MARCH 2024

QUANTA TECHNOLOGY

hydro one

High-Voltage and High-Current Testing of Non-Conventional Instrument Transformers

Speaker Introductions

Mohsen Khanbeigi
Senior Protection and
Control Specialist

hydro one

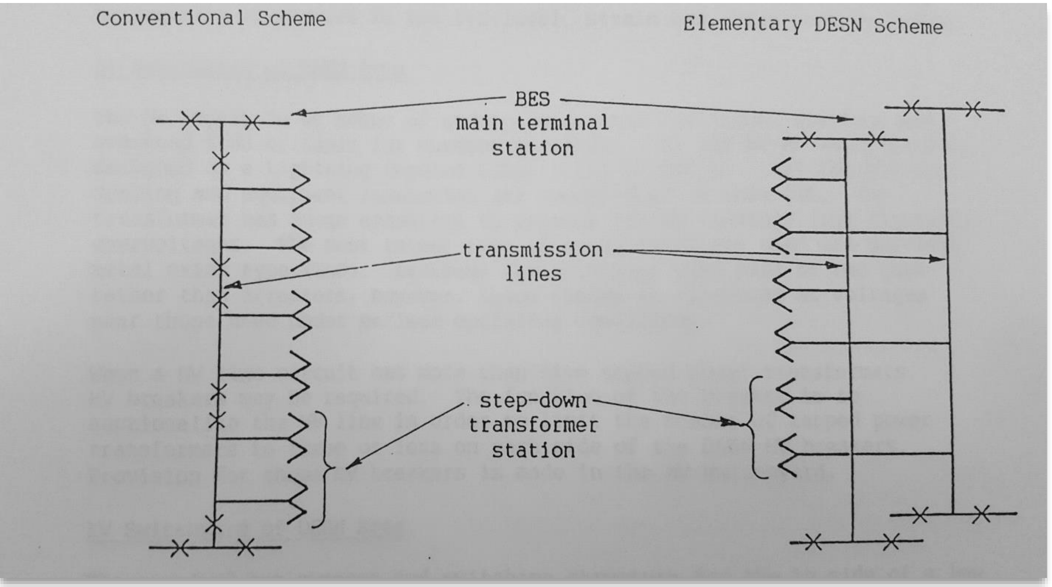
Hadi Khani
Senior Advisor
Protection, Control and Automation

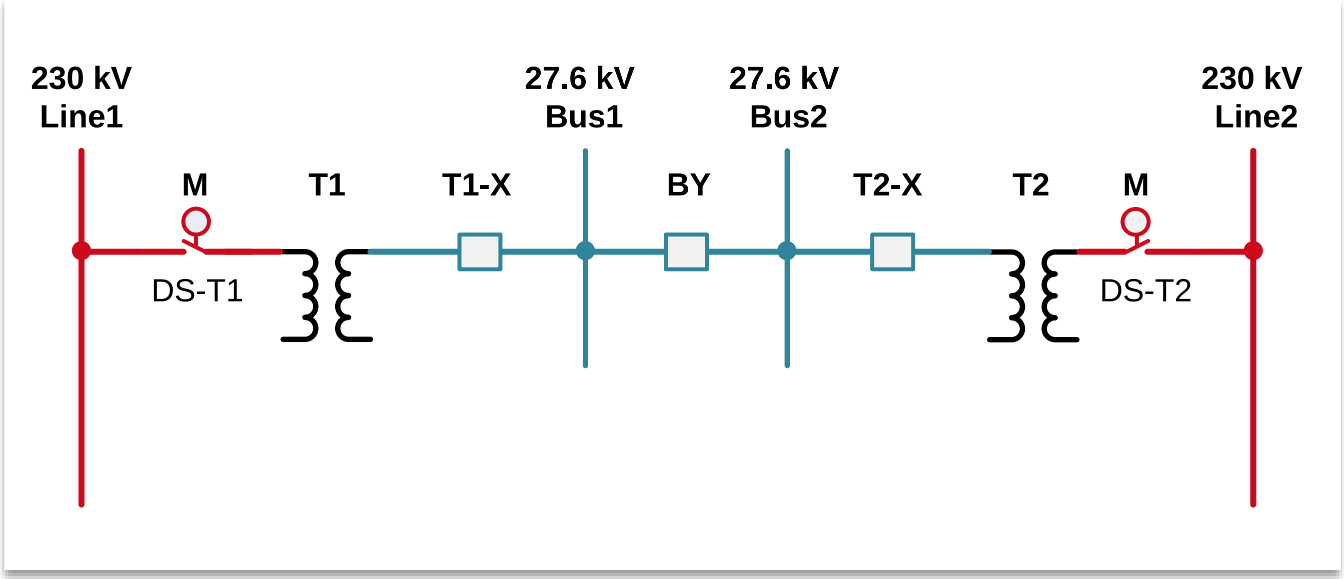
QUANTA TECHNOLOGY

Agenda

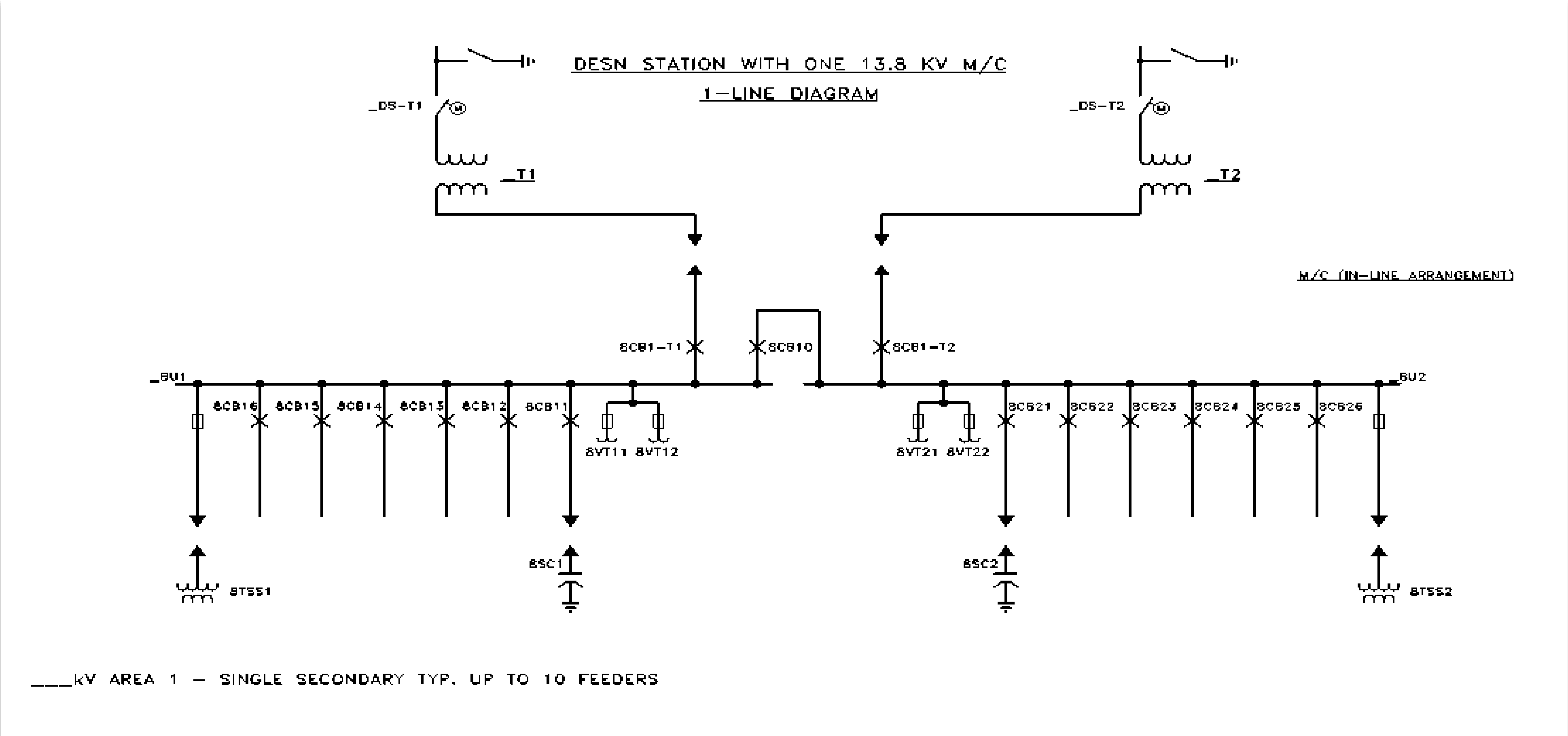
- Hydro One DESN station
- Introduction on **L**ow-**P**ower **I**nstrument **T**ransformers (**LPIT**s)
- Benefits of LPITs
- How LPITs work
- LPIT Testing Concept
- High-voltage and high-current testing test scenarios
- Summary

DESN Stations in the Hydro One System

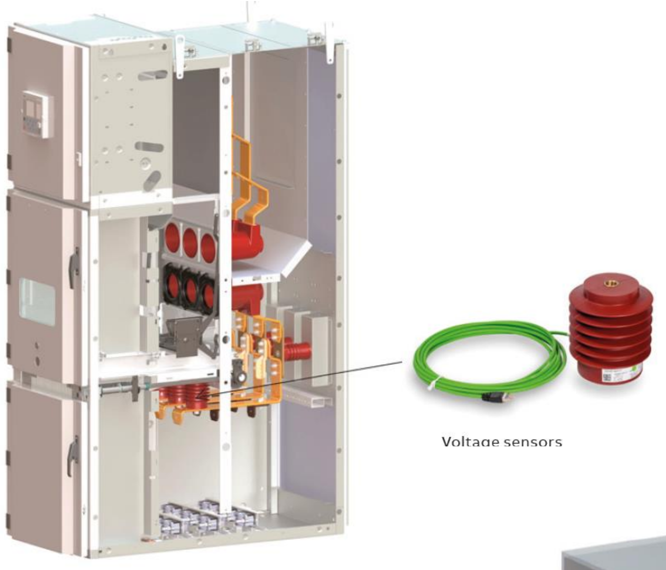


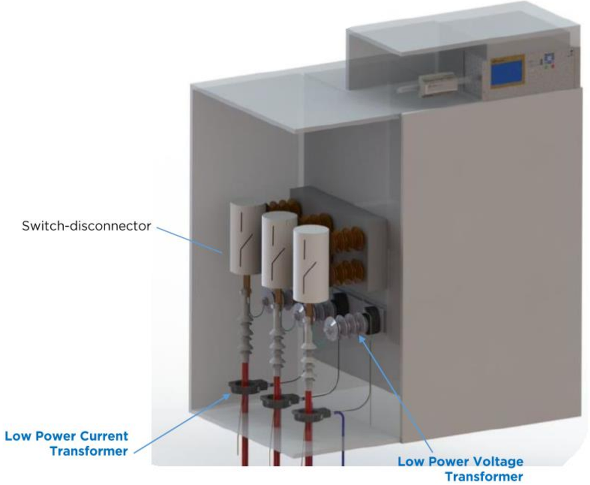


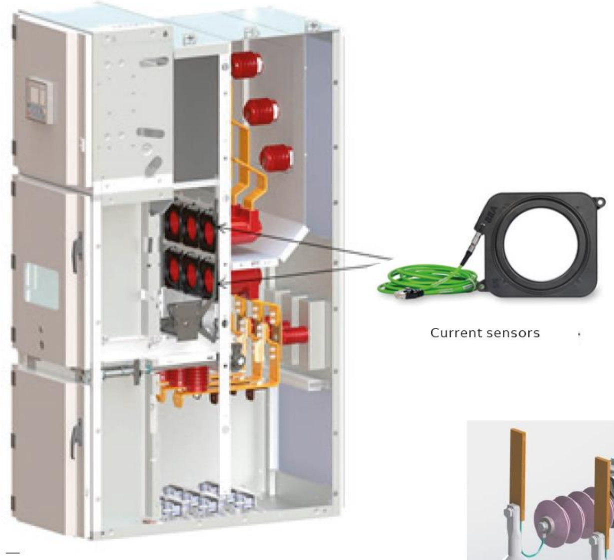
Metal-clad DESN Station SLD

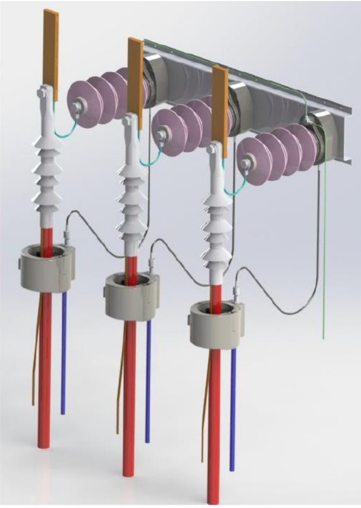


LPITs Installation in Metal-clad Switchgear









Sources: ABB and Arteche catalogs

Introduction of Low-power Instrument Transformers (LPITs)

LPITs help as a subset of non-conventional instrument transformers

- Optimizes the substation footprint
- Minimizes the deployment cost and data management within a digital substation
- Increases personnel's safety

LPITs act as measurement transducers

- Uses a measurement technique different from that of traditional instrument transformers

LPITs provide an alterative solution to address design and equipment rating challenges

- For utilities with conventional substations

LPITs can easily be integrated with merging units and communicate low-power signals

- Via the protocol defined by the IEC 61850 standard

LPITs are considered valuable assets

- For optimal deployment of advanced digital substations

Benefits of LPITs

Enhances
safety around the substation

Applications include
distribution, transmission, and generation

Can serve
both protection and metering applications

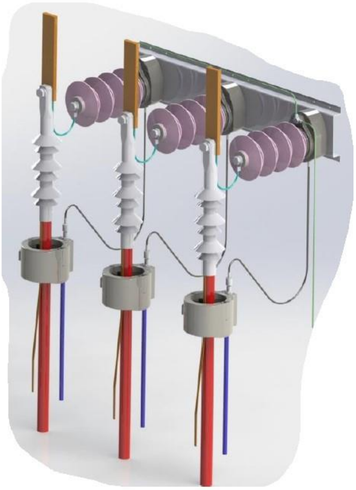
Can be used for both AC and DC measurements (including high- and low-frequency applications, such as measuring geo-magnetically induced currents, harmonics, and transients)

Utilized in
both air-insulated substations, metal-clad switchgear, and gas-insulated substations

It is a natural fit for the modern grid

Benefits of LPITs

Design:
- Safety by design, no CT open circuit, saturation or ferroresonance
- Environmentally friendly due to no SF_6 or oil
- AC measurements convert to digital redundantly available on process bus (for all IEDs)
- Self-monitoring and maintenance-free
- Can be adjusted to any size and any number of turns ratio
- Voltage and current sensors can be combined into single unit
- Easy design process



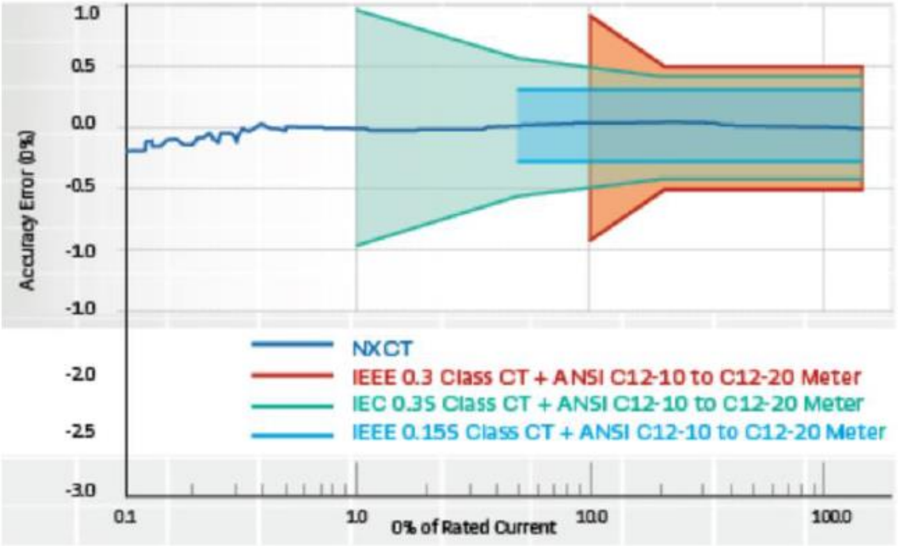
Sources: ABB and Arteche Catalogs

Installation:
- Lightweight and compact
- Easy integration into digital network so no need for heavy copper cabling
- Good seismic performance
- Flexible user-adjustable ratio for efficient spares stocking

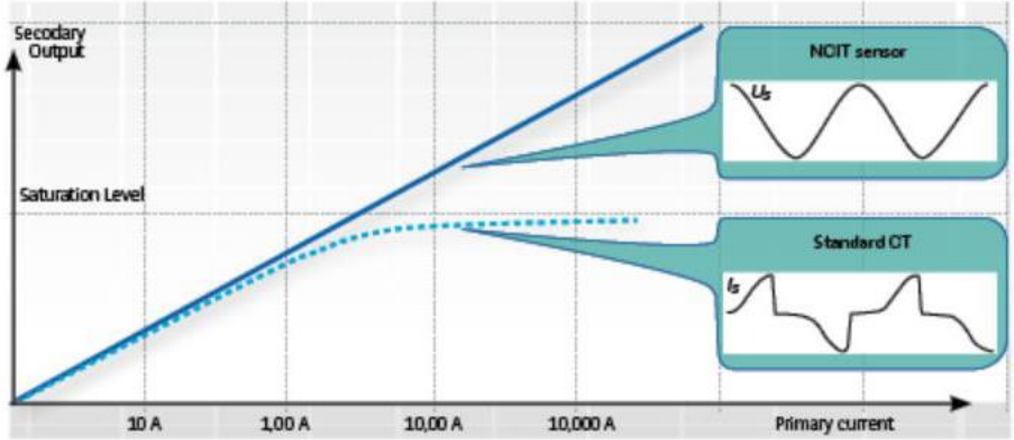
Performance:
- Not prone to noise and distortions as much as conventional counterparts
- Linear characteristics make it suitable both for protection and precision measuring applications

Cost:
- Low-cost manufacturing and installation
- Fast delivery, installation and replacement

Benefits of LPITs



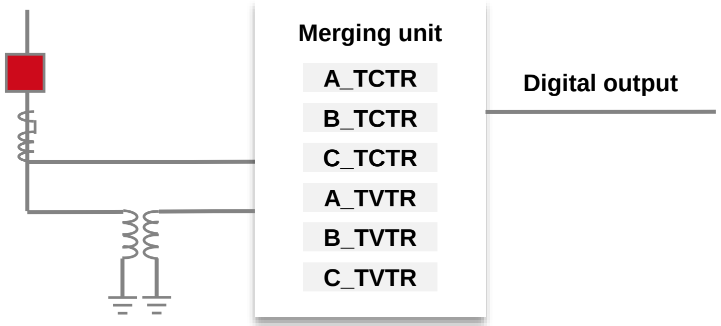
NCIT wide accuracy range



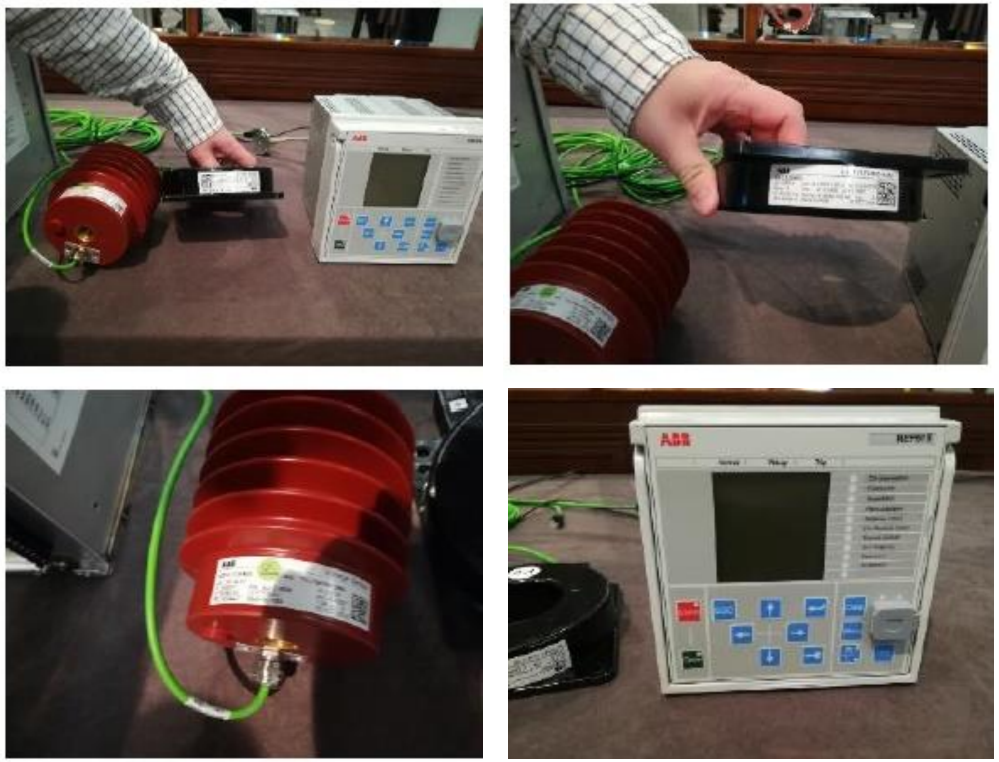
NCIT doesn’t saturate

Source: PACWorld Magazine, March 2018

How LPITs Work



Basic merging concept



Voltage and current sensors and IED

Source: Omicron CPS 2019, ABB exhibition booth.

How LPITs Work

Medium-voltage switchgear with NCIT components

Voltage sensor in busbar compartment

Current sensor and optimal current sensor

Voltage sensor in cable compartment

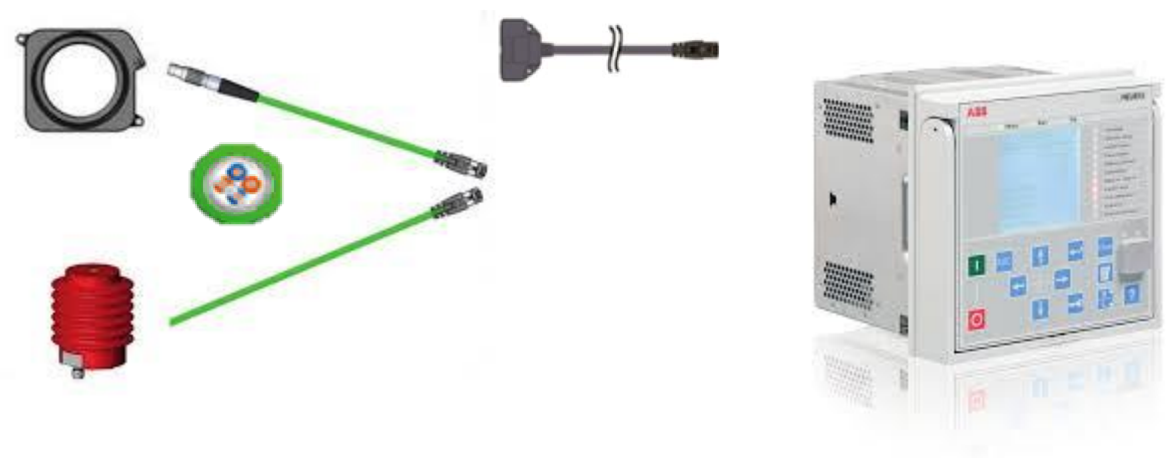
Source:
https://library.e.abb.com/public/58530dc3a669428eaa578af322d3fe4c/Digital_MV_switchgear_9AKK107045A9180_ENd.pdf?x-sign=ZnG9m0Pj5MnY4nCB2M+ok+yztEcLtM3tQfaiaiz80oHolZepsXCFvFDsM95RQ5kb

Voltage and current sensors interface with IED

Sensors include shielded cable with male RJ-45 connectors

Coupler adapter AR4 for one phase

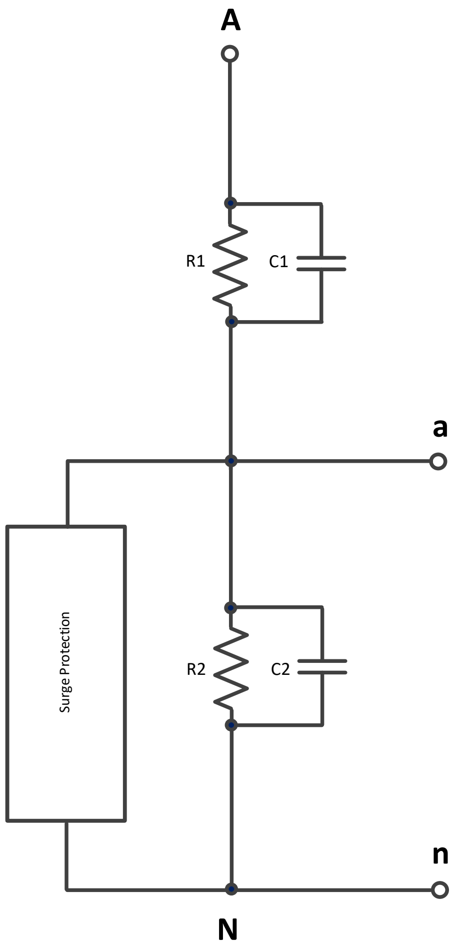
Protection relay with 3x female RJ-45 combined sensor inputs



Source:
https://library.e.abb.com/public/a2939a4951bf4c3194b20a66c796b57d/UniGear%20Digital_Brochure.pdf

Source:
https://library.e.abb.com/public/796a3f2f98d24b75a27de6fa8866384a/DA_offering_for_switchgears_broch_758196_LRENa.pdf

Low Power Voltage Transformer (LPVT) Simplified Model



$$\varepsilon\ [\%] = \frac{Kr * Us - Up}{Up} * 100\%$$

ε : Phase Error [%]

K_r : Rated Voltage Ratio

U_s : RMS Value of Secondary Voltage

U_p : RMS Value of Primary Voltage

$\phi_e = \phi_s - \phi_p$

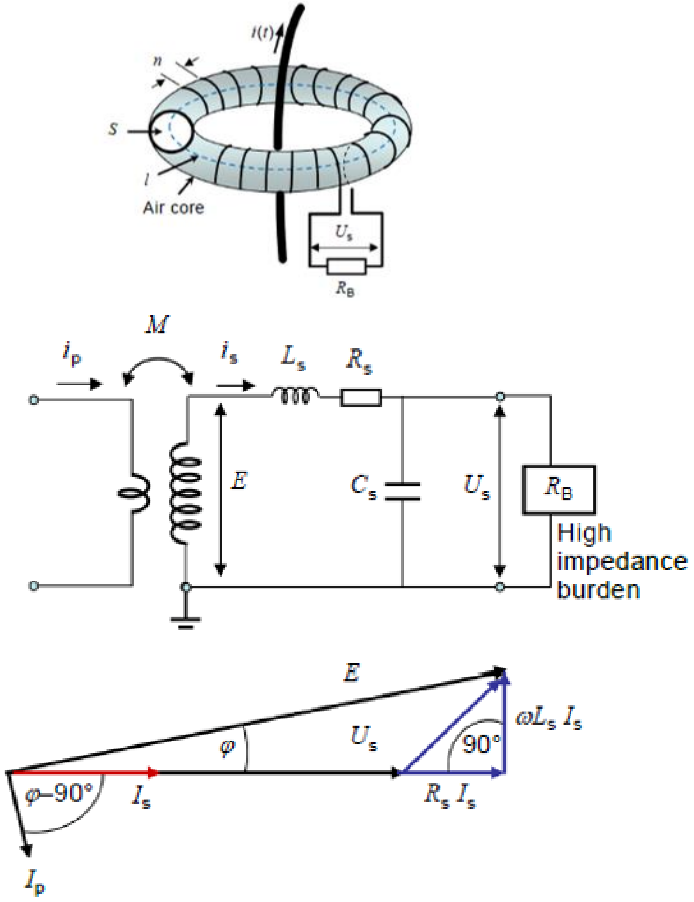
ϕ_e : Phase Error

ϕ_s : Phase Angle of Secondary Voltage

ϕ_p : Phase Angle of Primary Voltage

Low Power Current Transformer (LPCT) Simplified Model

IEC 61869-10:2017 © IEC 2017



Rogowski coil Equivalent Circuits

$$\varepsilon\,[\%] = \frac{Kr * Us - Ip}{Ip} * 100\%$$

ε : Phase Error [%]

K_r : Rated Current Ratio

U_s : RMS Value of Secondary Voltage

I_p : RMS Value of Primary Current

$$\phi_e = \phi_s - \phi_p - 90°$$

ϕ_e : Phase Error

ϕ_s : Phase Angle of Secondary Voltage

ϕ_p : Phase Angle of Primary Current

High-voltage and High-current Testing Scenarios

- Linearity and accuracy
- Dynamic tests
- Withstand capability: over-voltage handling
- Temperature effect
- Impact of frequency on the sensors
- EMI tests

High-voltage and High-current Testing Scenarios

High-voltage testing

- Type testing of the selected current and voltage sensor in a high-voltage laboratory
- Based on general testing requirements defined in the IEEE/ANSI C57.13 and the IEC 61869 standards
- To show the performance of the selected current and voltage sensors
- Focus on accuracy for protection performance

Test Types

Linearity and accuracy

- Inject a traceable primary current or voltage into the sensor and capture the output current and voltage to plot the accuracy and linearity of the sensor
- Across the measurement range of 0 primary amps to the rated continuous thermal current of the sensor
- Across the measurement range of 0 primary volts to 110% of the primary voltage rating of the sensor
- Step change tests to understand the sensor's performance under a simulated fault event
- A nominal current or voltage is supplied, then the current or voltage is changed to simulate a fault
- The sensor output is compared to the primary values

Test Types

Withstand capability

- Withstand capability will be tested as defined in C57.13 and IEC 61869

Temperature impact

- The impact of temperature by repeating the linearity and accuracy tests at various temperature points: -75 °C and +85 °C

Frequency

- The impact of frequency by repeating the linearity and accuracy tests at frequencies +/- 5 Hz

Test Types

Electromagnetic Interference Impact (EMI)

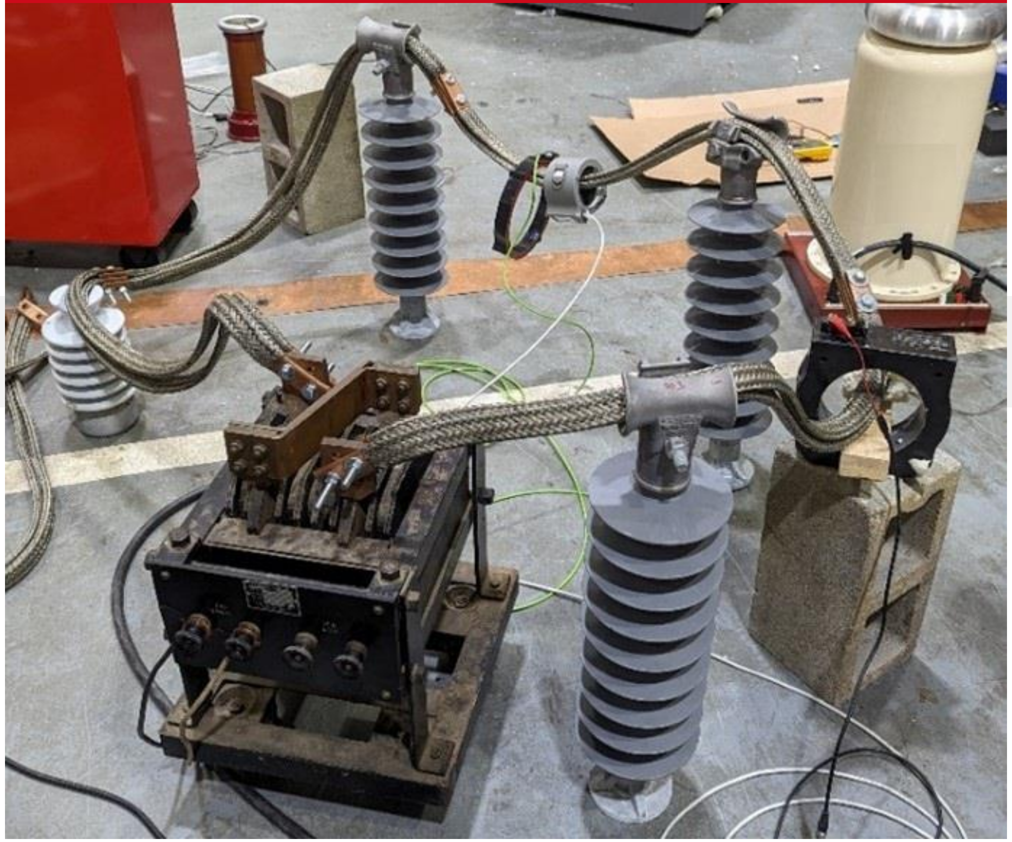
- Evaluate if EMI would affect the output quantities of the voltage and current sensors
- Expose the sensor to the electromagnetic field of a live wire to see how the sensor output will be impacted
- Measure current and voltage sensors near each other to assess how the EMI from one sensor can impact the other

Impact of dynamic changes of primary current and voltage values

- Primary current and voltage values would change dynamically
- Evaluate how secondary current and voltage values of sensors would be affected by such changes

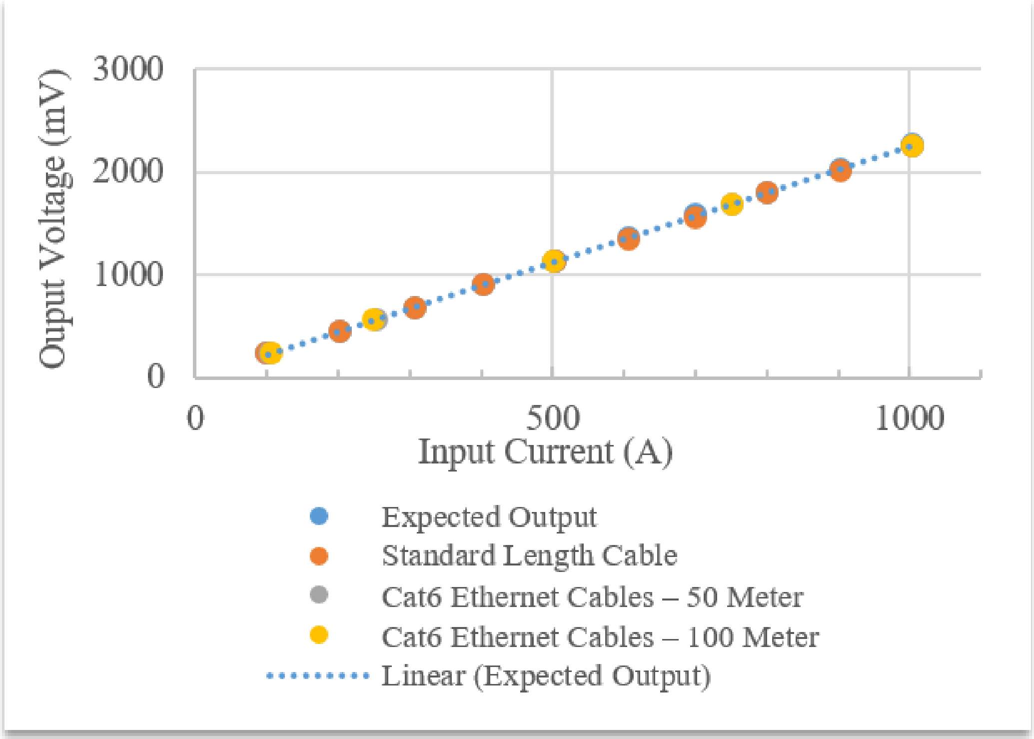
Current and Voltage Sensors Setups in the Lab

Current sensor

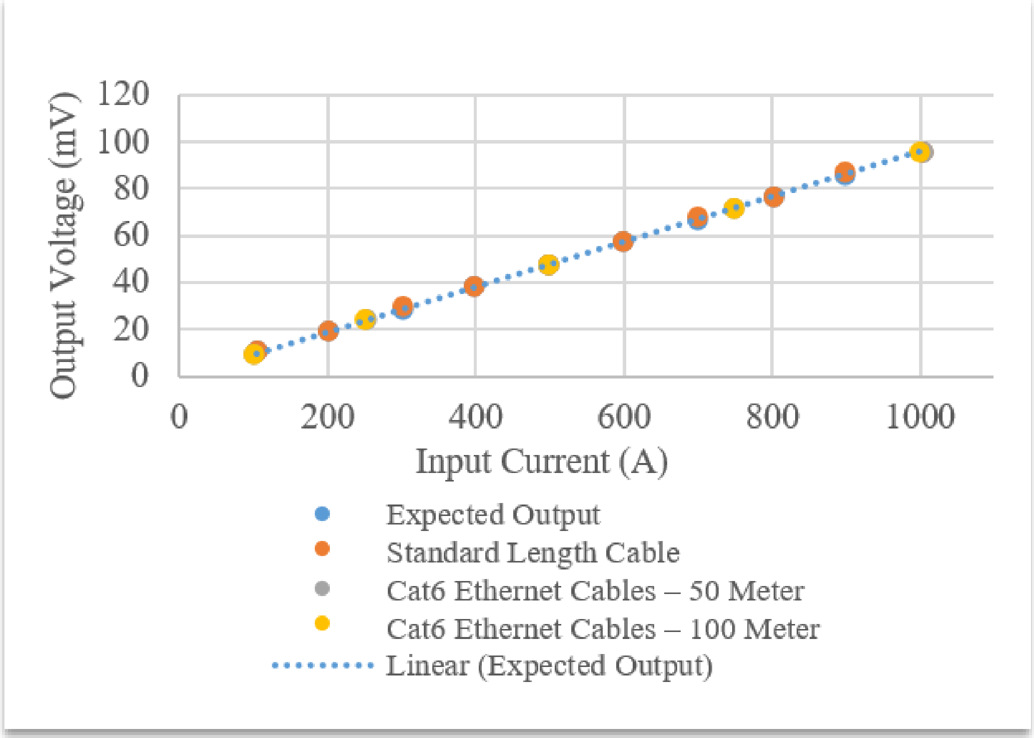


Voltage sensor

Linearity and Accuracy Test Results

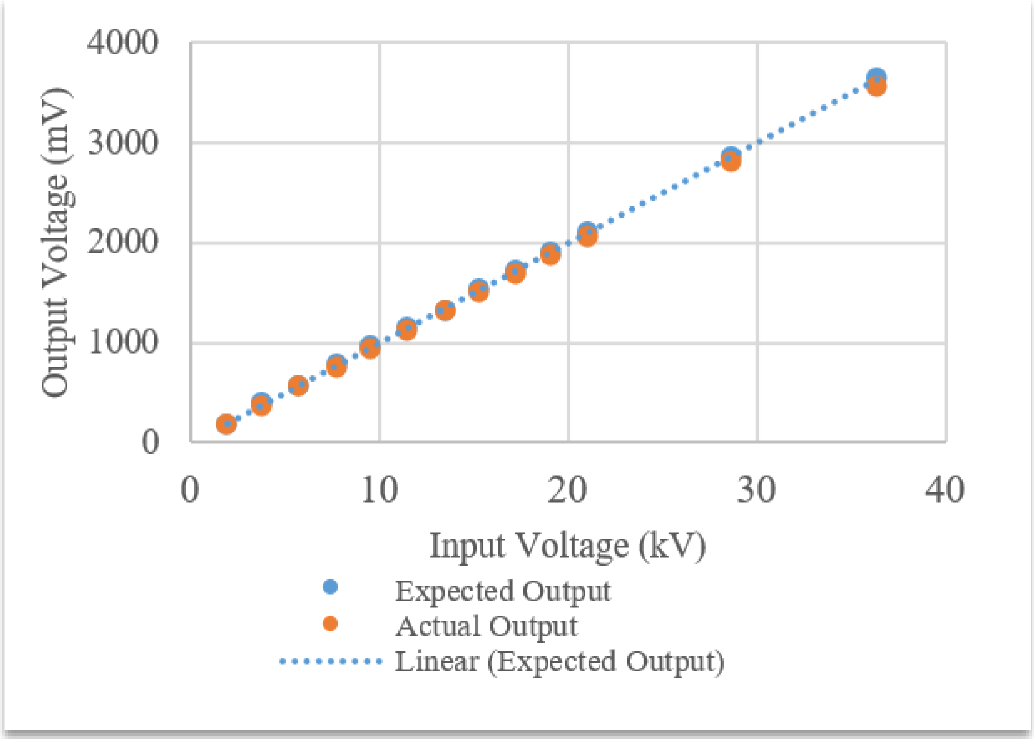


Linearity and accuracy test results for current sensor A

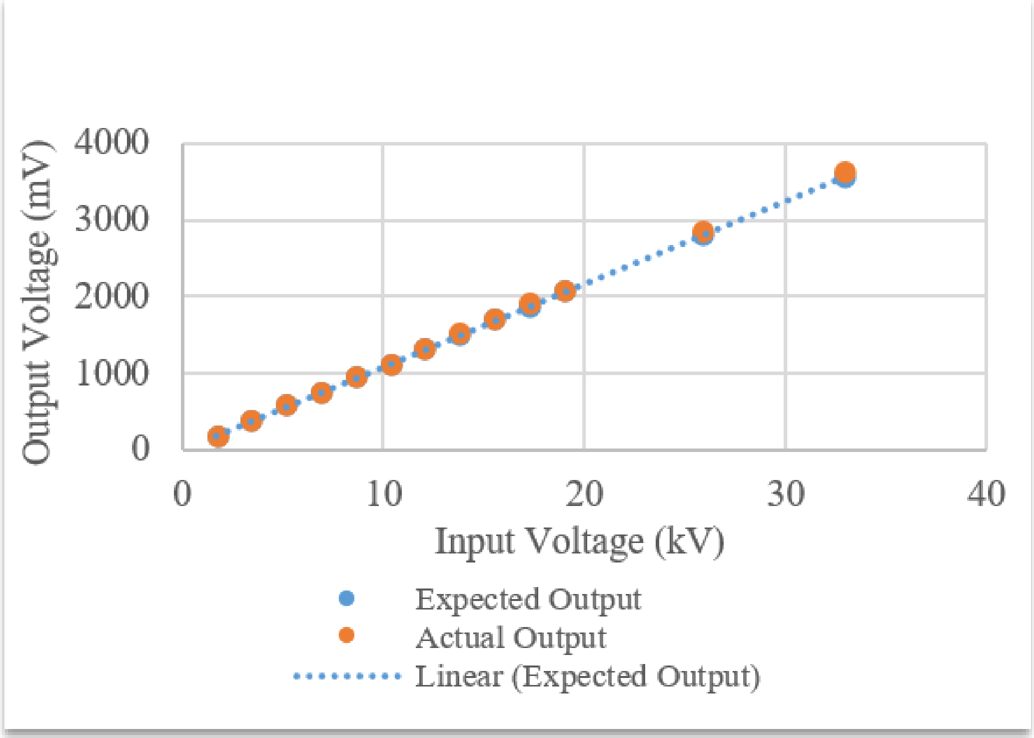


Linearity and accuracy test results for current sensor B

Linearity and Accuracy Test Results



Linearity, accuracy, and withstand capacity test results for voltage sensor A



Linearity, accuracy, and withstand capacity test results for voltage sensor B

Linearity and Accuracy Test Results

For current sensor A, the magnitude of the error for linearity testing results for all cable lengths remained <0.62%

- Results show current sensor A measures current accurately and maintains linearity
- Modifying the cable length does not have a noticeable impact on linearity and accuracy for this sensor

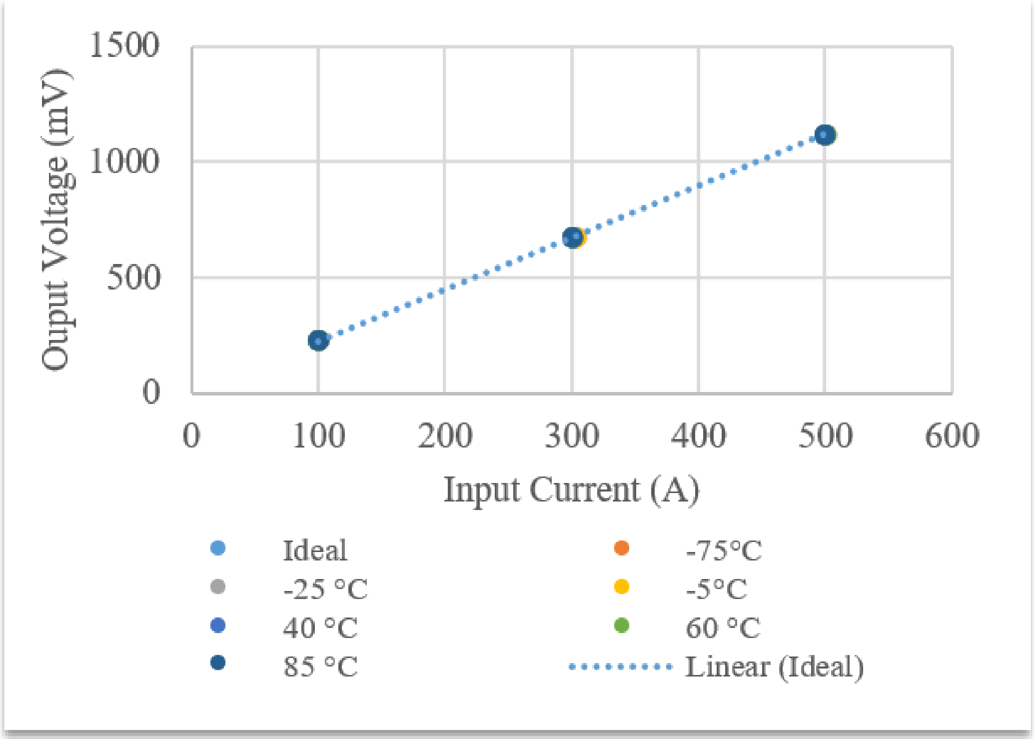
Current sensor B's waveform shown through the lab's oscilloscope contained significant noise

- Distortions in the waveform from the noise prevented the oscilloscope from determining phase shift
- For the lowest primary current applied, the magnitude of the error for the measured output reached a peak of 10.25%
- This could be the result of the observed noise interfering with the low-voltage output signal enough to cause a significant error
- The cable length at the sensor output does not negatively impact linearity and accuracy for this sensor

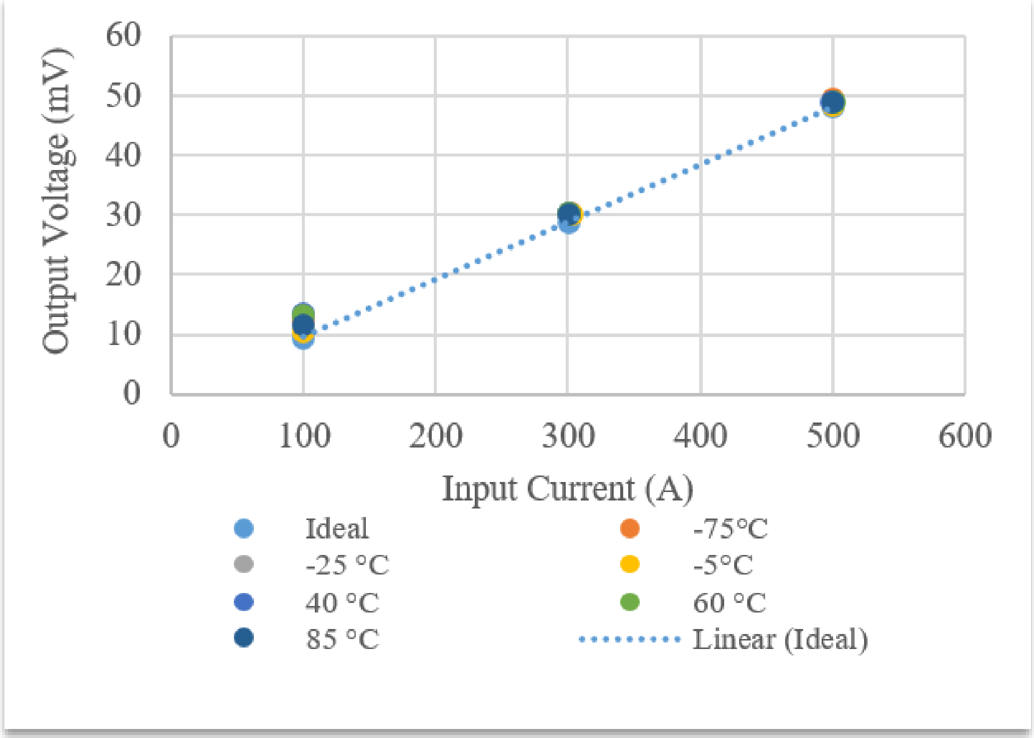
For voltage sensor A, the average error between the expected and actual voltage output for the sensor was 1.9681%

For voltage sensor B, the average error between the expected and actual voltage output was lower than that of the manufacturer A voltage sensor at –0.5713%

Temperature Impact Test Results

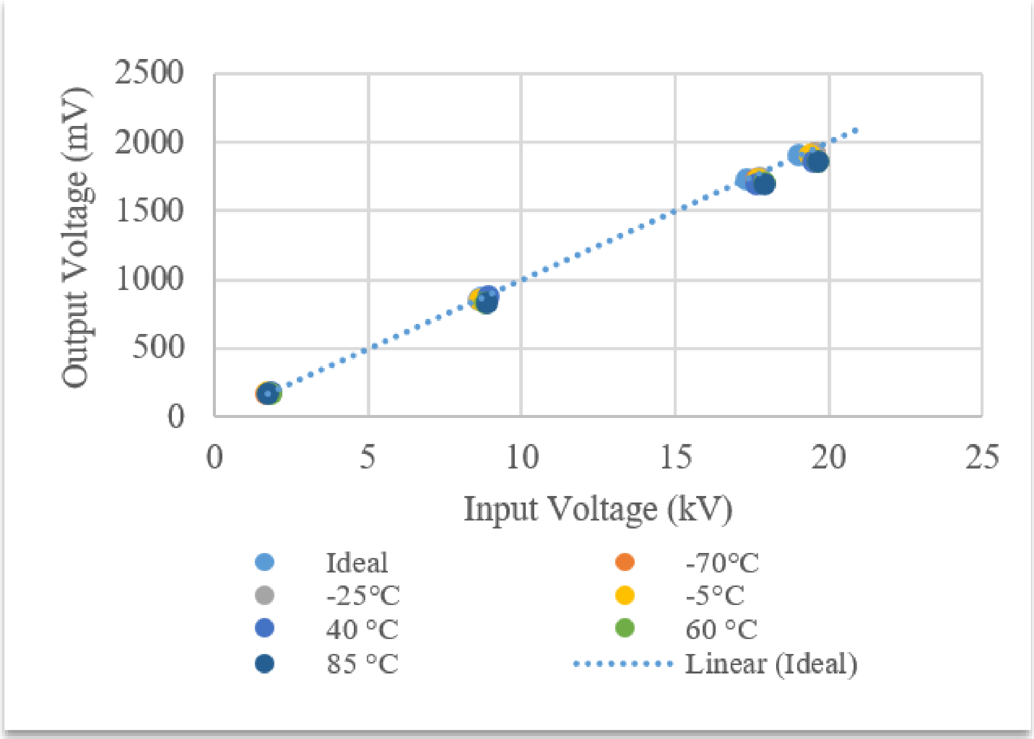


Temperature impact test results for current sensor A

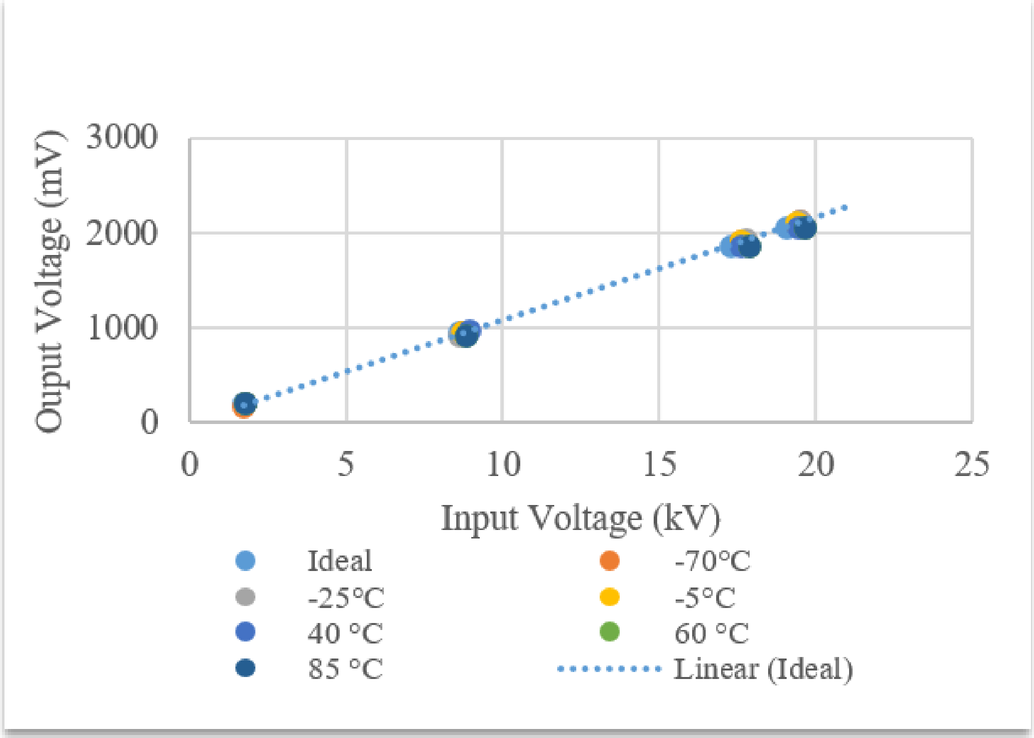


Temperature impact test results for current sensor B

Temperature Impact Test Results



Temperature impact test results for voltage sensor A



Temperature impact test results for voltage sensor B

Temperature Impact Test Results

For current sensor A, there was no significant difference between the error observed in this test compared to the linearity and accuracy test

- The temperature does not greatly impact the sensor’s performance

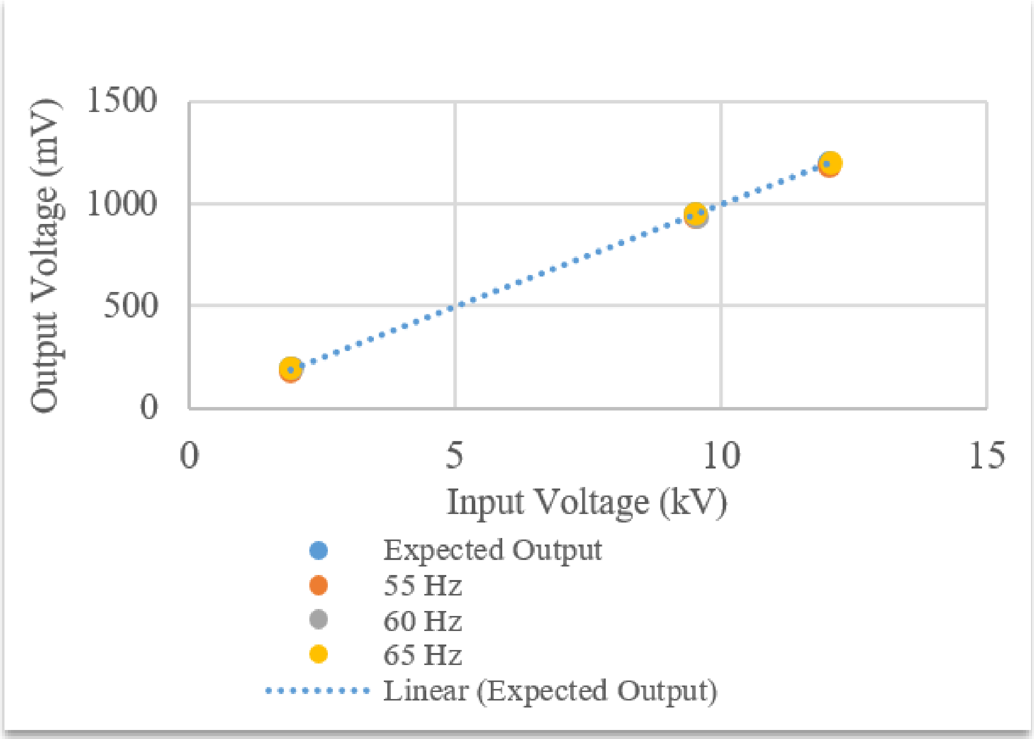
For current sensor B, the error magnitude was generally larger under non-ideal temperatures

- This sensor does not have the same accuracy when exposed to extreme temperatures

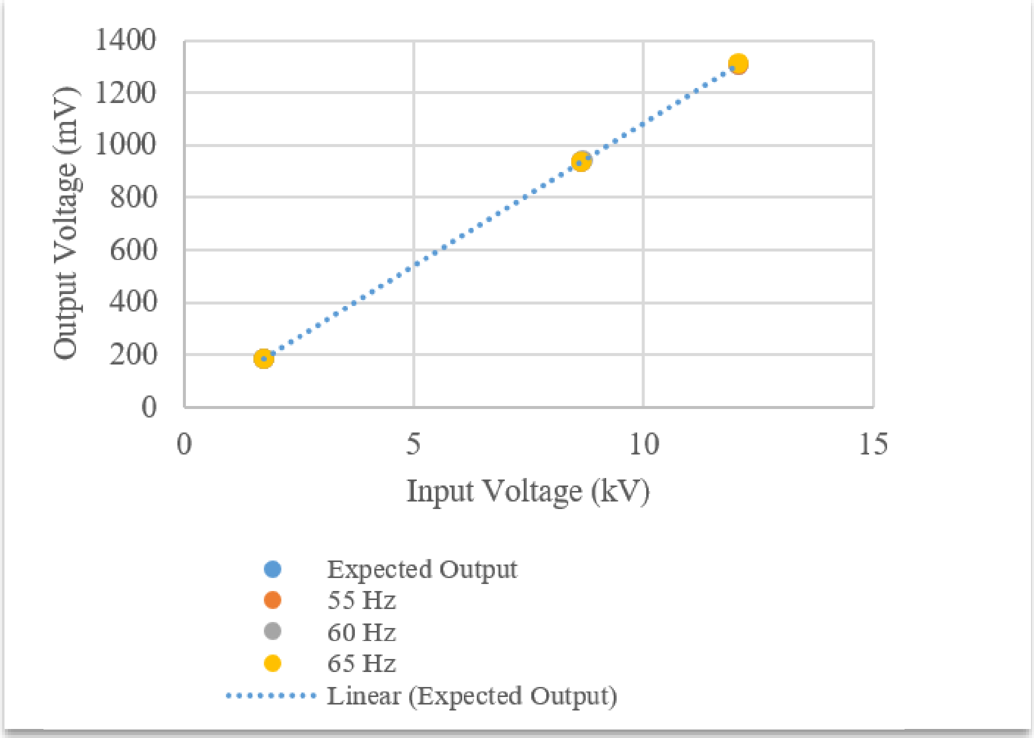
For voltage sensors A and B, the highest error came from test cases with higher applied temperatures

- Considering this and that the largest error observed in the linearity and accuracy test was 2.356% and 3.8451% for sensors A and B, respectively
- Temperature appears to impact the ability of the sensor to measure the voltage accurately and linearly

Frequency Impact Test Results

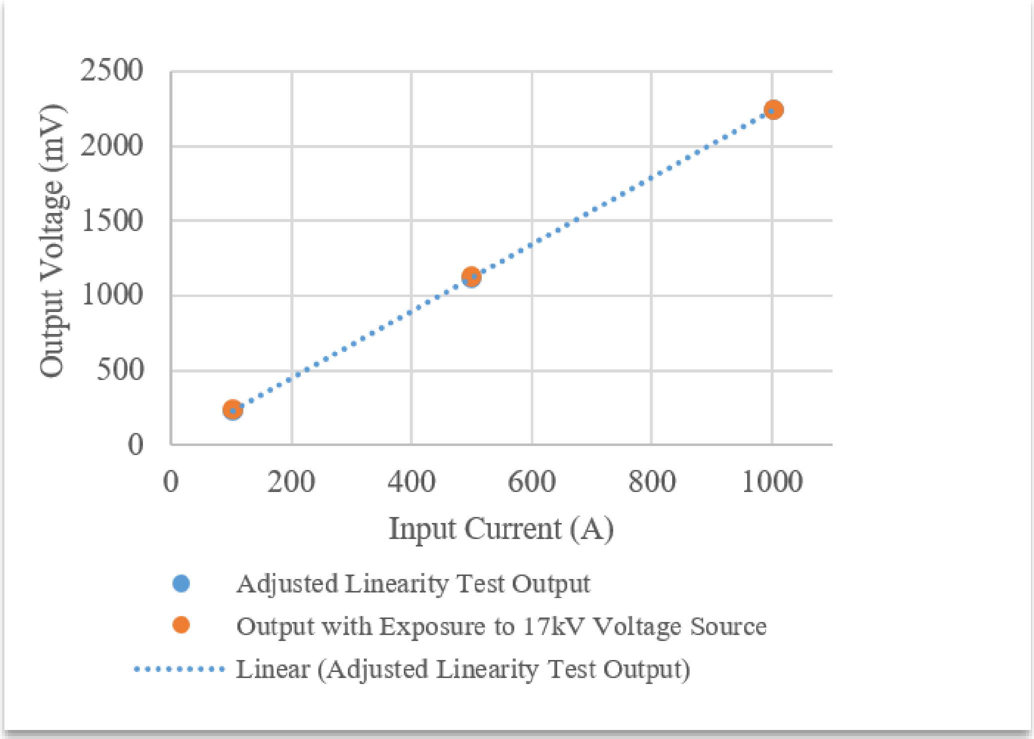


Frequency impact test results for voltage sensor A

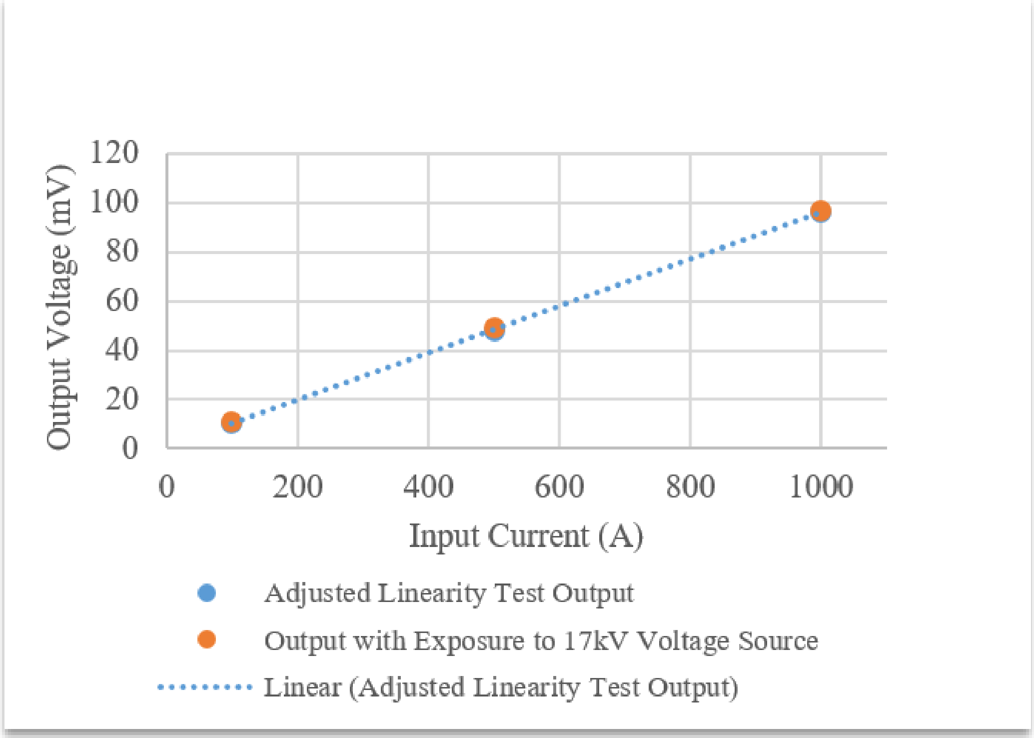


Frequency impact test results for voltage sensor B

EMI Impact Test Results – Current Sensors

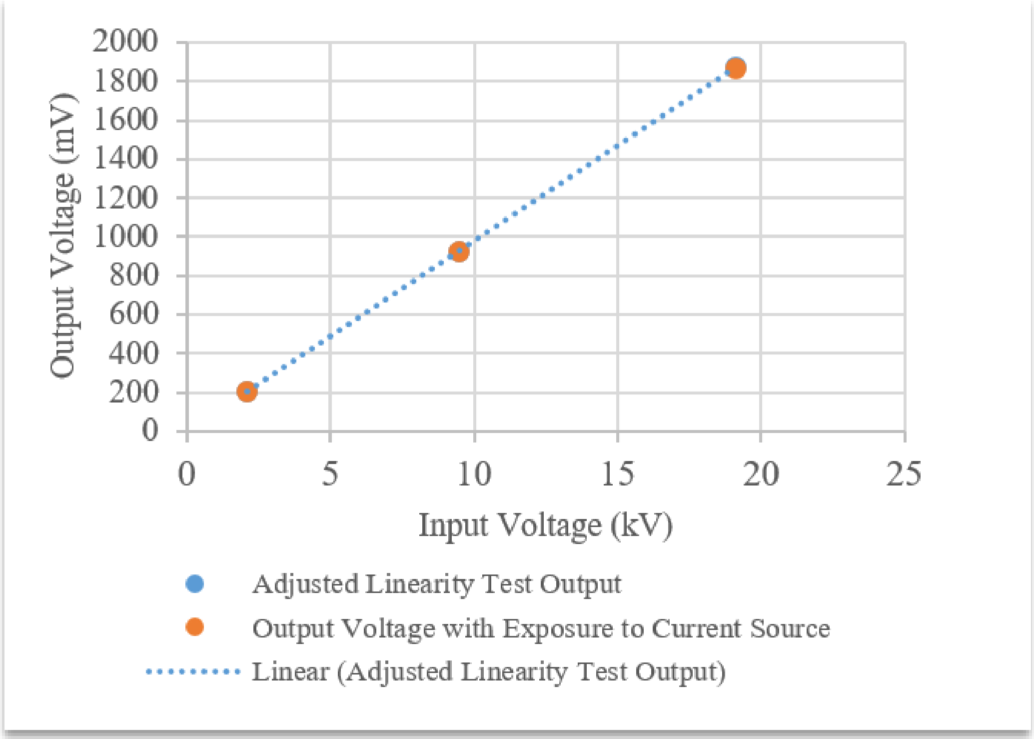


EMI impact test results for current sensor A

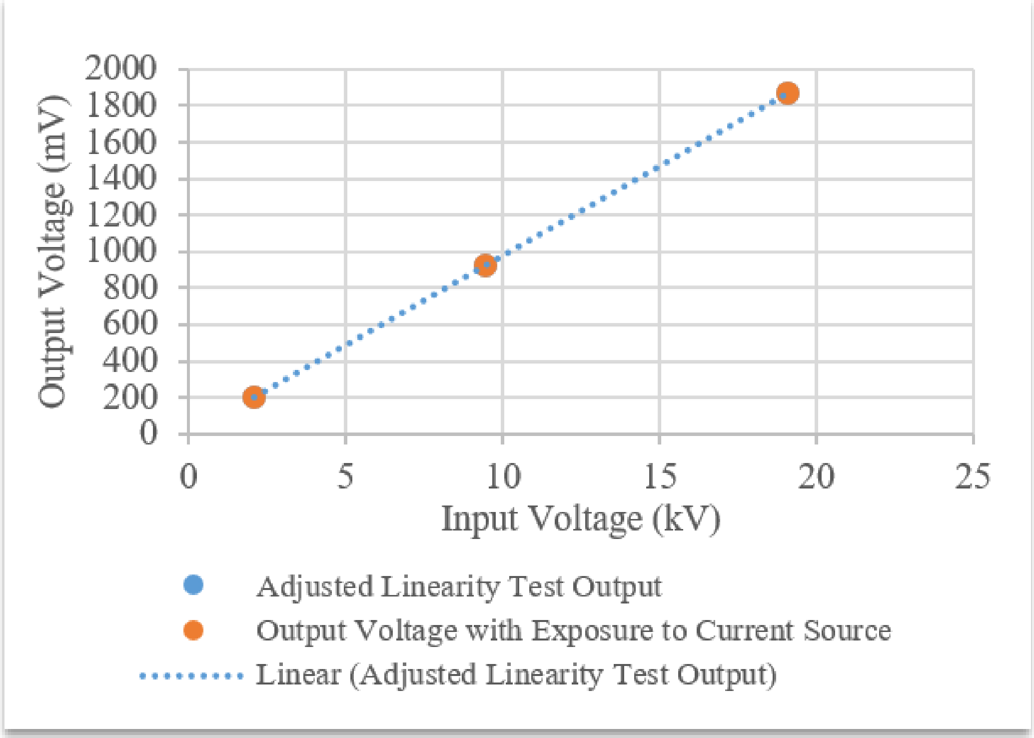


EMI impact test results for current sensor B

EMI Impact Test Results – Voltage Sensors



EMI impact test results for voltage sensor A



EMI impact test results for voltage sensor B

Impact of Dynamic Changes

IMPACT OF DYNAMIC CHANGES OF PRIMARY CURRENT TEST RESULTS FOR CURRENT SENSOR A

Step	Input (A)	Observations
Change primary current from 0% to 100%	1000	Same response as normal operation
Change primary current from 0% to 50%	500	Same response as normal operation

For all sensors tested, the observed output waveforms during the dynamic changes test showed no noticeable differences in response compared to the linearity and accuracy test waveforms

IMPACT OF DYNAMIC CHANGES OF PRIMARY CURRENT TEST RESULTS FOR VOLTAGE SENSOR A

Step	Input (kV)	Observations
Change primary voltage from 0% to 100%	19.2	Same response as normal operation

IMPACT OF DYNAMIC CHANGES OF PRIMARY CURRENT TEST RESULTS FOR VOLTAGE SENSOR B

Step	Input (kV)	Observations
Change primary voltage from 0% to 100%	19.6	Same response as normal operation

Summary

LPITs benefits:

- **Optimizes** the substation's footprint
- **Minimizes** deployment cost and data management within a digital substation
- **Improves** safety of personnel

LPITs features:

- **Integrates** easily with merging units
- **Communicates** low-power signals via the protocol defied by IEC 61850 standard

Test results:

- **Operates** sensors linearly and accurately in general
- **Impacts** minimally from temperature, dynamic changes, EMI, and frequency variations

Accelerate Successful Outcomes for Your Projects

919-334-3000

quanta-technology.com

info@quanta-technology.com

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