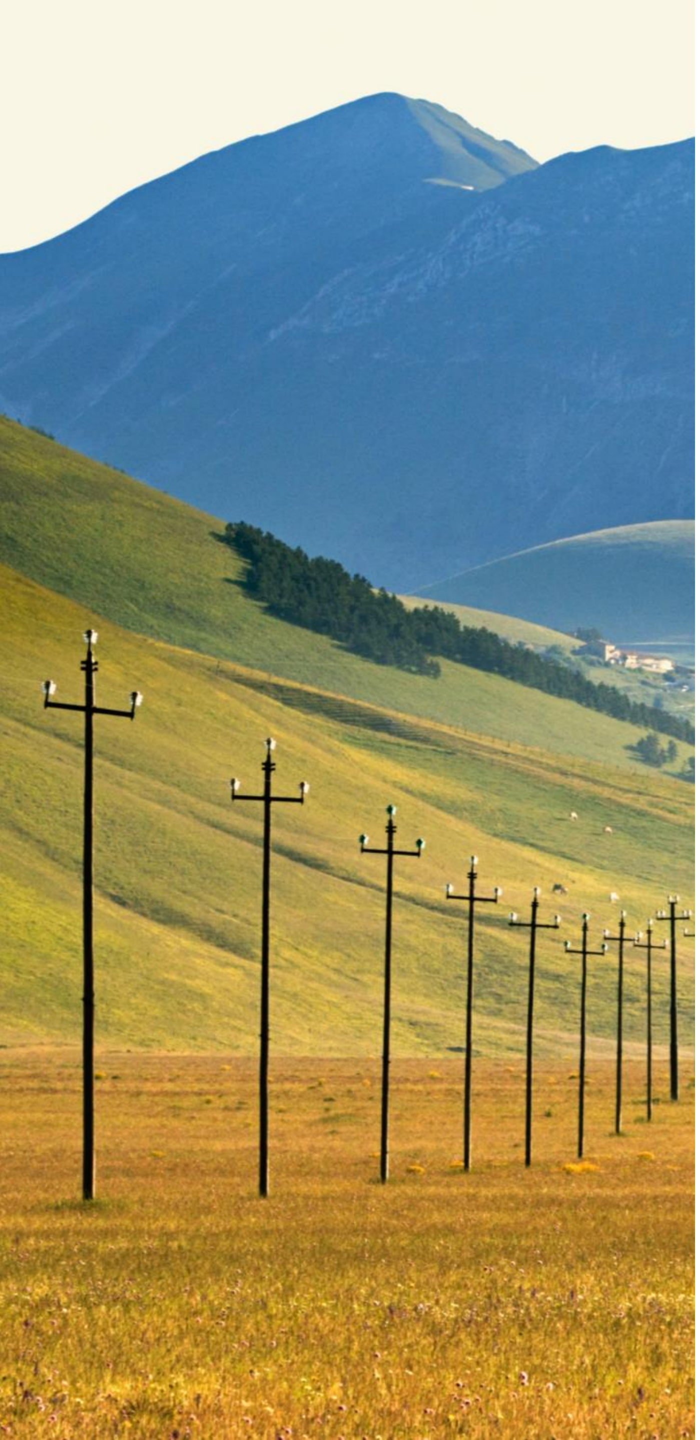

Solving Complex Feeder Protection Challenges and Reducing Wildfire Risks With Remote Measurements

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Distribution feeders become more complex

- Complex topology, multiple sections and branches
- Looped circuits, reclosers, and bidirectional short-circuit current flow
- Increasing load (EVs, heating)
- Distributed energy resources (DERs)
- Microgrid protection issues, islanded operation concerns

Powerline-caused wildfires become concerns

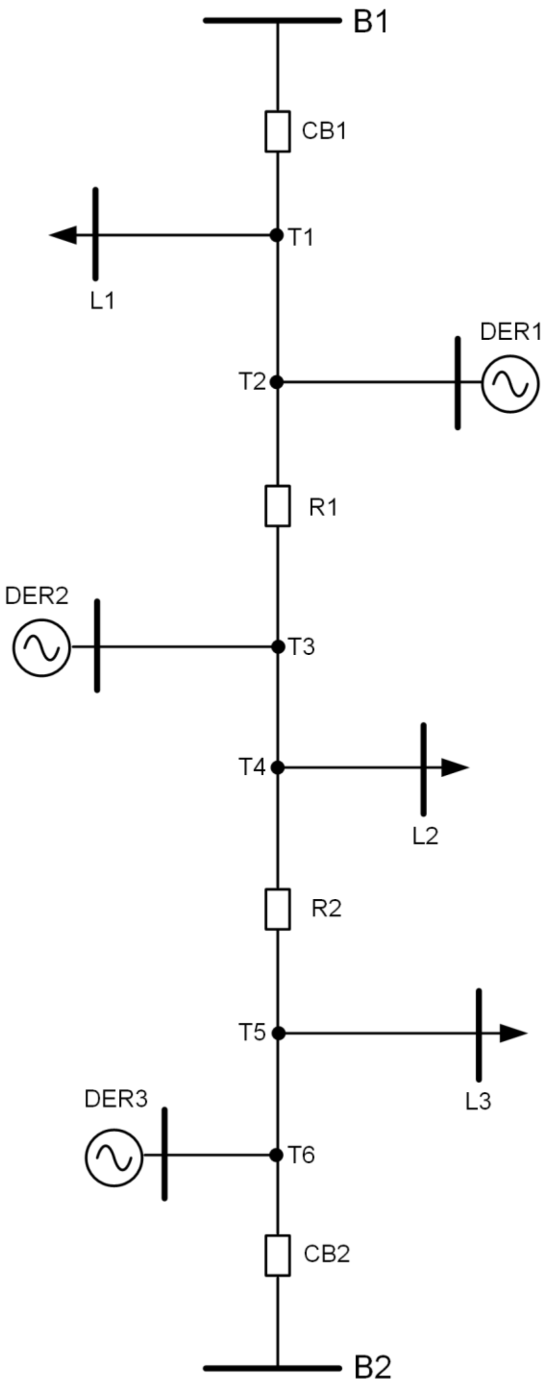
- Long fault clearing time and high energy released at the fault point
- Tree contacts last for a long time before high current follows
- “HiZ” and downed-conductor protection methods are too slow
- Low protection sensitivity for
  - High-impedance faults
  - Downed conductors

Powerline-caused wildfires
Mitigation is expensive

- Rigorous right-of-way vegetation management (mineral soil, gravel)
- Undergrounding overhead feeders
- Insulated overhead conductors
- Converting distribution networks to compensated ungrounded networks
- Experimental protection technologies




TOC protection becomes inadequate



- Historically, TOC feeder protection was
  - Technically adequate
  - Economically cost-efficient
- Today's feeders resemble scaled-down portions of a transmission system
- The industry desperately tries to "make the TOC protection work"
- We do have transmission-grade methods to protect complex feeders

Transmission-grade feeder protection
Obstacles

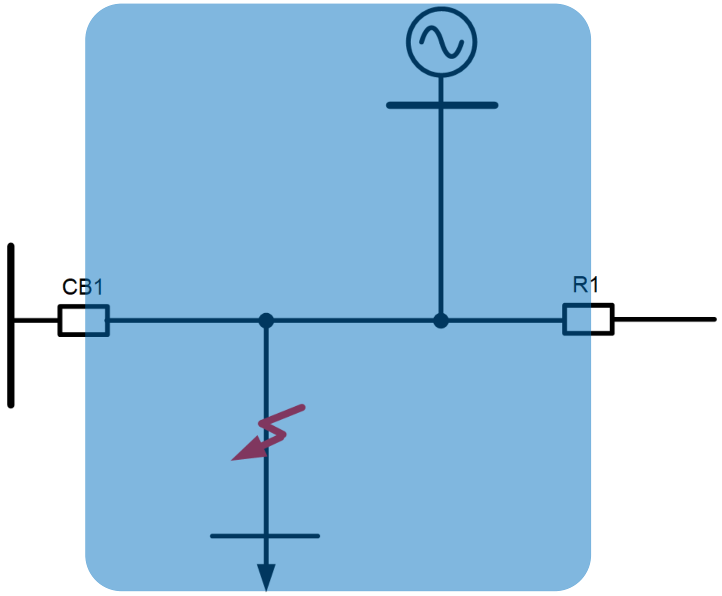
- A “microsubstation on a pole”
  - Devices to measure and communicate
  - Low-latency dependable communications
  - Control power to run the devices
  - Housing to host the equipment
  - Crew access for maintenance
  - Physical and cybersecurity
- A solution exists but is dismissed because of cost and complexity

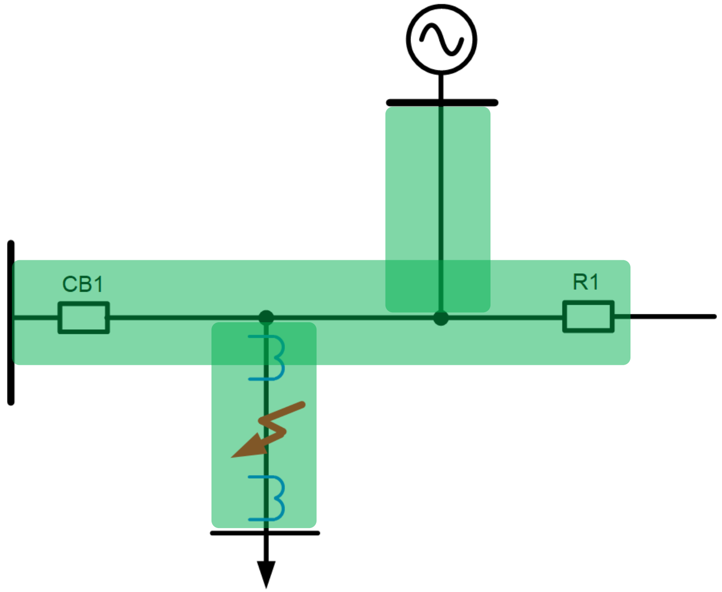
Powerline-caused wildfire mitigation

- Feeder maintenance
  - Managing vegetation to high standards
  - Installing spacers to eliminate midspan phase faults
- Fault energy reduction
  - Tripping instantaneously for all fault locations
  - Tripping before a downed conductor hits the ground
  - Tripping instantaneously for tree-contact faults
- Multizone feeder differential protection can deliver the required protection speed and sensitivity

Multizone feeder differential protection

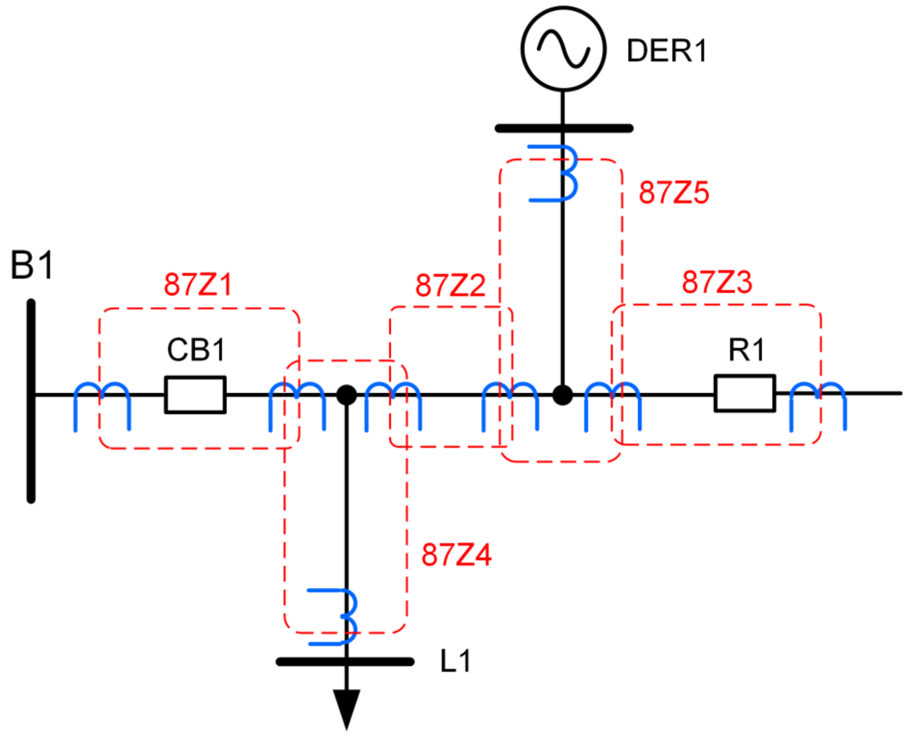
- Protection zones in general
  - Protection tripping zone defined by current interrupting devices
  - Fault detection zone defined by current measurement points
  - Ideally, the two zones overlap to maximize return on investment
- Feeder applications
  - Large protection tripping zones (necessity)
  - Small fault detection zones (objective)





Currents measured throughout the feeder

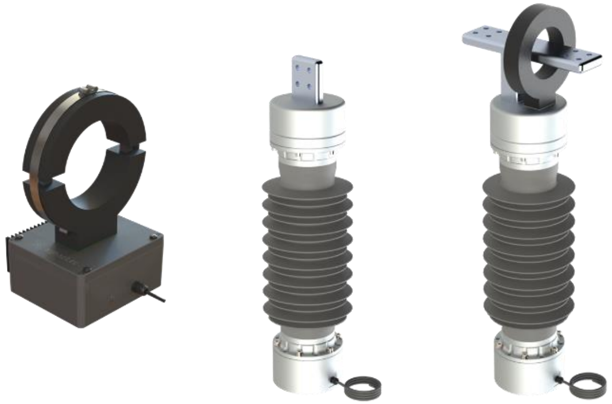
- Dramatically improve primary protection
  - Multizone differential protection
  - Sensitivity and speed for tree-contact faults
  - Speed for midspan phase faults
  - Downed-conductor detection
  - Dependable operation despite DERs
- Improve feeder, load, and DER backup protection
- Allow impedance-based fault locating
- Improve selectivity of autoreclosing
- Simplify settings
- Enable microgrid applications



Enabling technologies

Distributed Electrical Sensing (DES)

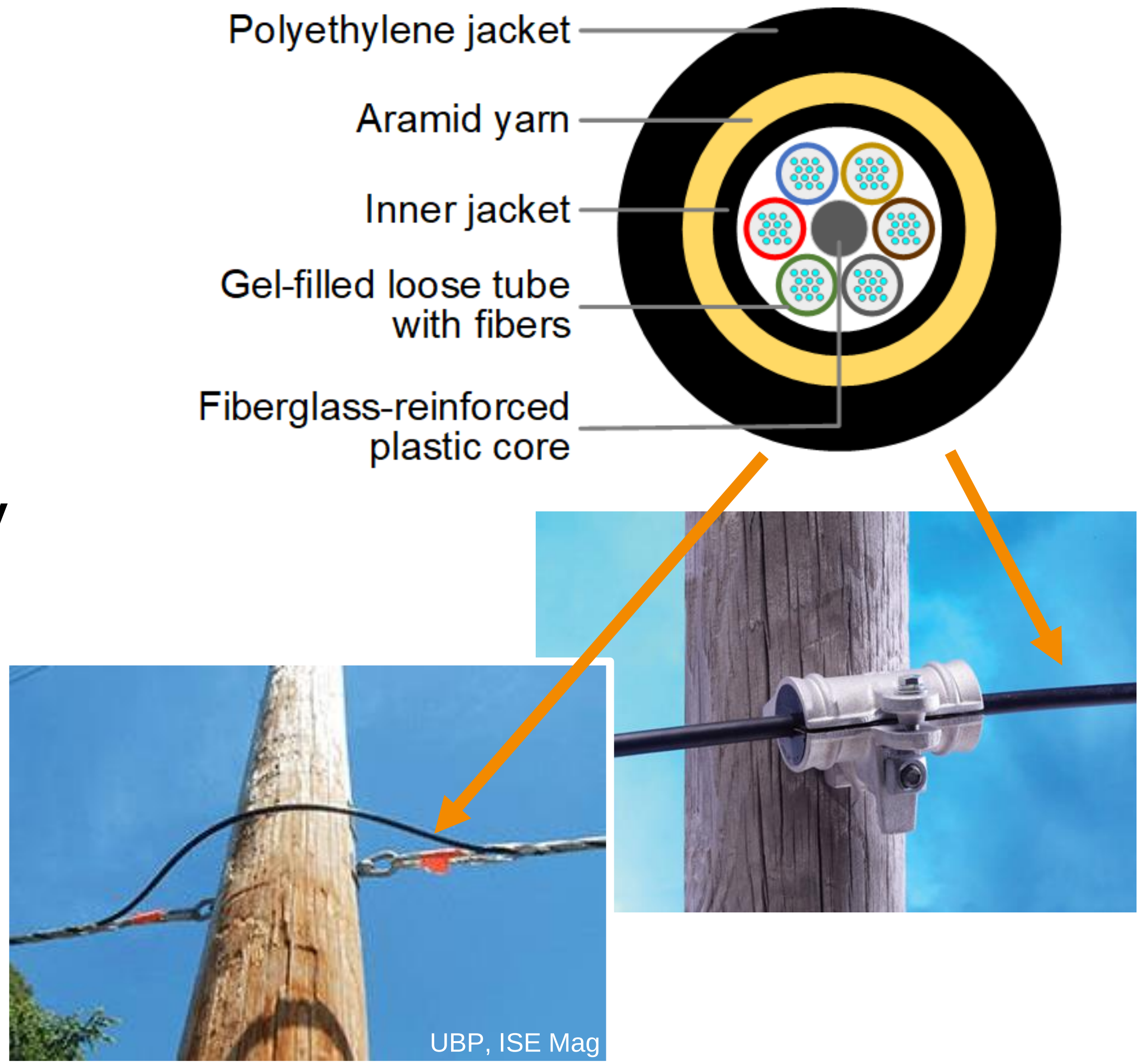
▪ Remote	CTs/VTs interrogated via fiber
▪ Passive	No active electronics or control power outside the fence
▪ Weatherproof	No housing required
▪ Distributed	Many CTs/VTs share the same fiber
▪ Coherent	No need for time synchronization
▪ Concentrated	All current and voltage signals available in the substation



Enabling technologies

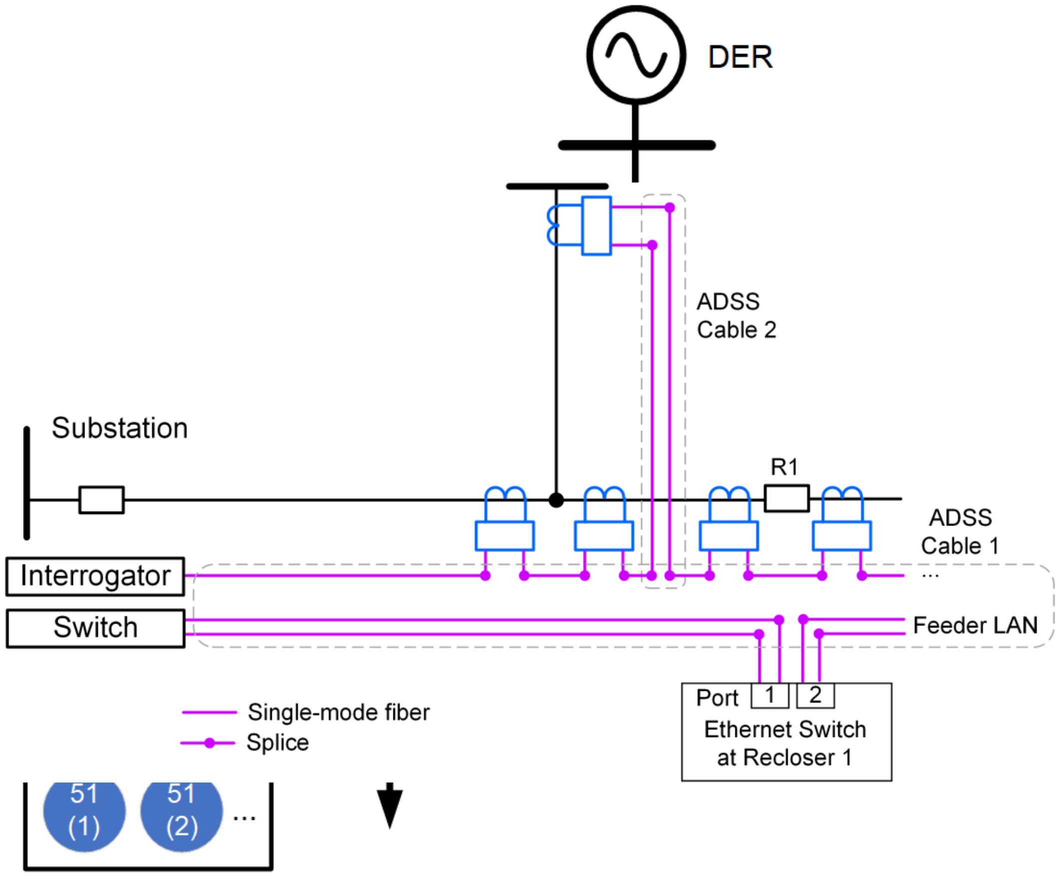
All-dielectric self-supporting fiber cables

- Relatively inexpensive
- Easy to install
- Some utilities already use ADSS on lower-voltage circuits
- Used in third-party networks on utility poles
- Allows Ethernet network to reach reclosers, DERs, and remote substations



Simplified system architecture

- ADSS fiber daisy-chains CTs
- Interrogator located in the substation provides the measurements
- Relays provide protection and other functions
- Tripping of reclosers and remote breaker via ADSS-based Ethernet feeder LAN



Distributed Electrical Sensing

Multiplexed passive sensing of current or voltage

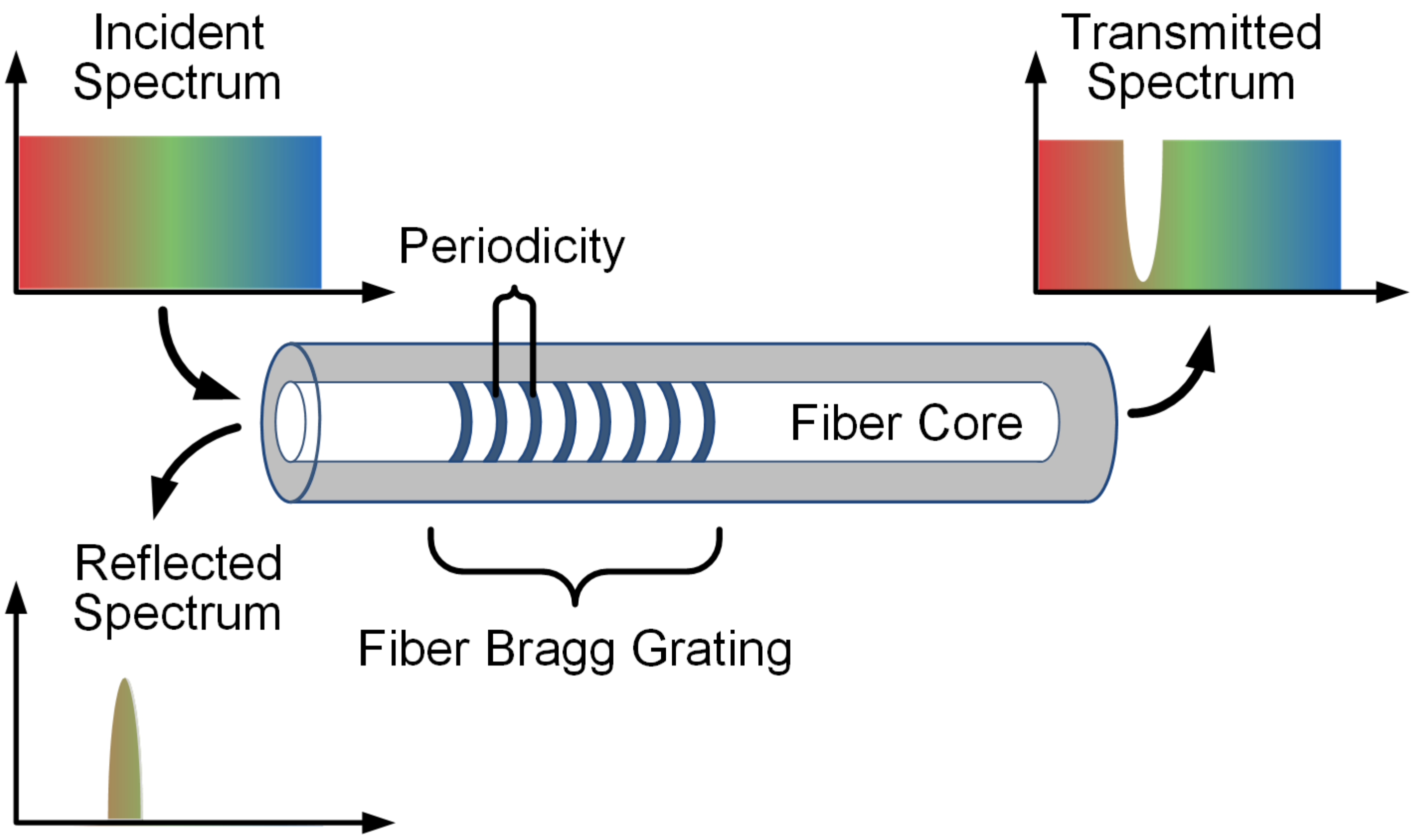
- Passive sensing allows remote measurements outside the substation fence
  - Use conventional CTs
  - Up to 30 single-phase measurements per fiber, up to 60 km (37 mi)
  - Measurements are inherently synchronized – no time source needed
  - No electronics or control power required
- Electronics and digitization of measurements are kept within substation
  - No cyber assets outside the substation fence
  - All sensors sampled synchronously, centrally

Passive Converter and CT

ADSS

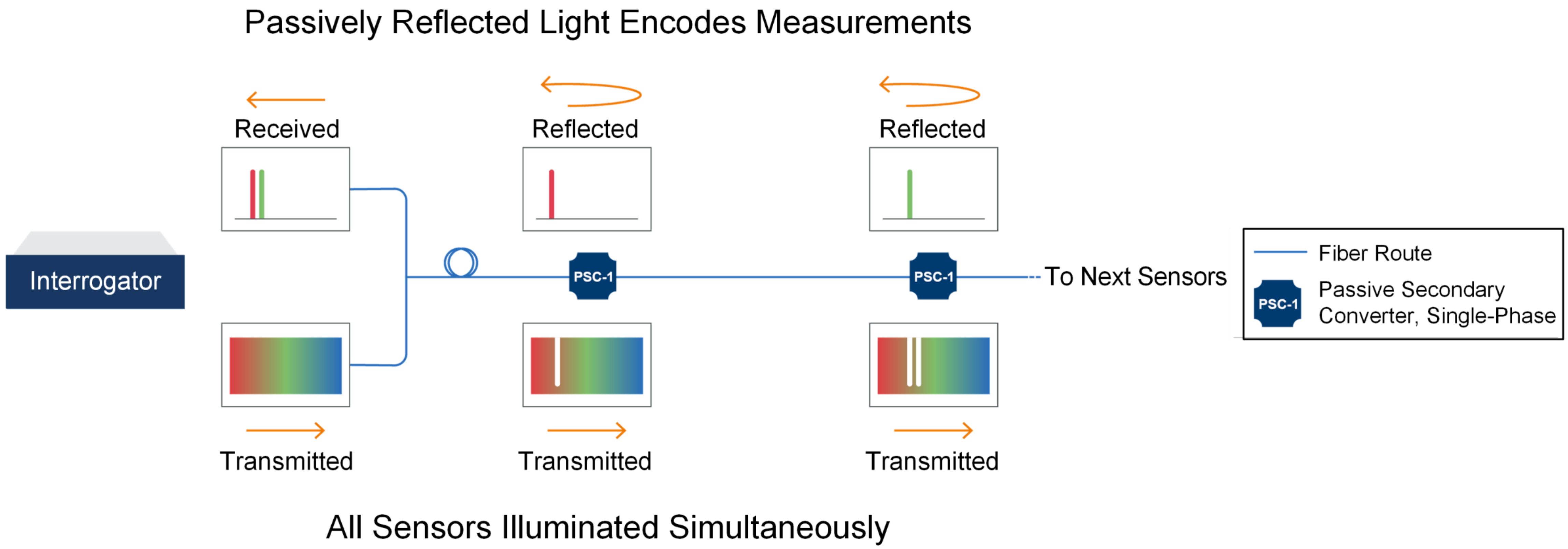
Fiber Bragg grating principle and application

- A source shines a wide-spectrum light
- Reflected light encodes periodicity (notch spacing)
- Measured quantity affects periodicity (stretching or contracting)
- Reflected light encodes measured quantity



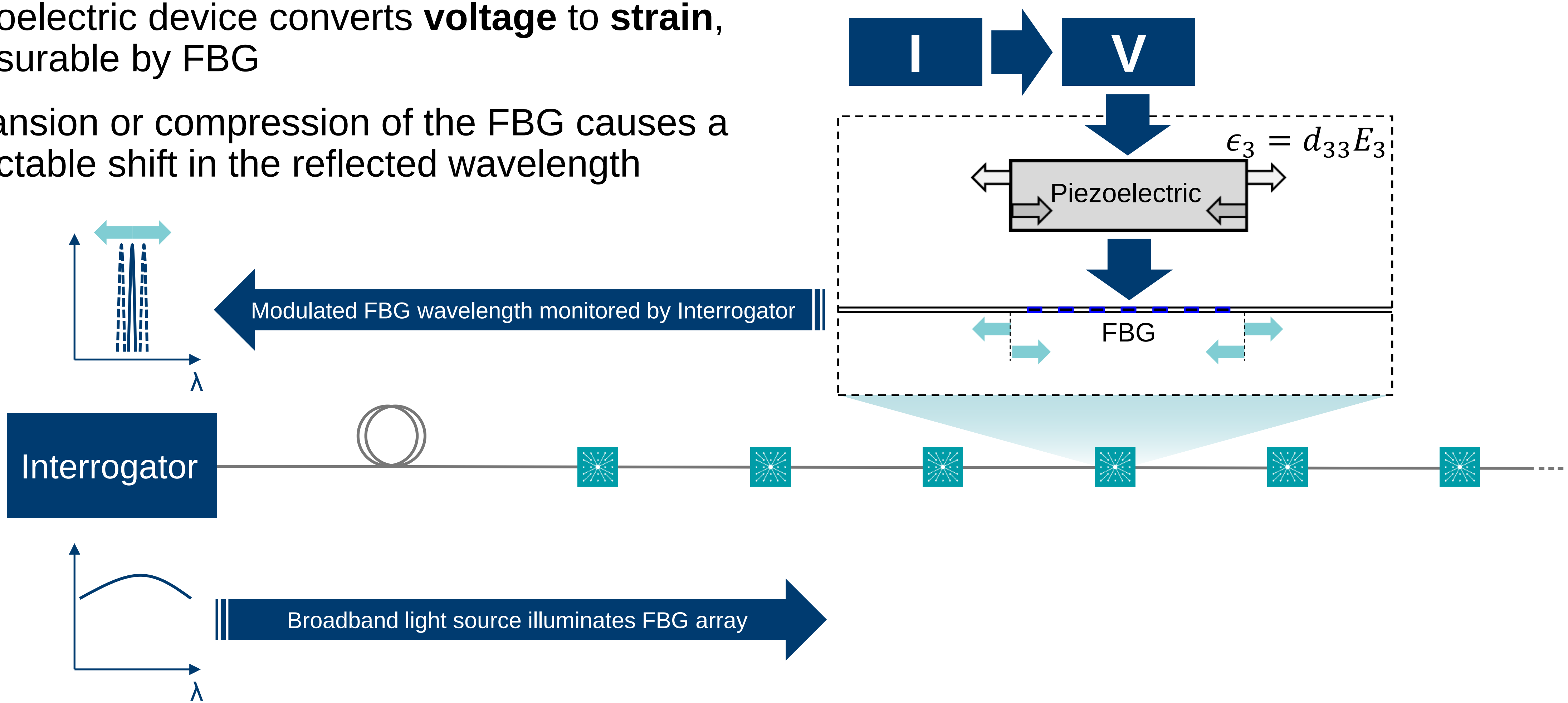
Optical measurement and multiplexing

- Wavelength also permits serial multiplexing – each sensor is placed at a unique nominal wavelength
- Sensors are interrogated from a suitable central measurement point



Electrical measurement technique

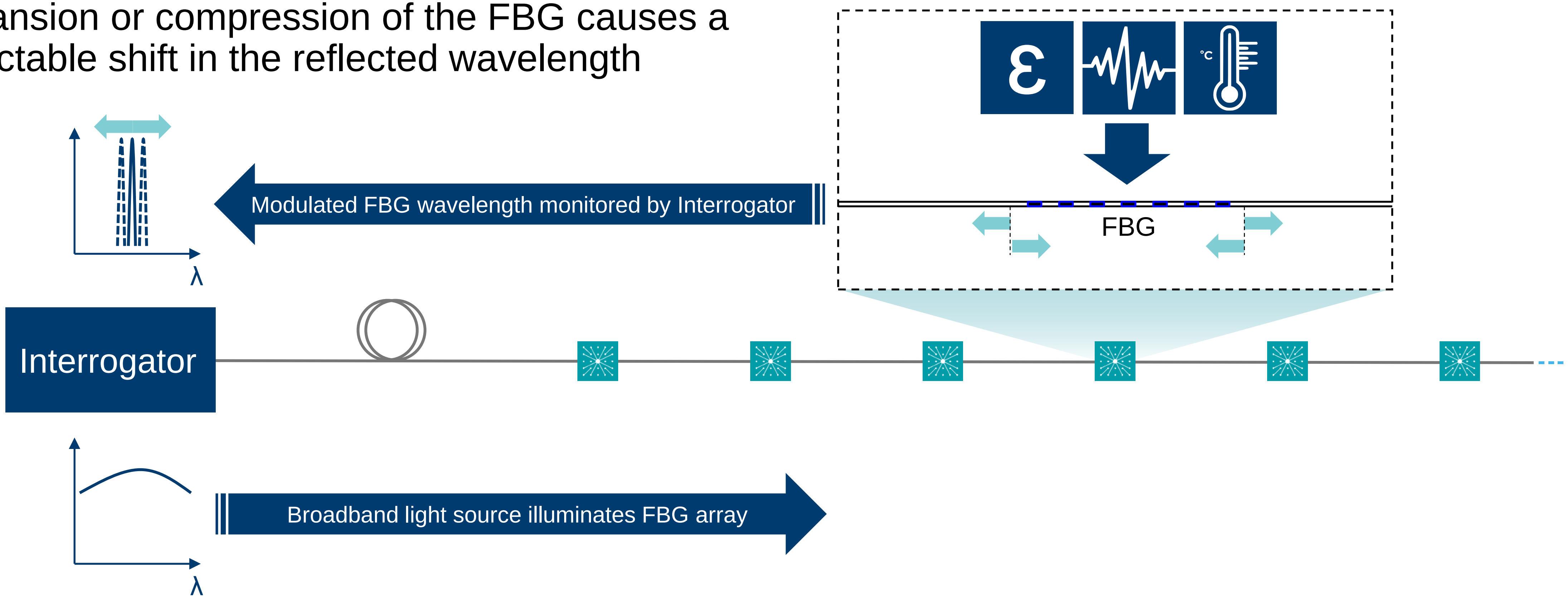
- CT and precision resistor are used to convert primary current to voltage
- Piezoelectric device converts **voltage** to **strain**, measurable by FBG
- Expansion or compression of the FBG causes a detectable shift in the reflected wavelength



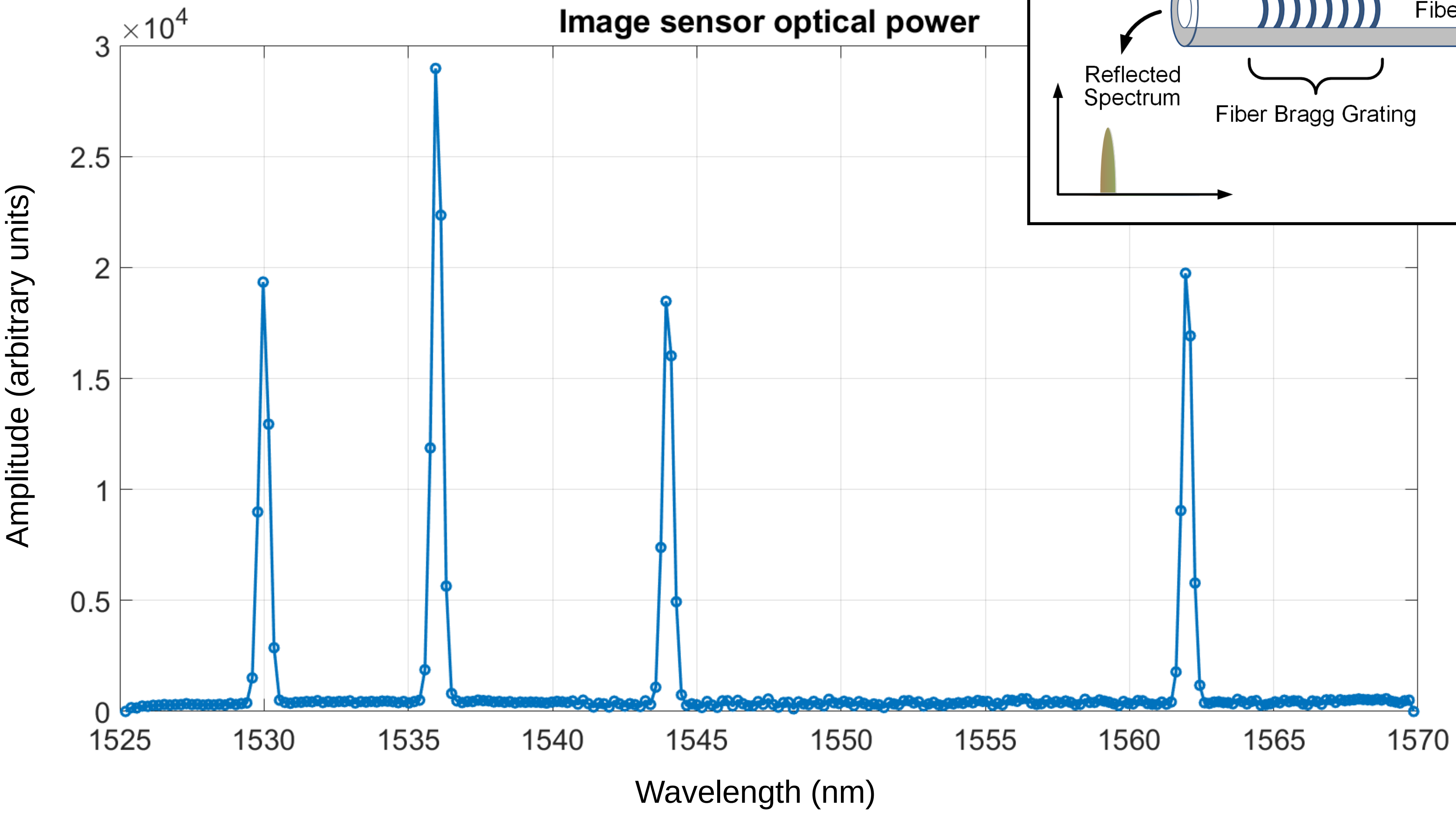
And optional mechanical measurements

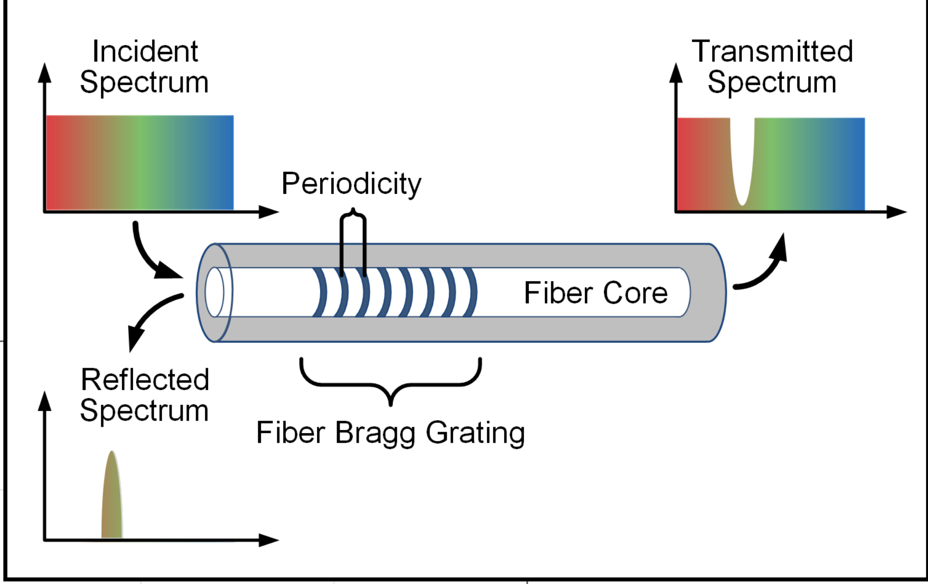
- CT and precision resistor are used to convert primary current to voltage
- Piezoelectric device converts **voltage** to **strain**, measurable by FBG
- Expansion or compression of the FBG causes a detectable shift in the reflected wavelength

OR remove piezo to directly measure **strain**, **vibration**, **temperature**



Measurement processing



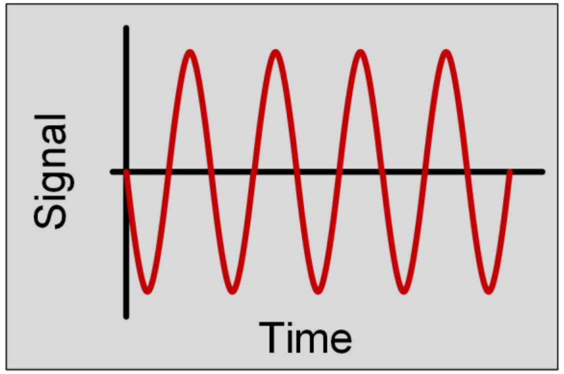


Measurement processing

$$V_2 = xV_1$$

$$\lambda(nm) = A_0 + A_1 pix + A_2 pix^2 \ldots + A_5 pix^5$$

Peak pixel number → Peak wavelength → Electrical measurand → Temperature-compensated electrical measurand

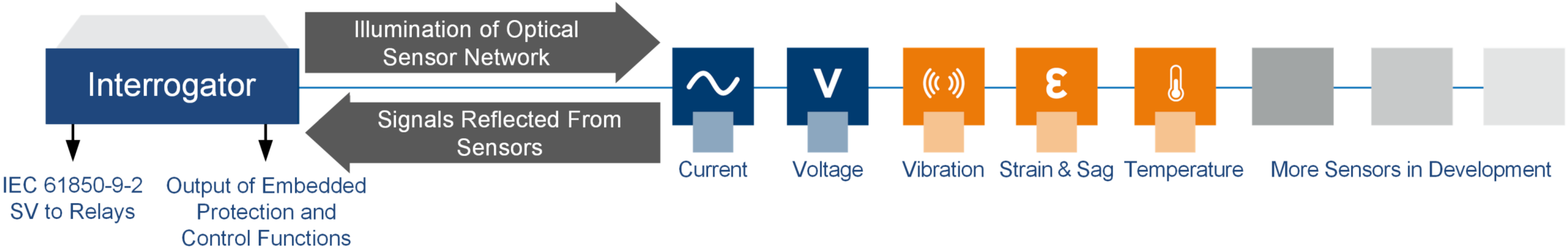


$$V_{inst} = B_0 + B_1 \lambda_{inst} \lambda_{pp} + B_2 \lambda_{inst} \lambda_{pp}^2 + B_3 \lambda_{inst}^2 \lambda_{pp} \ldots + B_{28} \lambda_{inst}^6 \lambda_{pp}^6$$

- Measurement chain (CT to SV) is 5P class and compliant with IEC 60044-8 / IEC 61869-10
- Synchronization and latency comply with IEC 61850-9-2 / IEC 61869-9

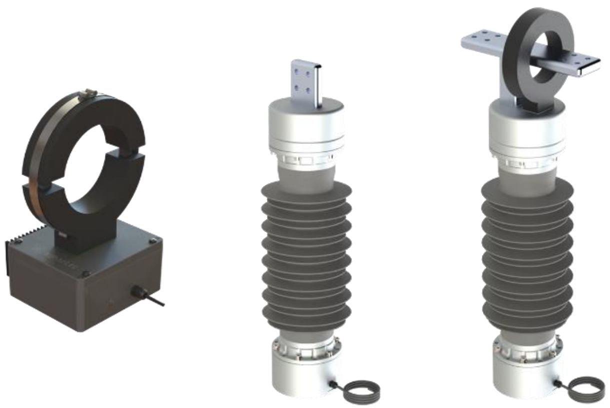
Centralized measurement platform

- Wavelength-based sensing enables simple multiplexing and environmental resilience
- Mechanical and electrical measurements are synchronized on one platform
- Measurement system installation is fast and safe because of minimal wiring and power

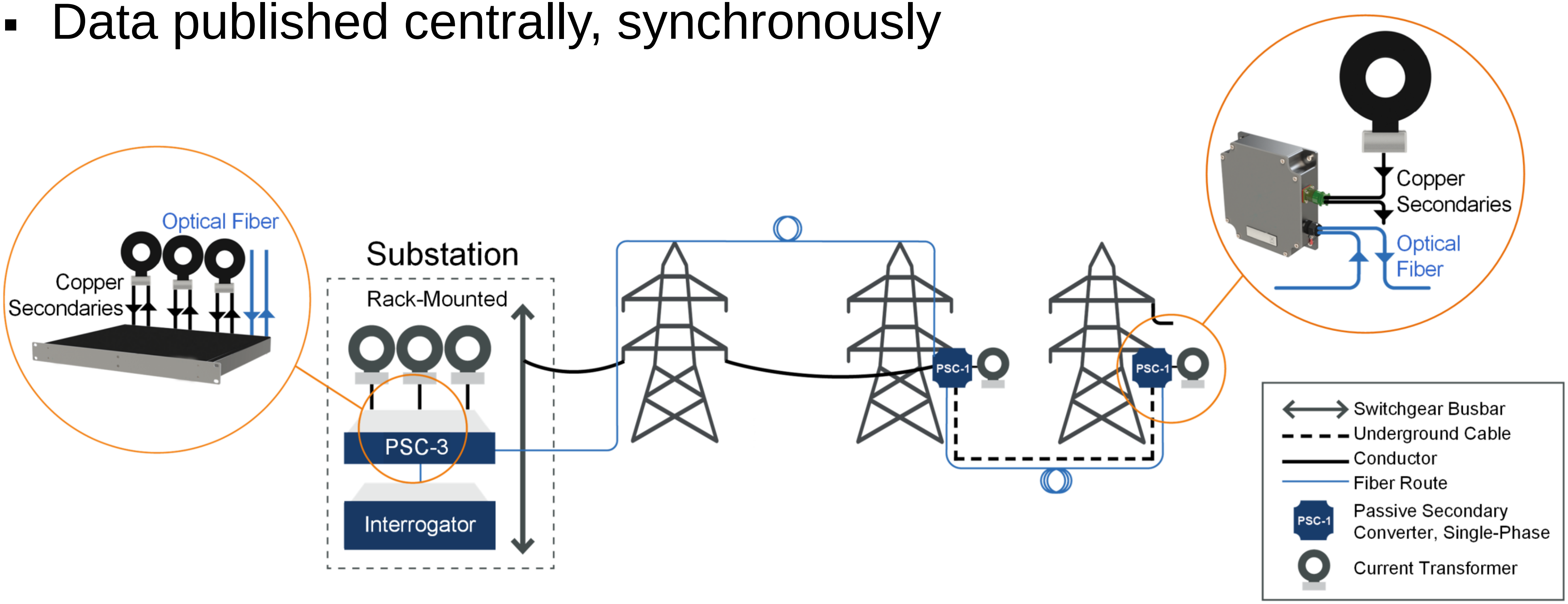


- Every sensor is sampled centrally at up to 288 s/c
- Produces synchronized waveforms from each measurement point
- Supports multiple functions from one data source

Enabled topology



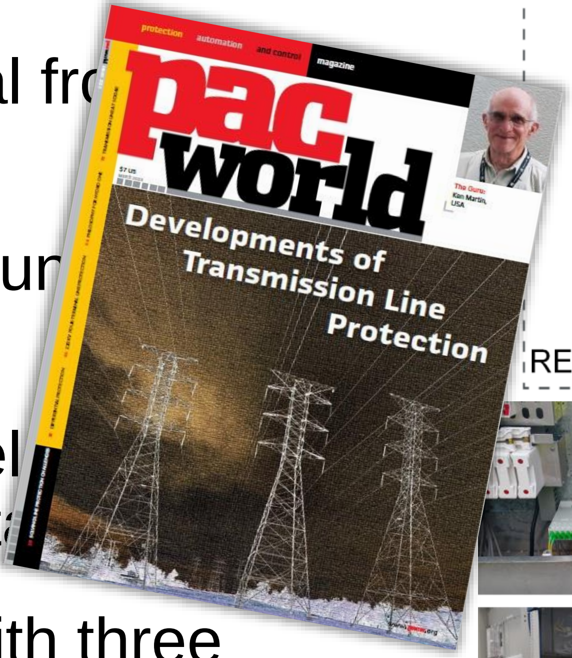
- Deploy conventional CTs at multiple remote locations
- Data published centrally, synchronously



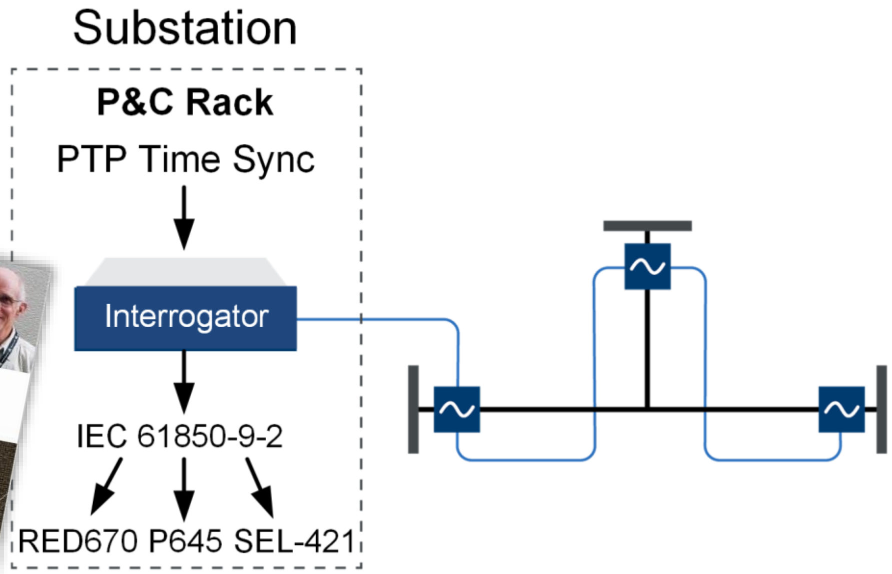
Deployment with SSE Transmission, UK

Facilitating new grid connections from renewables in remote locations

- Overcame limitations of distance protection
- Achieved multi-ended differential fr single end
- Enabled wide-area, fully digital, ur protection scheme
- Avoided major civil works and tel upgrades for older remote subst
- Proved IEC 61850 operability with three relay brands



https://www.pacw.org/



Benefits and Conclusions

Protection benefits

- **Scalable** – Differential protection for a single feeder section or many/all sections of a complex feeder
- **Ultra-sensitive** – Protection for tree-contact faults and downed conductors
- **Instantaneous** – Reduced fault energy, protection for galloping conductor faults
- **Dependable** – Breaker failure and recloser failure protection, faster backup protection, not affected by DERs
- **Future-ready** – Anti-islanding protection, microgrid monitoring, easier DER ride through

Passive current sensing

+

Cost-effective ADSS fiber

“See” beyond the substation fence

Radical reframing of how to protect distribution feeders

Transmission-grade protection for complex distribution feeders

Fast, sensitive, granular unit protection

Addresses needs of high-risk wildfire areas