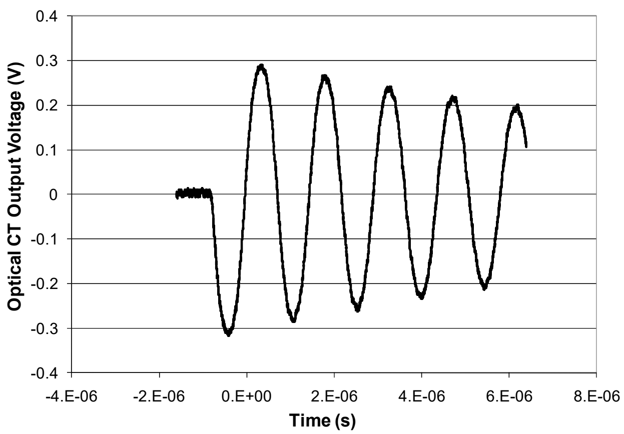
550 kV class testing for harmonics (Bandwidth 20 kHz)

High-Frequency Measurements

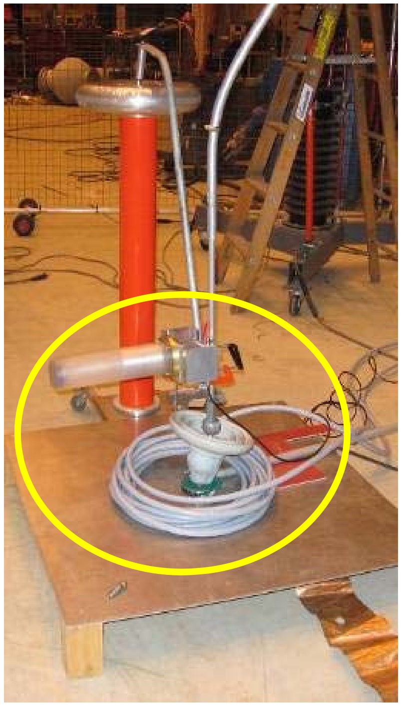
Impulse and fast transient voltage and current measurements, e.g., for reactive switching test (in laboratory and on site)



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



Sample Current Measurement Waveform:
26 kA peak at 0.7 MHz



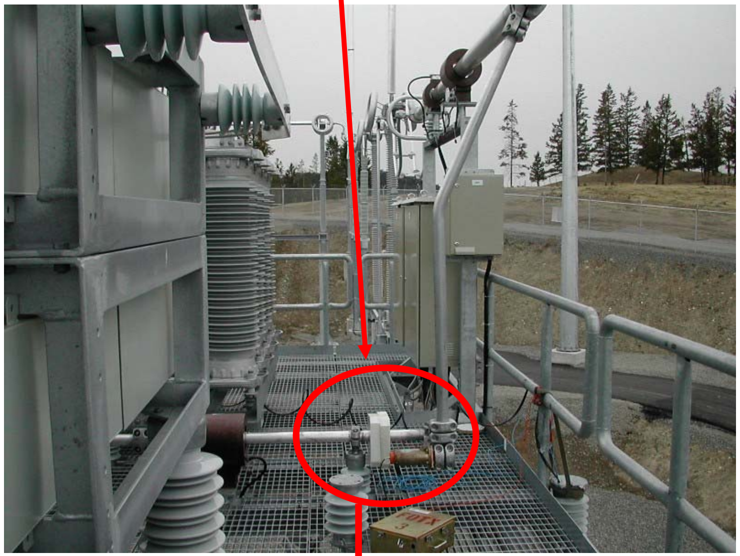
Series Capacitor Staged Fault Testing

Fiber Optic CT and VT were used because of

- Wide bandwidth (harmonics-rich signals)
- Wide dynamic range (10 to 12000 A were expected)
- Safety: passive optical isolation from high-voltage
  - varying ground voltage during the fault
- Immunity to electromagnetic interference
  - May be strong in the presence of fault arc
- Ease of set up

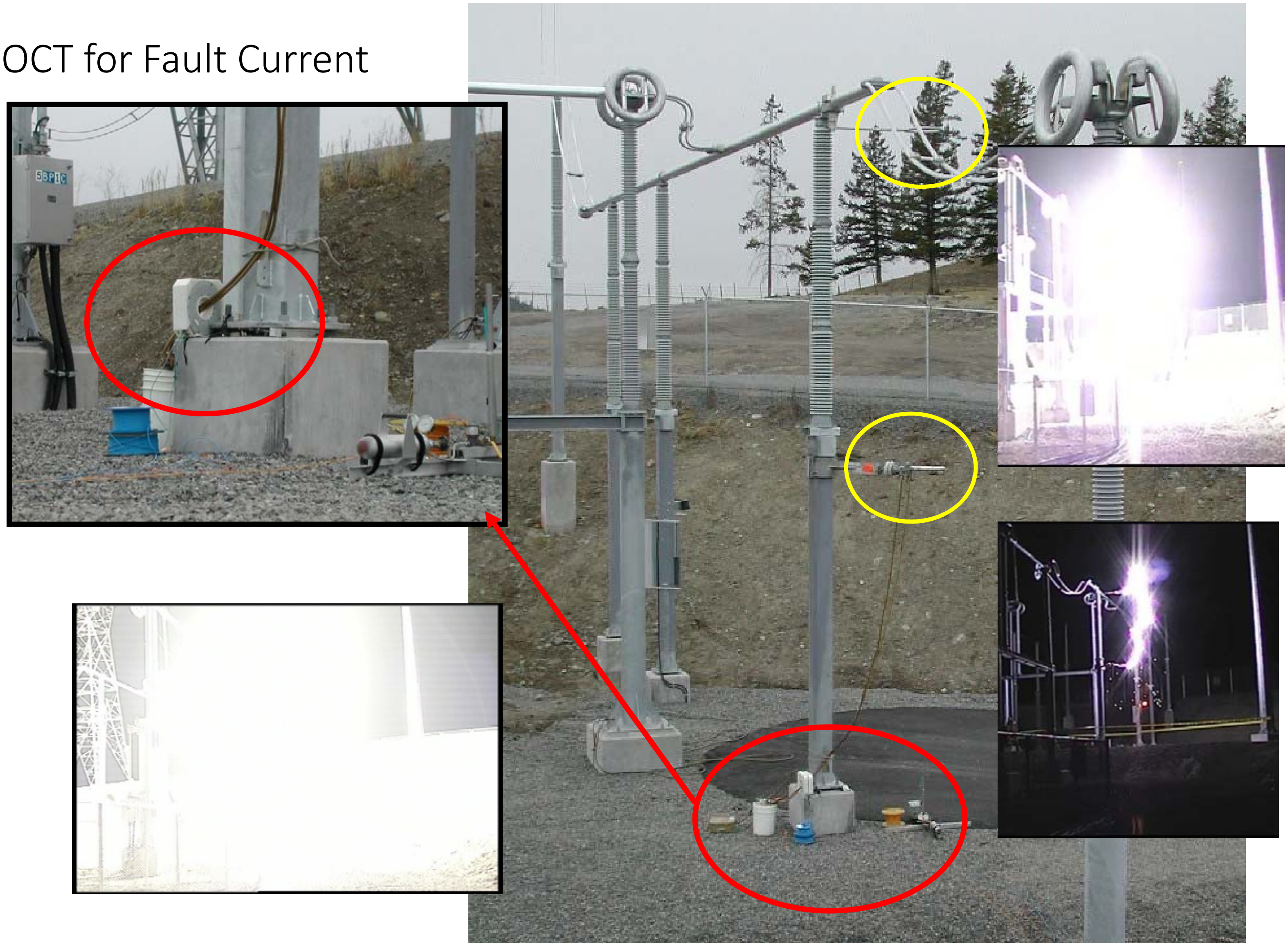
OVT-138kV for MOV Voltage

OCT for MOV Current

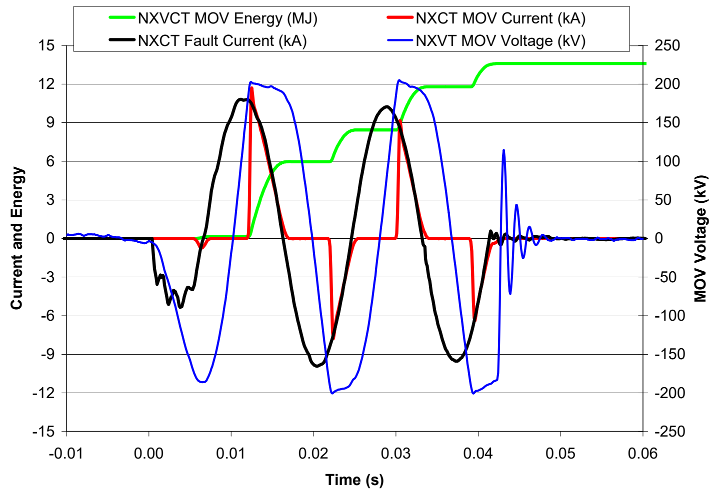


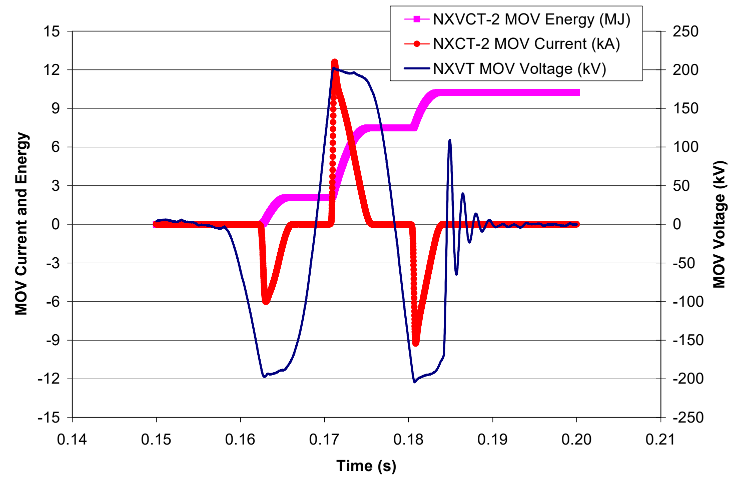
- OVT-138kV, Bandwidth ~ 40 kHz, Ratio = 201,250:10
- OCT for MOV current, Bandwidth ~ 6 kHz, Ratio = 12,000 A : 10 V
- Window OCT for fault current, Bandwidth ~ 6 kHz
  - Ratio 1 = 12,000 A : 10 V
  - Ratio 2 = 750 A : 10 V
- Time delay ~ 43 μs

OCT for Fault Current

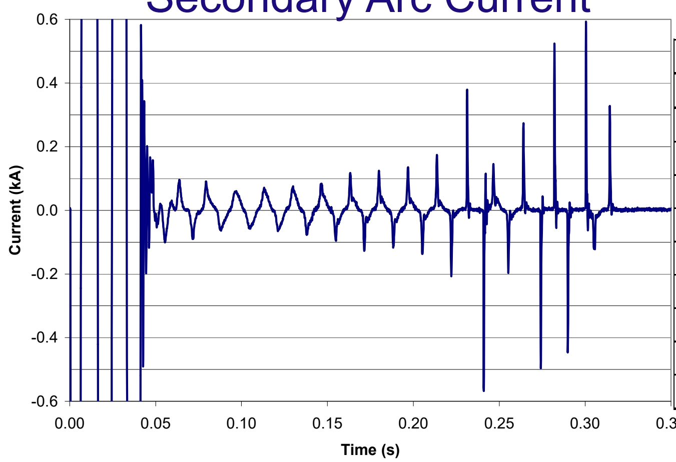


Results – 5 Shots





Secondary Arc Current



Summary Results

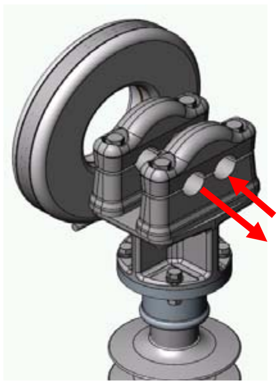
	Units					
Fault number		**1**	**2**	**3**	**4**	**5**
Primary arcing time	ms	**36**	**36**	**36**	**36**	**42**
Secondary arcing time	ms	425	863	606	290	276
Number of voltage peaks clipped by MOV		1	3	3	2	5
MOV energy absorbed	MJ	2.39	10.7	10.2	3.42	13.6
MOV Voltage Peak (absolute value)	kV	196	204	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

Shunt Capacitor Banks

Example: Capacitor Unbalance Protection

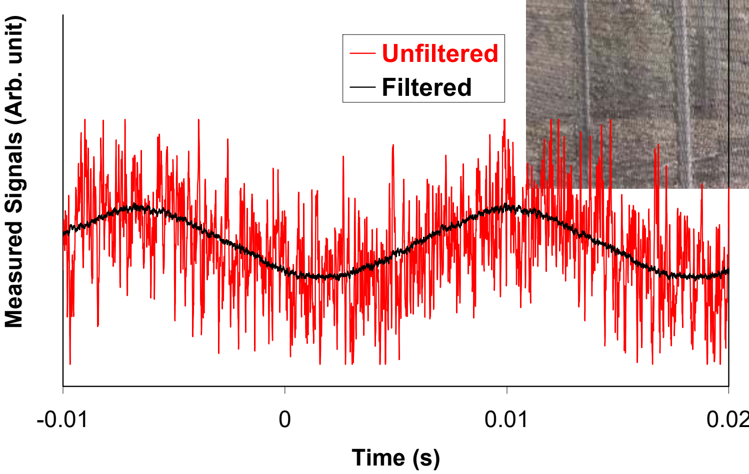
- Two outputs per optical CT
  - Output 1 Ratio, 1A:1A (Max 2 A), connected to an over current relay
    - Alarm level set at 0.8A (2+ can's failing)
    - Trip level set at 1.4A (4+ cans failing).
  - Ratio 25A:0.2V (Max 1000 A), for fault monitoring (connected to a recorder).
- Bandwidth 6 kHz

Shunt Capacitor Banks



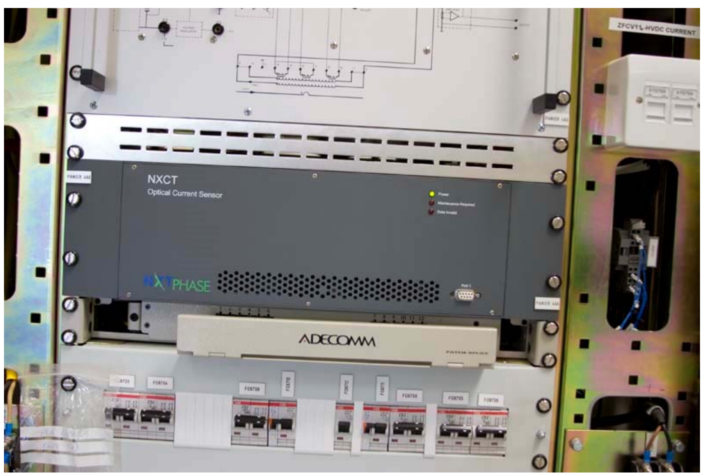
Showing Primary

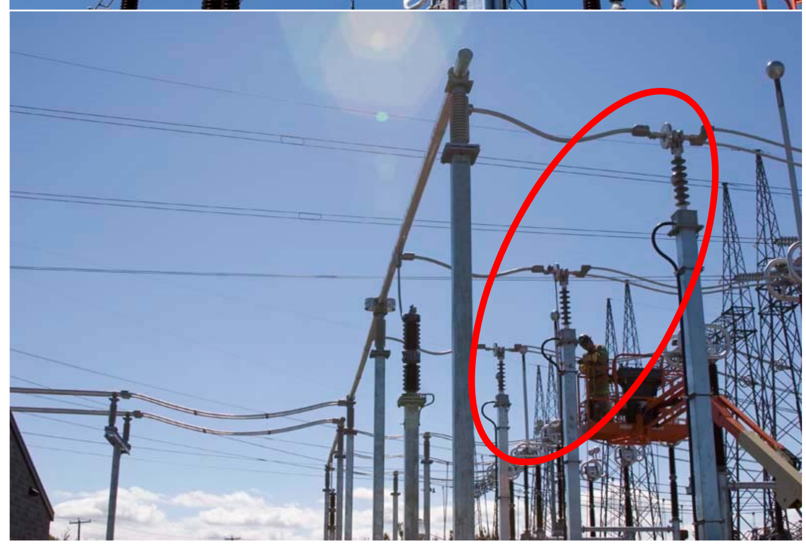
Current of 0.5 A



OCT-DC for HVDC/SVC/De-Icer

69 kV class
Bandwidth: DC to 10 kHz
Distance between CT columns and electronics = 1 km
Multiple output per CT
Electronics for 3 CTs in one chassis





Quebec, Canada

SC A3 2016 PARIS SESSION

VOLTAGE SENSORS FOR HARMONICS MEASUREMENT

PS 1 and Question 5

F. RAHMATIAN(Canada) and P. MAZZA(Italy)

WG A3.31

NuGrid

RSE Ricerca Sistema Energetico

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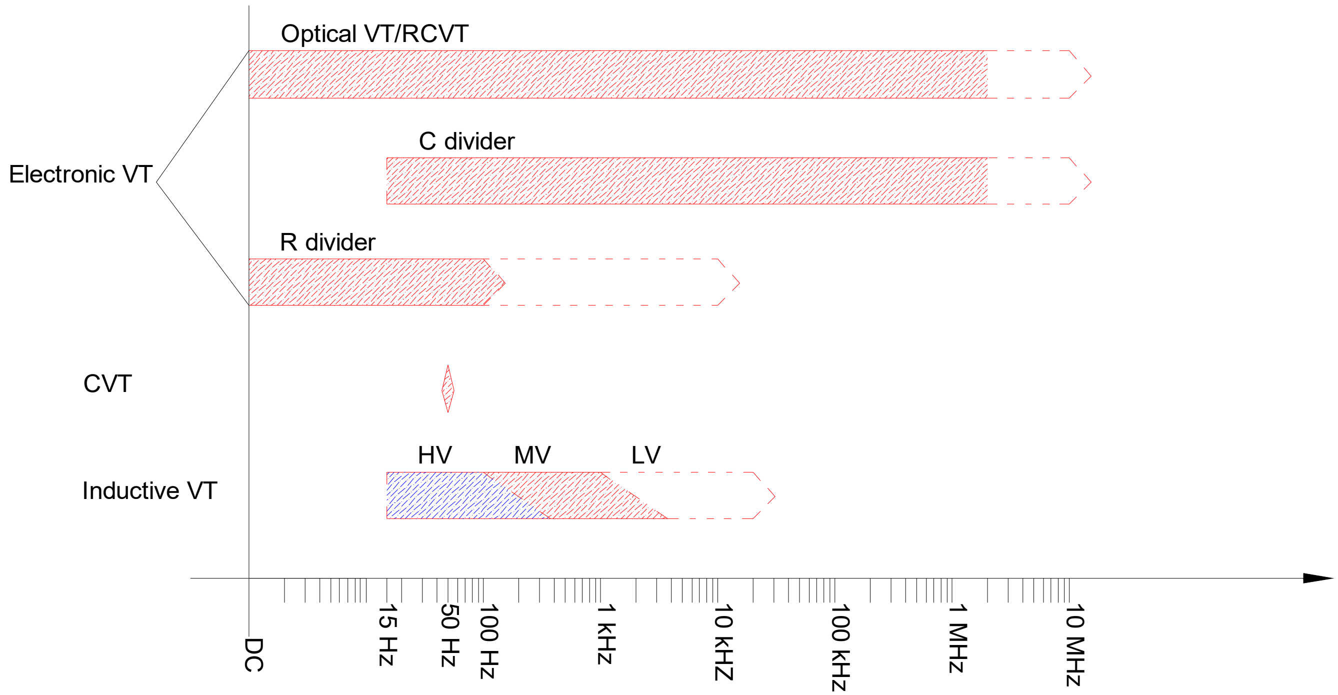
Question: Is there a need for voltage transformers that are better suited to measure harmonics?

Response:

- At the distribution levels, we strongly believe there is an increasing need for harmonics measurements due to the addition of more distributed generation, microgrids, etc. and the associated inverters.
- At the transmission levels, with more HVDC and FACTS deployment, as well as increasing interest in higher frequency measurements (e.g., TRV, switching phenomena, and lightning strikes), there seem to be growing need too.

Question: What technology is proposed?



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

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Question: What technology is proposed?

Response:

- Have successfully used:
  - Capacitive dividers
  - RC dividers
  - Optical VTs
  - CVTs with a special tap/equipment to bypass the inductive transformer (very similar to a capacitive divider)
  - Voltage transformers, mostly at distribution voltages for lower harmonics
- Do not recommend to use CVTs and VTs without special provisions.
- With analog outputs, particularly from resistive and capacitive dividers, attention has to be paid to cabling as it may have impact on bandwidth if it is not properly accounted for.
- Digital output at 14.4 kHz sampling rate (for power quality) per IEC 61869-9 and the frequency mask as given in IEC 61869-6 also impose limitations for higher harmonics measurements.