Passive Wireless Sensors for Power Distribution Grid Monitoring

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October 17, 2017

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Outline

- Brief overview of company capabilities
- MV test facility
- Power distribution line monitoring with SAW passive wireless sensor-tags
  - Approach
  - Current and E-field (voltage proxy) msmt.
- Introducing **PowerFree™ LineSenS™**
  Wireless Power Line Monitoring System
- Monitoring other grid components **PoleSenS™**

SenSanna company capabilities

SenSanna (formerly ASR&D Corporation):

- Is a passive wireless sensor application engineering firm that designs, manufactures, and sells passive wireless sensor systems
- Provides custom RFID/sensor-tag system development
- Actively partners with system integrators and end-use customers to develop solutions for challenging measurement problems
- Provides 3-phase test and characterization of MV equipment (to 25kV phase-to-phase)

SenSanna Capabilities

- ✓ RFID enabled sensor-tag wireless interface devices
  - Read SAW code & sensor reading(s)
  - Impedance varying & voltage producing external sensors
    - Strain gauges, AE sensors
    - Voltage, current and fault detection
    - Switch positions, bus voltages
- ✓ SAW sensors for:
    - Temperature, Strain
    - Chemicals (H_2, humidity, hypergolic fuels (MMH, DMH), methane)
    - Concrete maturity/curing
    - Volatile (cryogenic) liquid (level); biologics (Chlamydia EB)
- ✓ Sensor reading in multiple media (air-salt water-oil-cement)
- ✓ Software defined radio transceiver reads multiple sensors

Demonstrated multi-sensor calibrated output capabilities

Facility near BWI airport (Maryland)

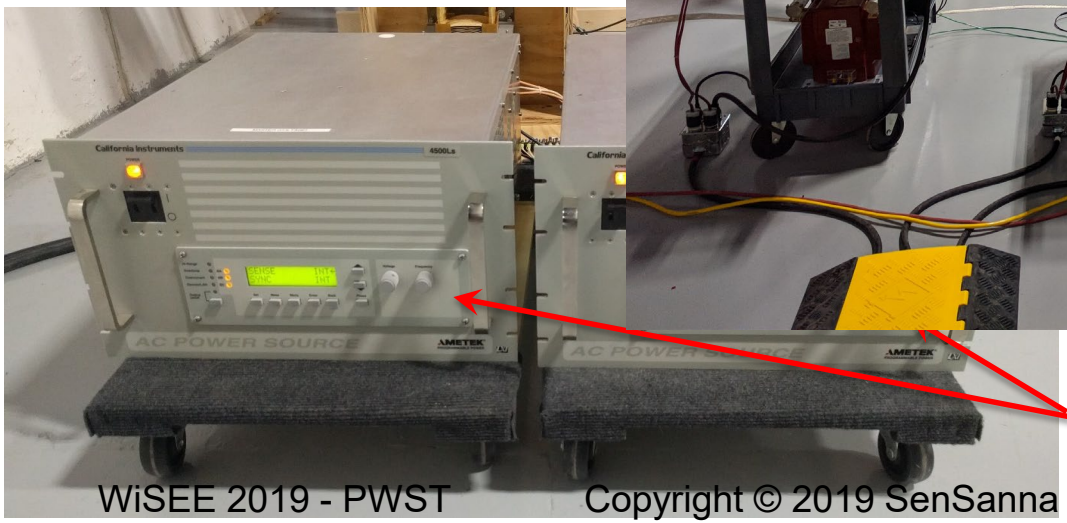
10,000 sq. ft. high-bay facility

- Class 10,000 clean room
  - Fume hood
  - Vapor dilution
  - RF/DC wafer probing
  - Semiconductor furnace
  - Wire bonding
  - SAW device assembly
- Electronic and functional testing of SAW sensors/tags
- Assembly manufacturing (sensor systems)
- System test & characterization

Medium Voltage (MV) test facility

Test rig transformers

- Step-up (voltage)
- Step-down (current)
- Independent control of phase between current and voltage on each phase
- Up to 25kV between phases at up to 200A



MV 3-Phase test rig precision voltage sources (for I and V)

Outdoor MV test facility

Three-phase system

- Fed by indoor precision sources
- Independent control of phase between current and voltage on each phase
- Up to 25kV between phases at up to 200A
- Lindsey reference sensors (3)
- Indoor test rigs for:
  - Steady state up to 200A, 24kV(l-l)
  - Current only up to 600A
  - Current transients up to 3,000A
- Contract testing with user-defined conditions on all three phases (A,B,C)
- System characterization services available up to 25kV line-to-line

Power Distribution Line Monitoring

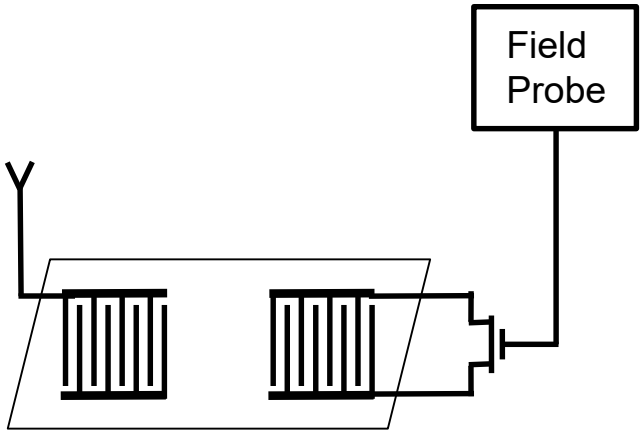
Supported by the

U. S. Department of Energy SunShot Initiative

2015 – 2019

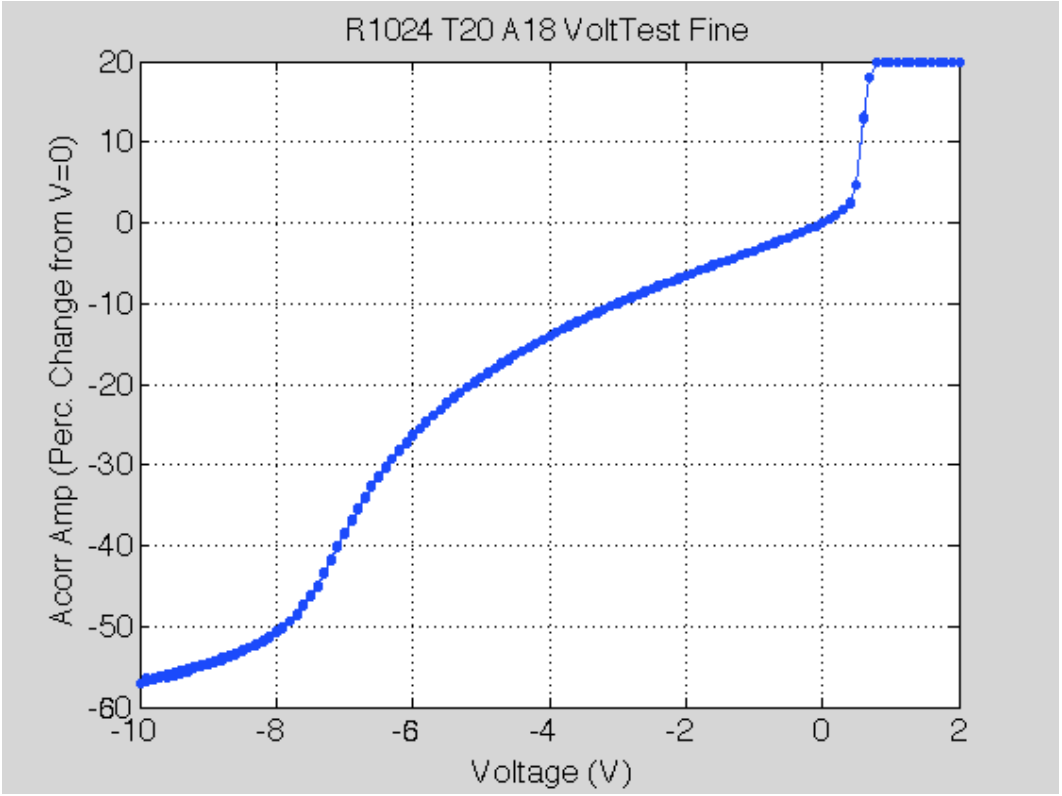
Current and voltage msmt.

Hybrid SAW sensor with FET and voltage-producing electric and magnetic field sensors



Voltage produced by electric and magnetic field probes is applied to gate of a FET, which modulates drain to source impedance, causing acoustic reflection to vary

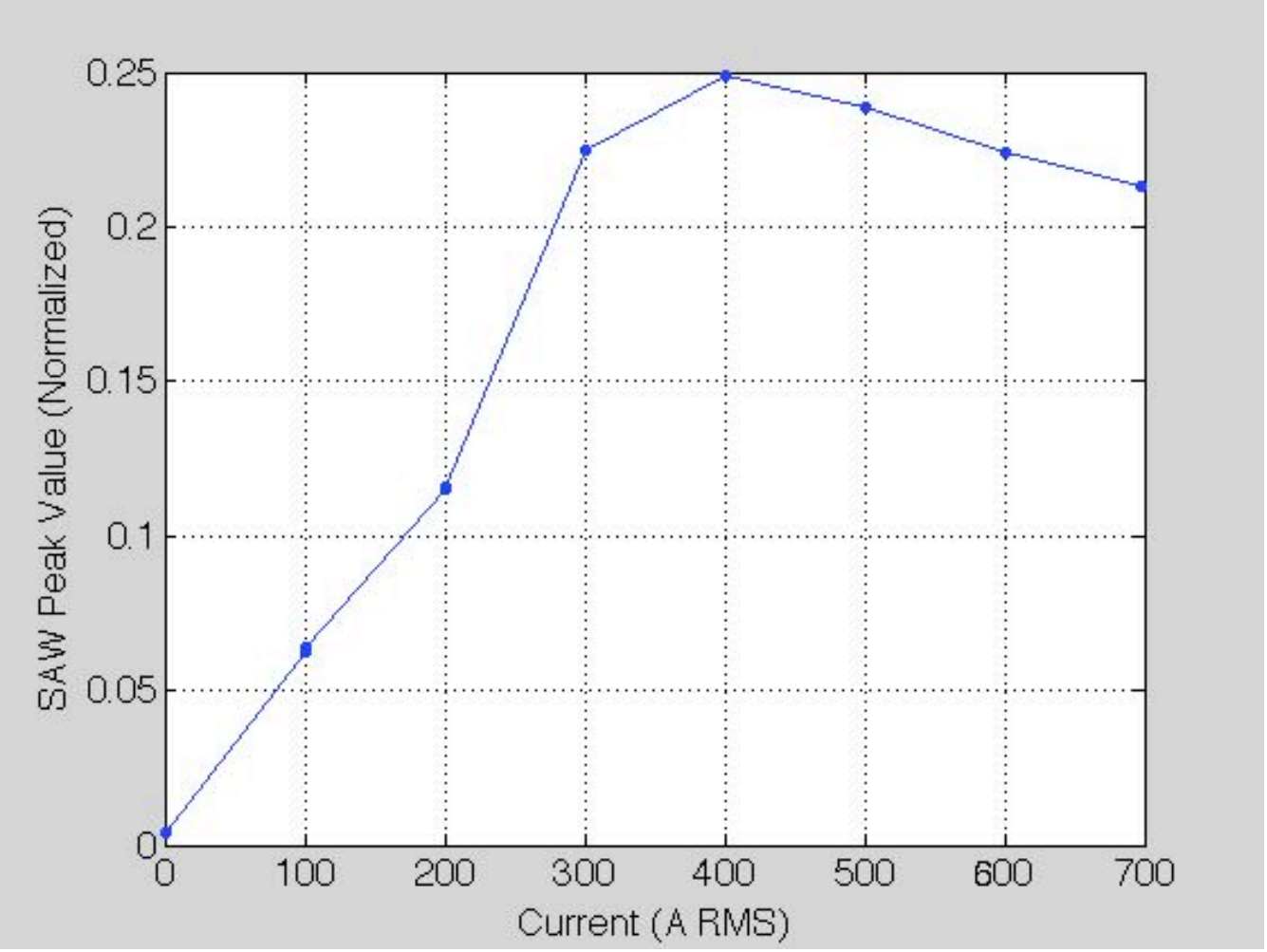
SAW reflection amplitude vs. probe voltage



Preliminary 600A testing (indoor test rig)

Initial Rogowski coil functions to ~300A

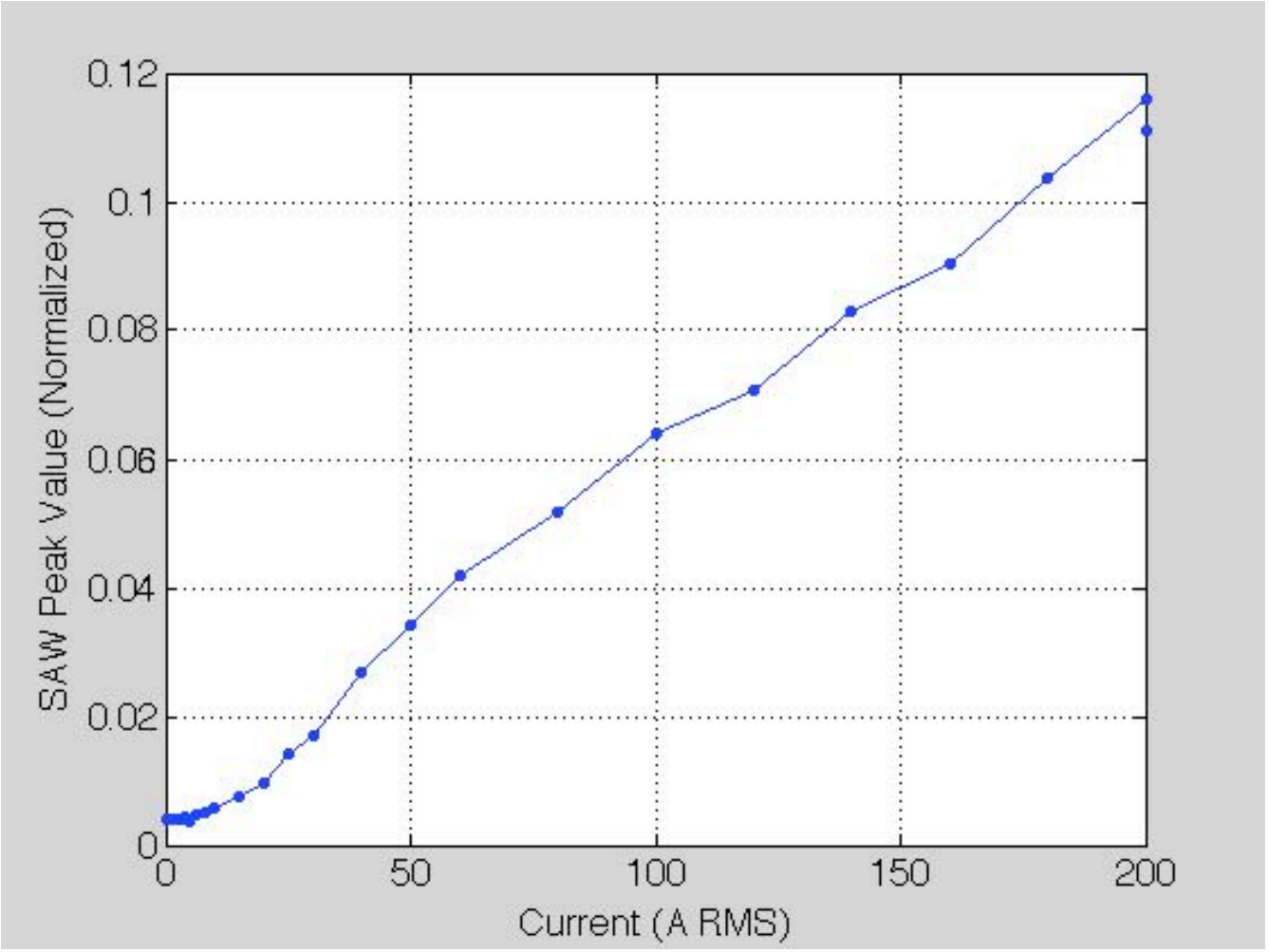
- Rogowski coil output saturates the FET voltage response above ~300A
- Modified Rogo with scaled output down developed
- Small Rogowski coil added for fault current measurement



Low current testing:

Lower current measurement limit is S/N dependent

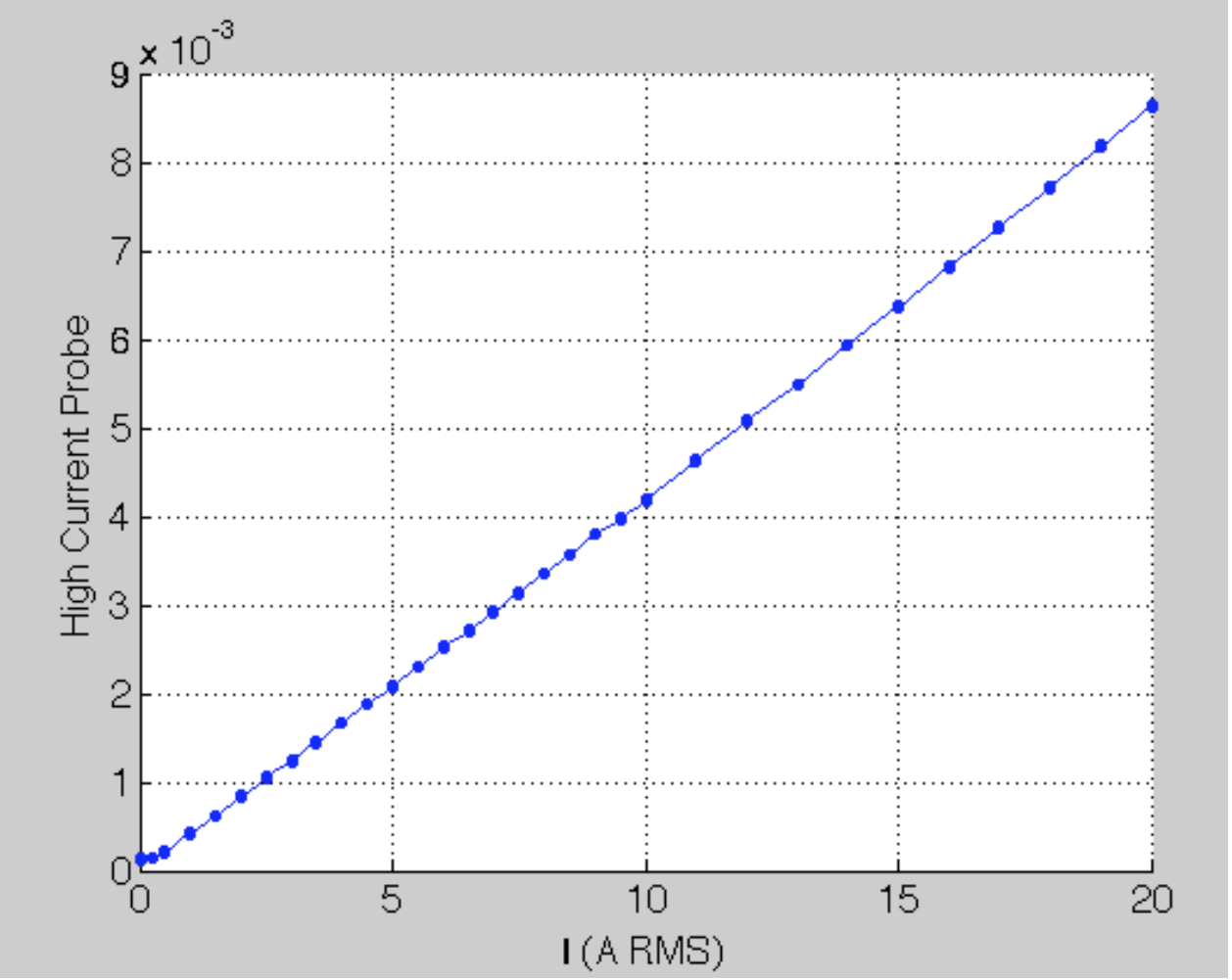
- Wireless tests on 200A indoor test rig
- Dipole antennas
- Response rolls off at very low current due to S/N limitations



Low current measurement:

Rogowski coil/SAW/FET dynamic range enables measurement at low current

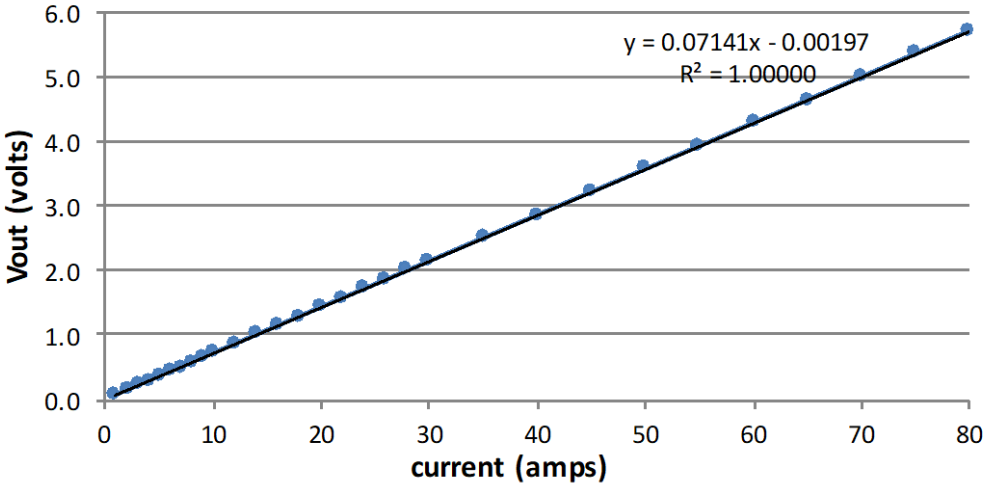
- Wired testing to provide optimal S/N
- Evaluate low current range for Rogowski coil
- Response linear all the way down to near zero current

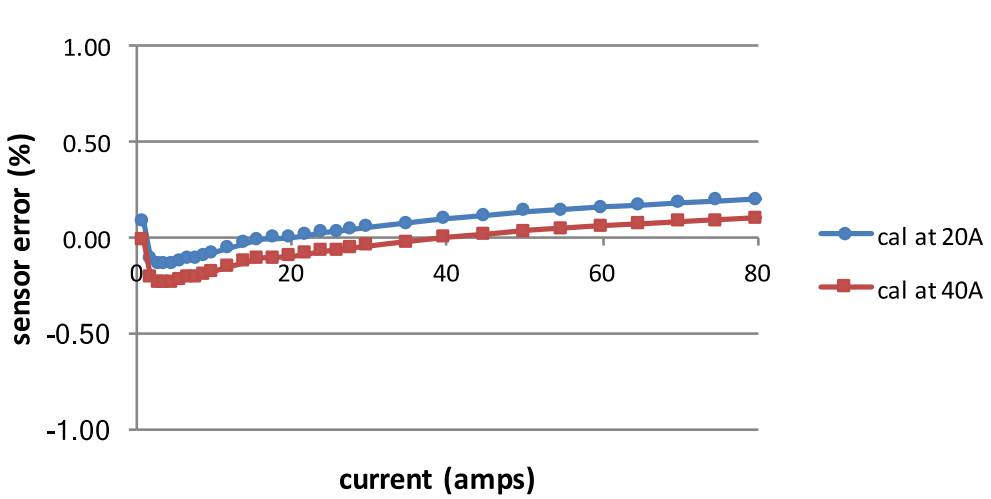


Low current measurement accuracy:

Enhanced magnetic field probe

- Transfer function is nearly linear down to low current
- Error in measured current is less than ±0.25% over low current measurement range
- Dependence of measurement on position of conductor within aperture is ~1.3%
- Variation with vertical line position less than 0.5%
- S/N impacts precision





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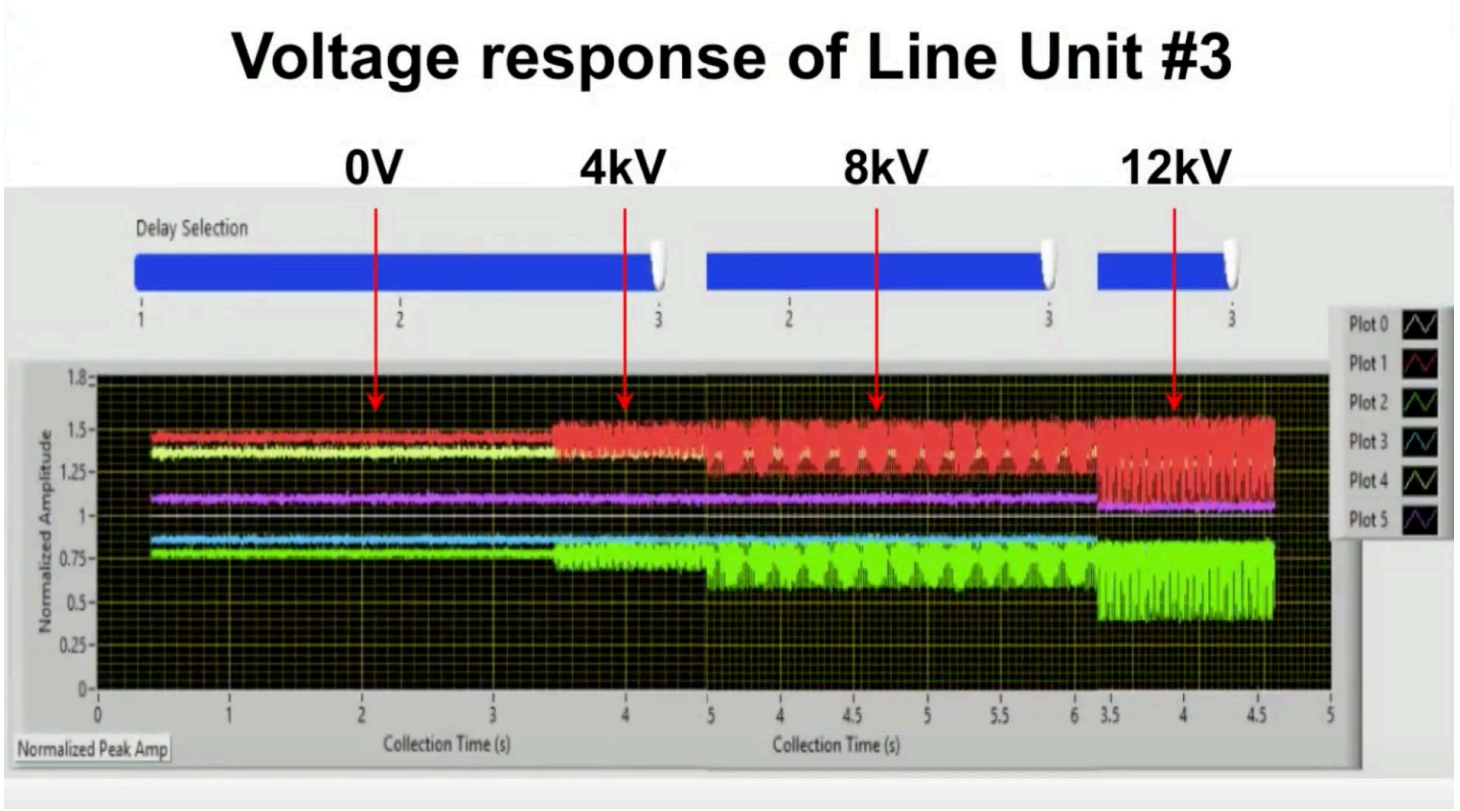
Power line monitoring

Current and voltage ramping at: https://youtu.be/TKSXdqz8ntQ



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NREL MV Power line testing:

Current & voltage waveforms, phase lead/lag, and temperature

LabView user interface showing:

- Raw sensor data (top left plot)
- Measured voltage waveform (lower left)
- Voltage and current responses (top right)
- Measured current (lower right)

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PowerFree™ LineSenS™

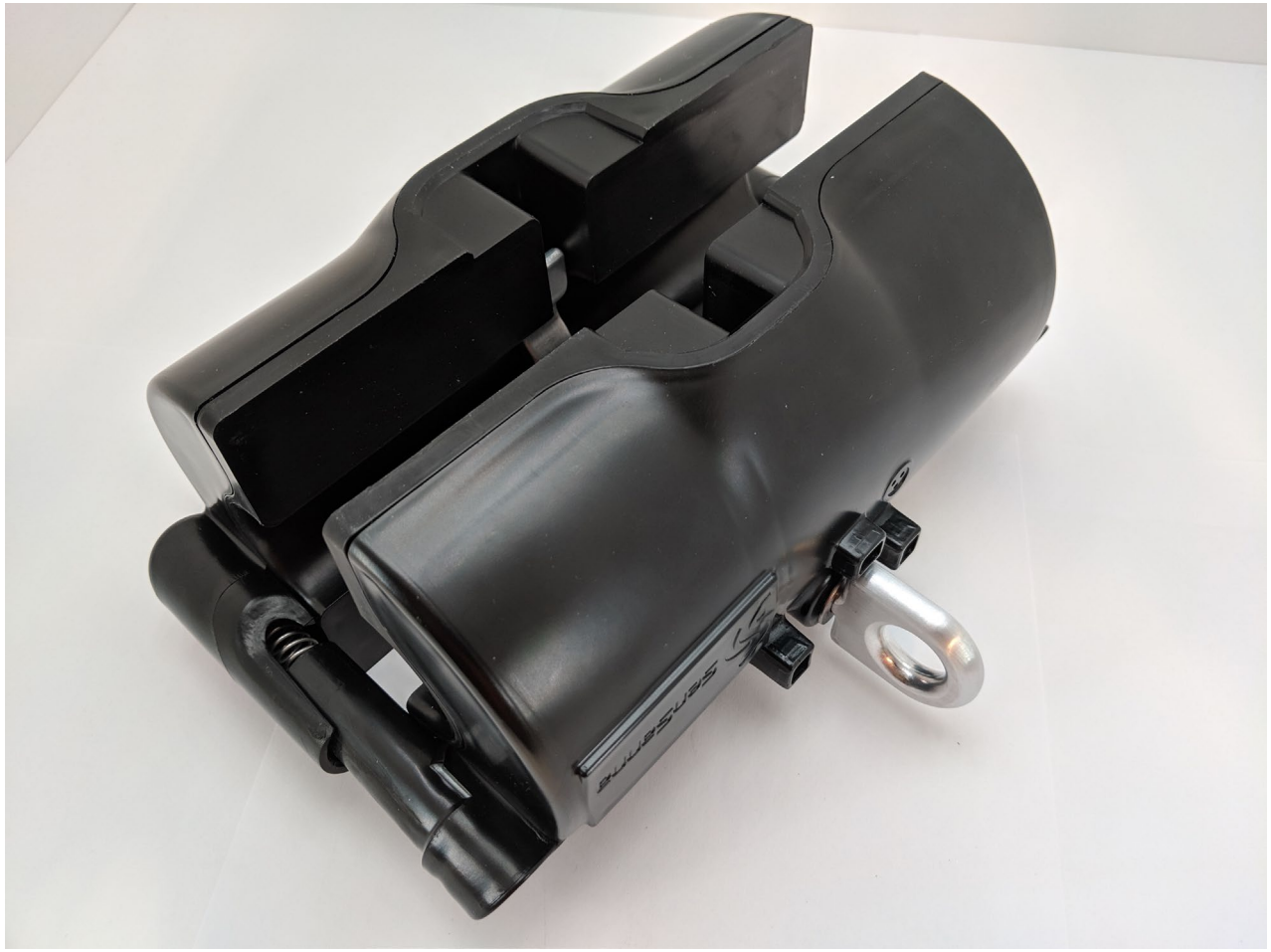
Wireless Power Line Monitoring System

Introducing:

Communicating line sensors without any energy harvesting or batteries on the line

Works continuously on both powered and unpowered MV lines – no minimum current

System consists of three line sensors and one pole-mounted data aggregator with selectable radio for data backhaul



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DistribuTECH 2019 in New Orleans, LA

- Five SenSanna engineers attended
- Data provided in advance to Oracle for use in their “Tiny Town” booth demo
- Oracle allowed us to meet customers in their booth
  - Multiple utilities viewed line sensor and discussed unit availability for field trials

Jackie holding one of three LineSenS units displayed at D-TECH

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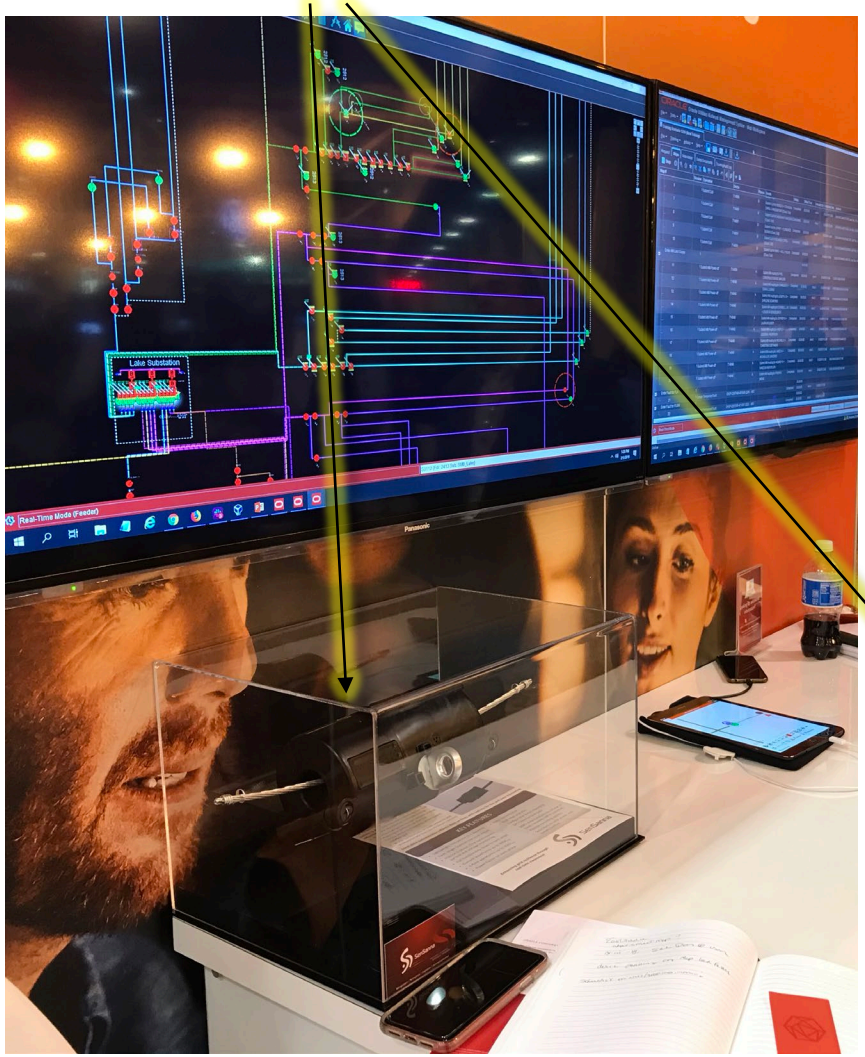
LineSenS in Oracle booth



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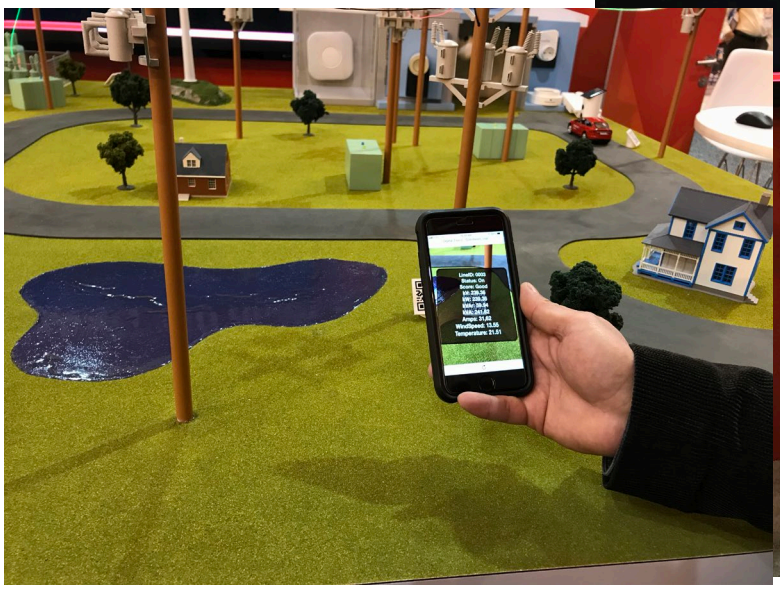
Oracle demo:

- "Tiny Town" booth demo had scale model of distribution grid
- Data from LineSenS sensors 'played' through demo app



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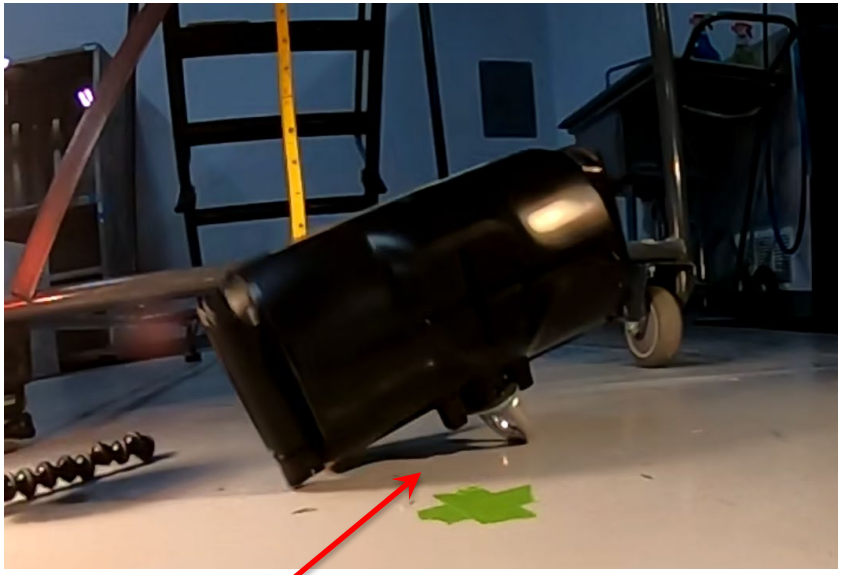
Drop testing:

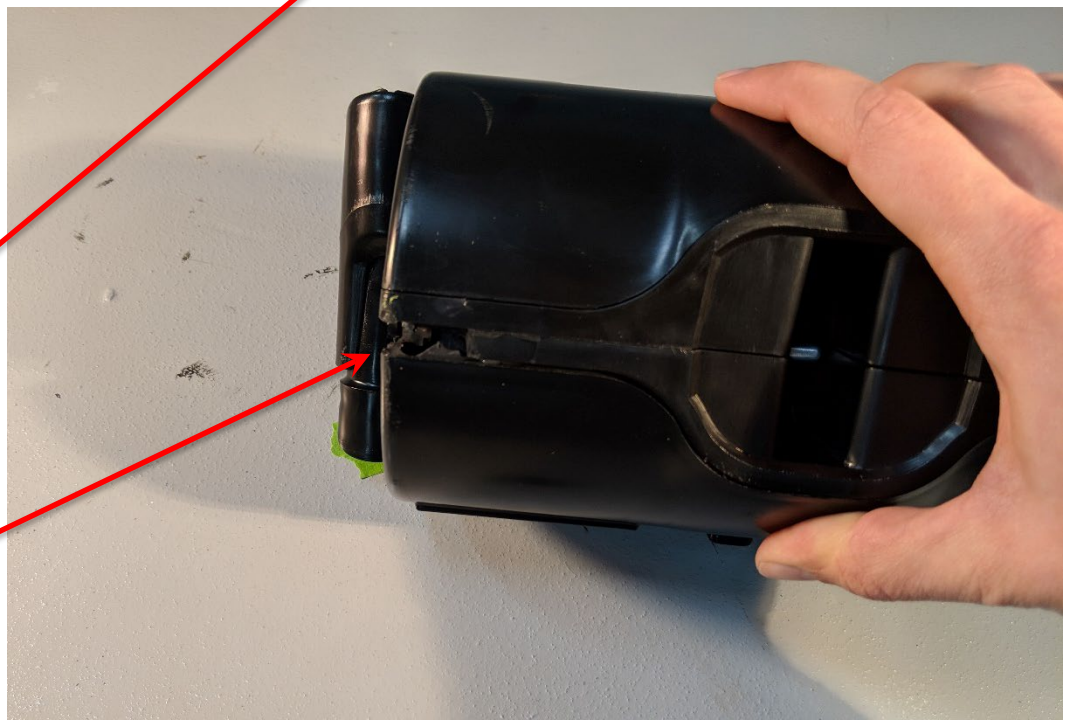
Drop testing from various heights onto concrete with line unit orientation varied for each height

Line unit survived all drops at up to 7 feet except direct drop onto screw eyelet which broke

Plastic housing broke at 10 ft and above



Goal: 4 foot drop



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Leak testing:

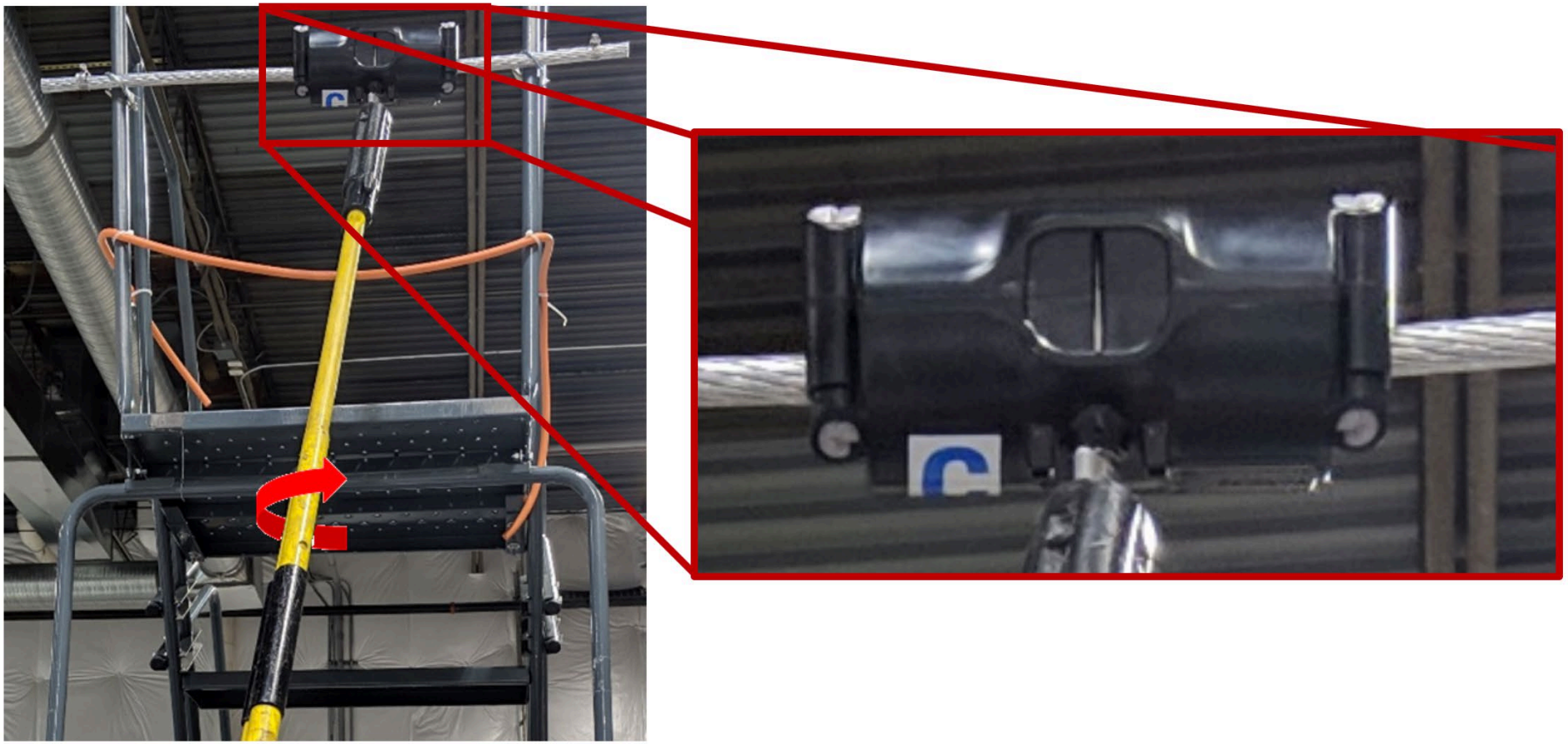
Pressure washer at a distance used to best reproduce pressure of actual IP testing

Line unit sprayed from multiple angles, then opened to verify no water entered housing

Formal IP testing at a 3rd party lab underway for aggregator (+FCC cert.) and line sensor

Hot-stick installation:

Tightening the line sensor on a typical power line



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Field trial line sensor placement – option 1

Line sensors installed on feeds from power lines to underground cables. Sensors clamped well to these insulated lines, but on-site personnel decided to relocate them to lines above

Installation took ~ 5 min for all 3 sensors.

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Field trial - alternate line sensor placement

Line sensors can also be installed on lines where shown. These were #6 cable, with an O.D. of 0.16 inch so the clamps did not hold the sensors tight. The lineman wrapped pieces of copper around the lines to make the clamp hold tight.

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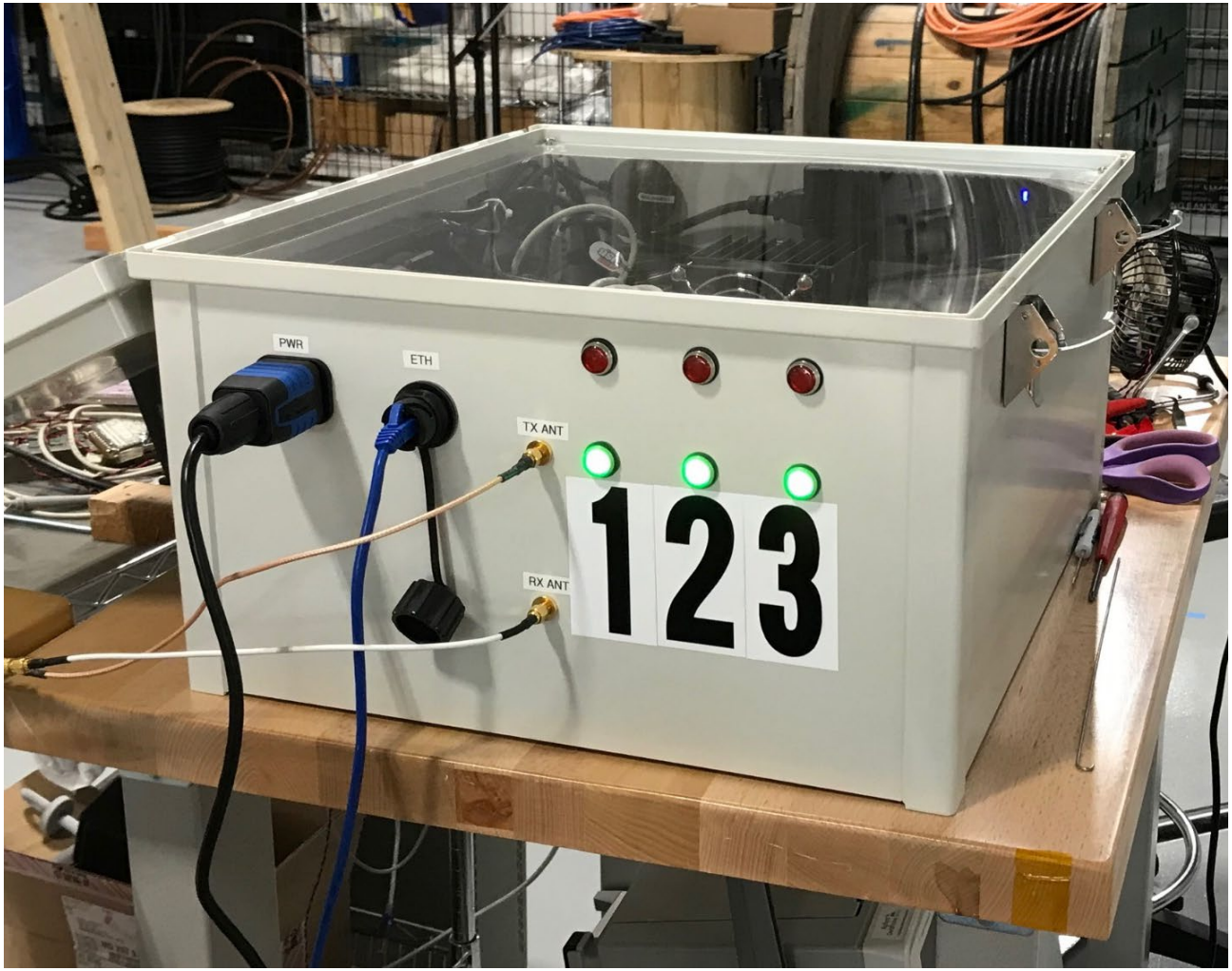
Field trial - aggregator pre-install operational testing



Lights on base give system status for each of the three phases

Optional local data download via ethernet connection shown in use

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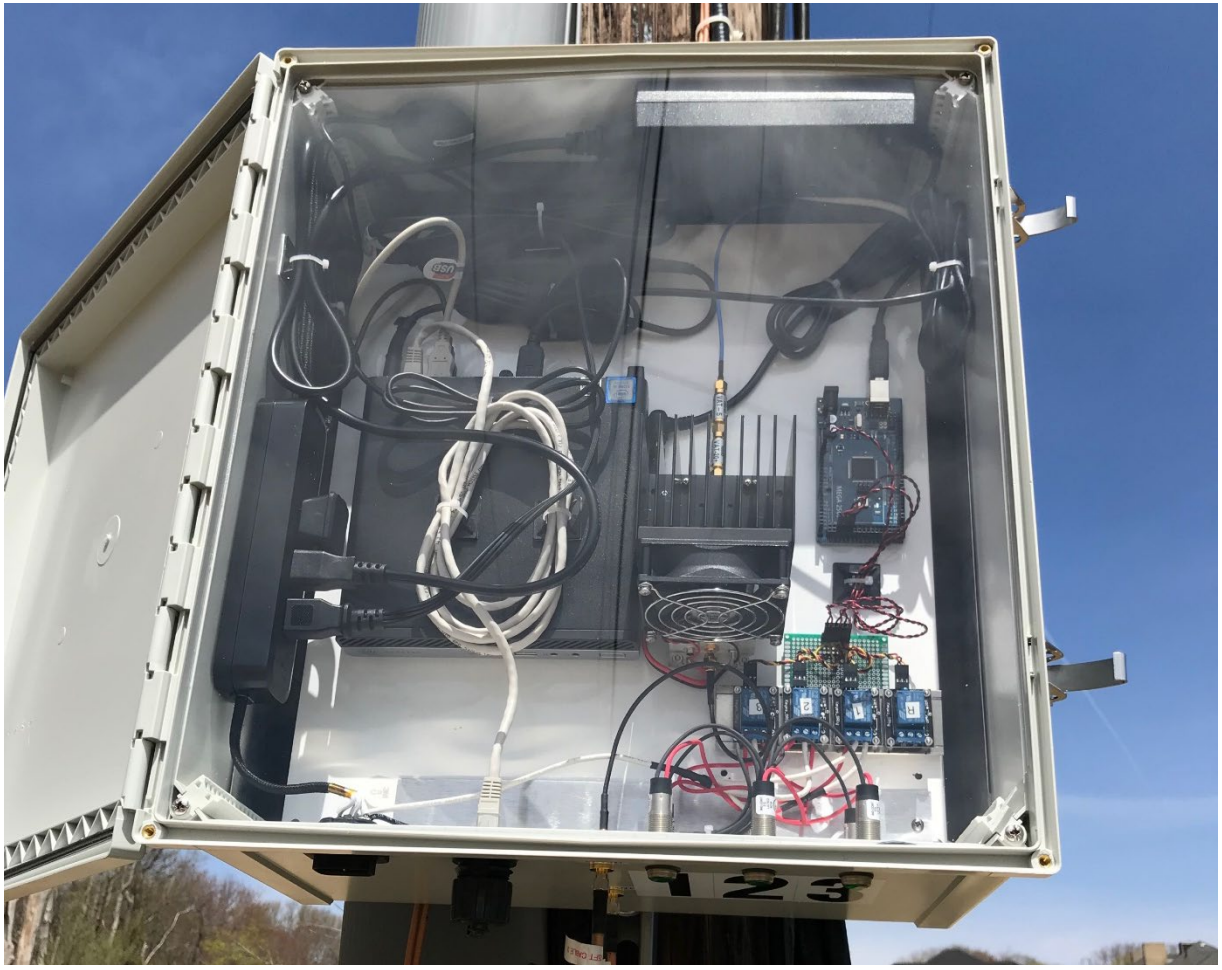
Field trial - aggregator mounted on pole



Aggregator was installed on pole with Unistrut back frame using two lag bolts

Installation took ~ 10 min plus time to attach antenna cables

Advantageous LineSenS™ Features

- Simple & rugged – no radio in the line mounted unit
  - Lightweight – only 3 lbs, can be used even on small lines
  - Pole mounted radio can read multiple local line units
- Operates even at zero line current and zero voltage
  - Enhances line worker safety – detects stray voltage/current on nominally isolated lines
- Synchronous data accumulation
  - Potential for a low-cost synchrophasor–like system
- Low cost ~ $3,000 per point monitored
  - Cost effective enough for widespread distribution grid monitoring
  - Widespread adoption could drive prices lower

New PoleSenS™ system

Monitoring of power distribution grid poles

PoleSenS™ detects:

- Pole tilt & changes in tilt
- Impacts
- Vibration
- Line break
- Changes in pole loading (optional)
- Fire detection near pole (optional)

Data backhaul via cellular (LTE) or handoff to mesh radio networks for SCADA system integration

Acknowledgements:

This work was supported by

U.S. Department of Energy SunShot Initiative

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Southern California Edison

The National Rural Electrical Cooperative Association

+ other industrial customers who prefer to remain anonymous

Questions, comments, collaboration, business development, or investment interest?

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Thank you