Traveling Wave Relays for Distribution Feeder Protection with High Penetrations of Distributed Energy Resources

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Co-ops Energy Supply & Distributed Energy Resources

- Co-ops energy supply is changing (distribution system in general)
- More inverter-based distributed energy resources (DERs) like PV, battery energy storage system, and electric Vehicles
- Higher levels of DERs create issues with voltage and frequency regulation, control of DERs, and protection.
- Protection requires special attention because it can limit the penetration level.
- Overcurrent protection is affected by the presence of generation sources in the distribution system.

DER Impact on Overcurrent Protection

- Low fault current (1–2 p.u.) makes it difficult to detect a fault.
- Bidirectional power flow affects the directionality of the device.
- Affects the reclosing, fuse saving, and coordination schemes
- IEEE 1547-2018 fault ride-through requirements.

Future Grid Challenges

High-Pen PV/DER:

- Low fault current
- Reverse power flow
- Bottleneck for high penetrations of PV
- Intermittent nature of DER resources.

Resilience:

- High-impact, low-frequency events
- Damage prevention
- System recovery
- Survivability.

Phasor-based protection:

- One full cycle observation window (slow)
- Might need adaptive or multiple settings.

Speed:

- Distribution network of the future needs high-speed fault detection and isolation.

Future Grid Challenges

High-Pen PV/DER:

- Low fault current
- Reverse power flow
- Bottleneck for high penetrat
- Intermit DER re

Resilience:

- High-impact, low-frequency events
- Damage prevention
- System recovery

Use of traveling wave-based protection for distribution system

Phasor protection:

- One full cycle observation window (slow)
- Might need adaptive or multiple settings.

- Distribution network of the future needs high-speed fault detection and isolation.

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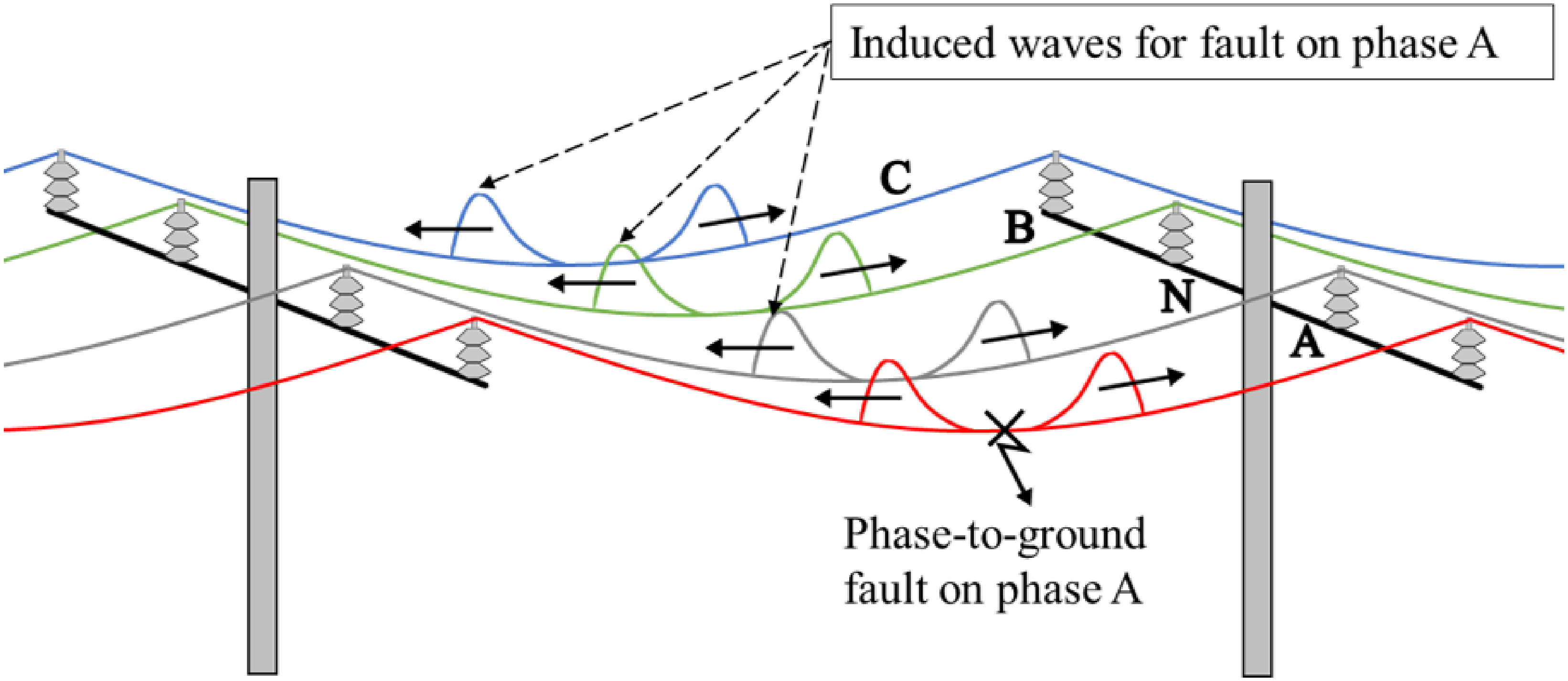
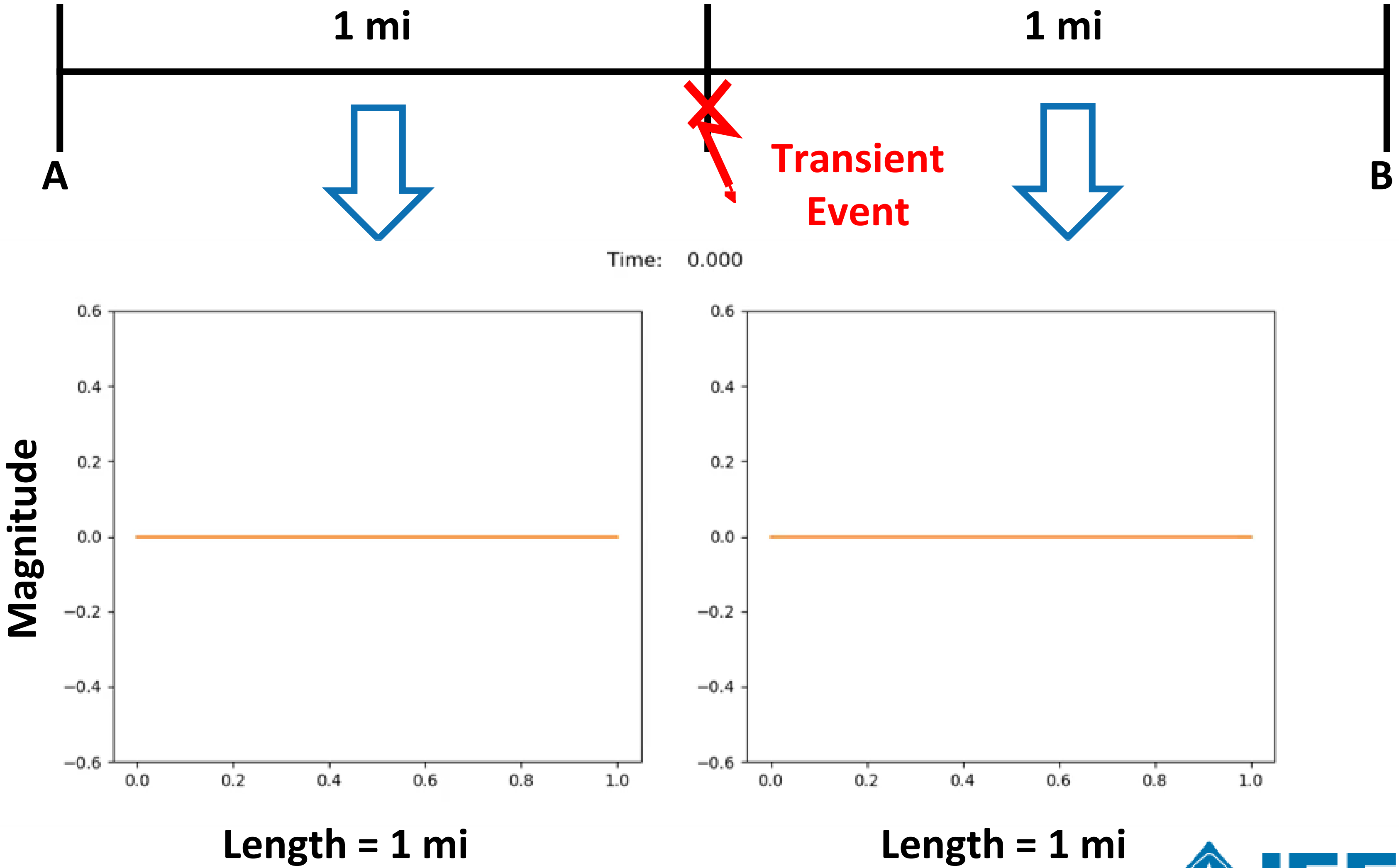
Traveling Waves in Power Systems

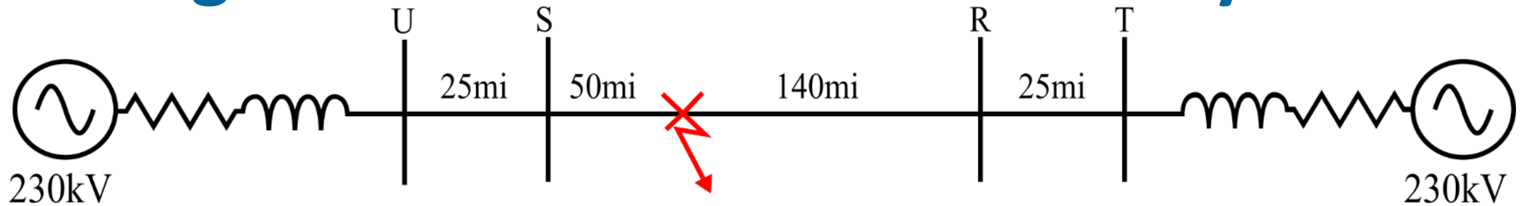


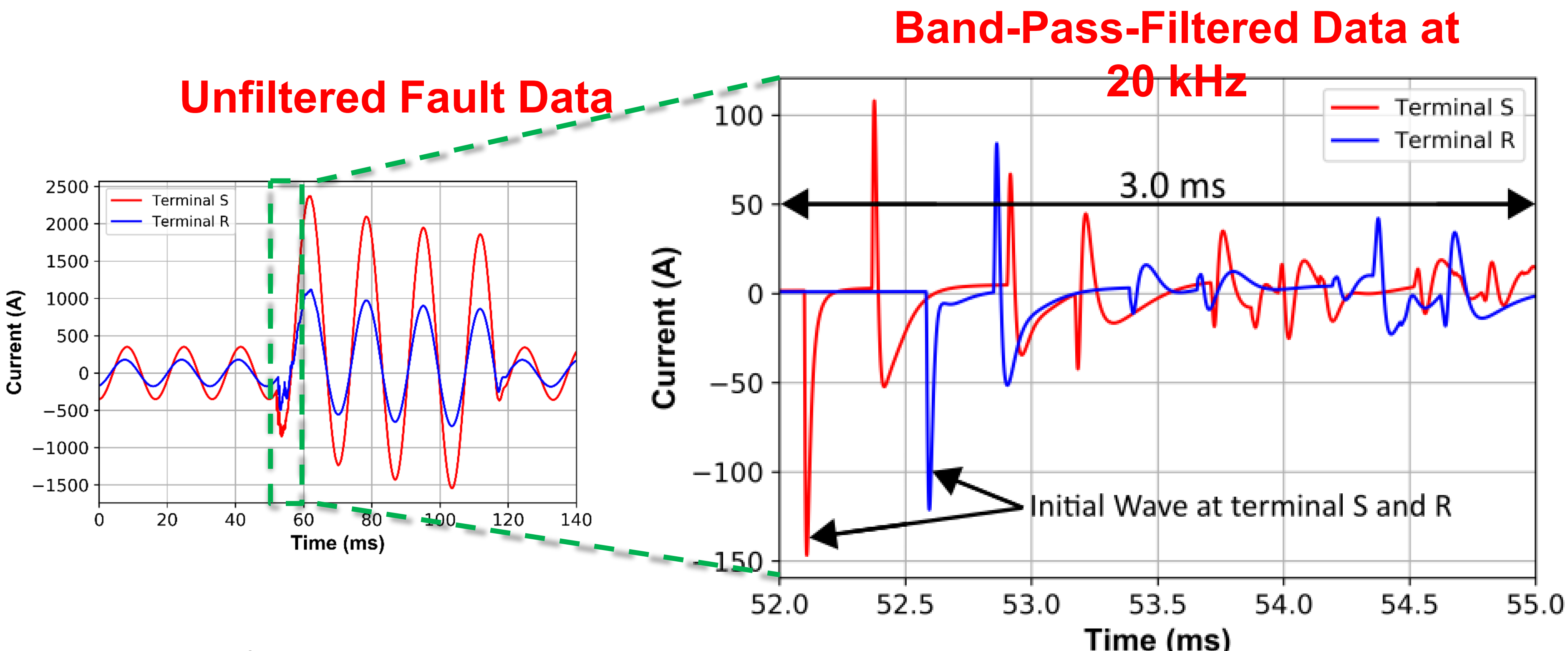
- Any disturbances in the circuit caused by fault, switching, or lightning creates a traveling wave transient.
- Traveling waves travel close to the speed of light (186,282 mi/s).
- They are used in insulation failure and surge protection design.

Traveling Waves in Power Systems



Traveling Waves in the Transmission System





- Traveling wave protection operates in 2 ms.
- Phasor protection operates in 1–1.5 cycles (16 ms–25 ms).

Traveling Waves in the Distribution System

Advantages:

- Independent of fault currents
- Not affected by CT saturation power swings, line compensation
- Application to single and two phases
- Faster fault detection.

Challenges:

- Frequent taps
- High attenuation
- Presence of transformers, capacitors
- Wide band requirements for CT and PT.

High-frequency signatures generated as a result of traveling waves are used to detect and locate a fault.

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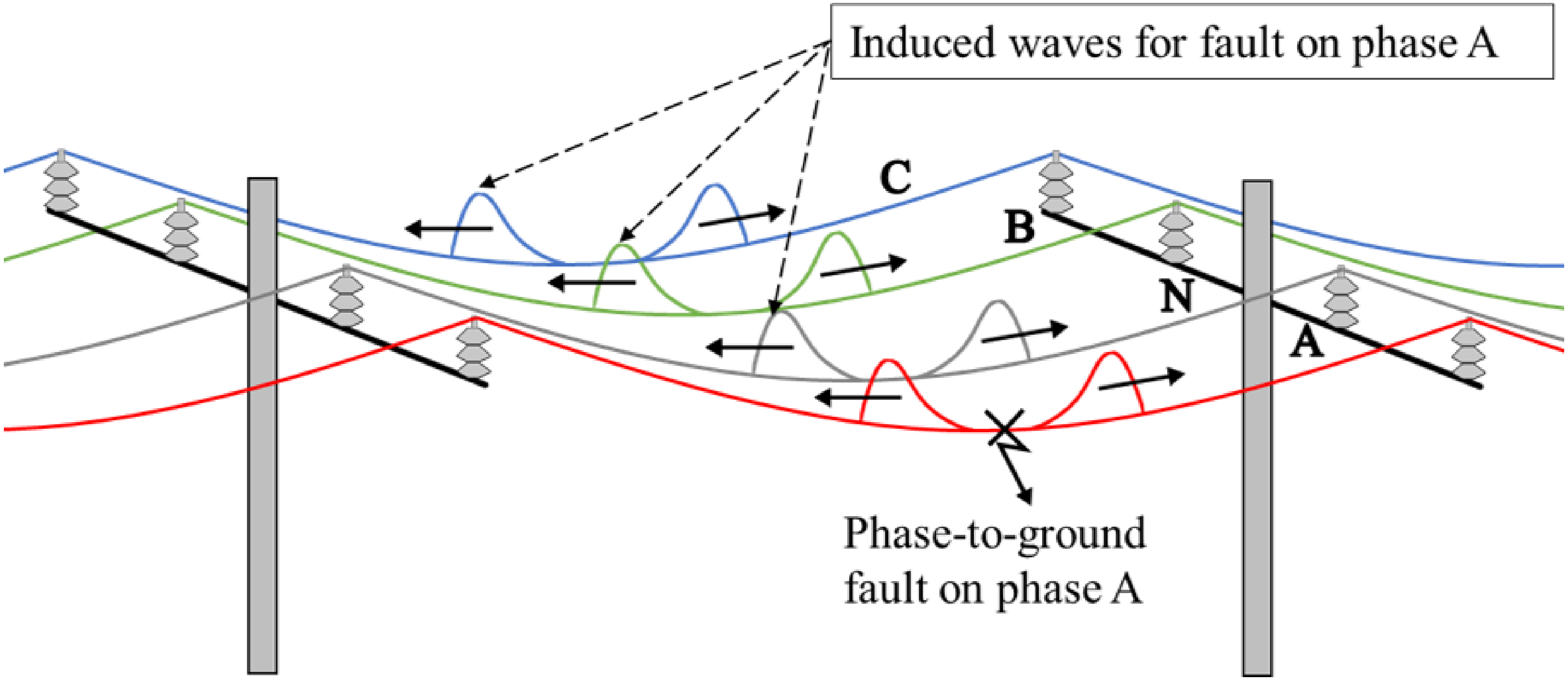
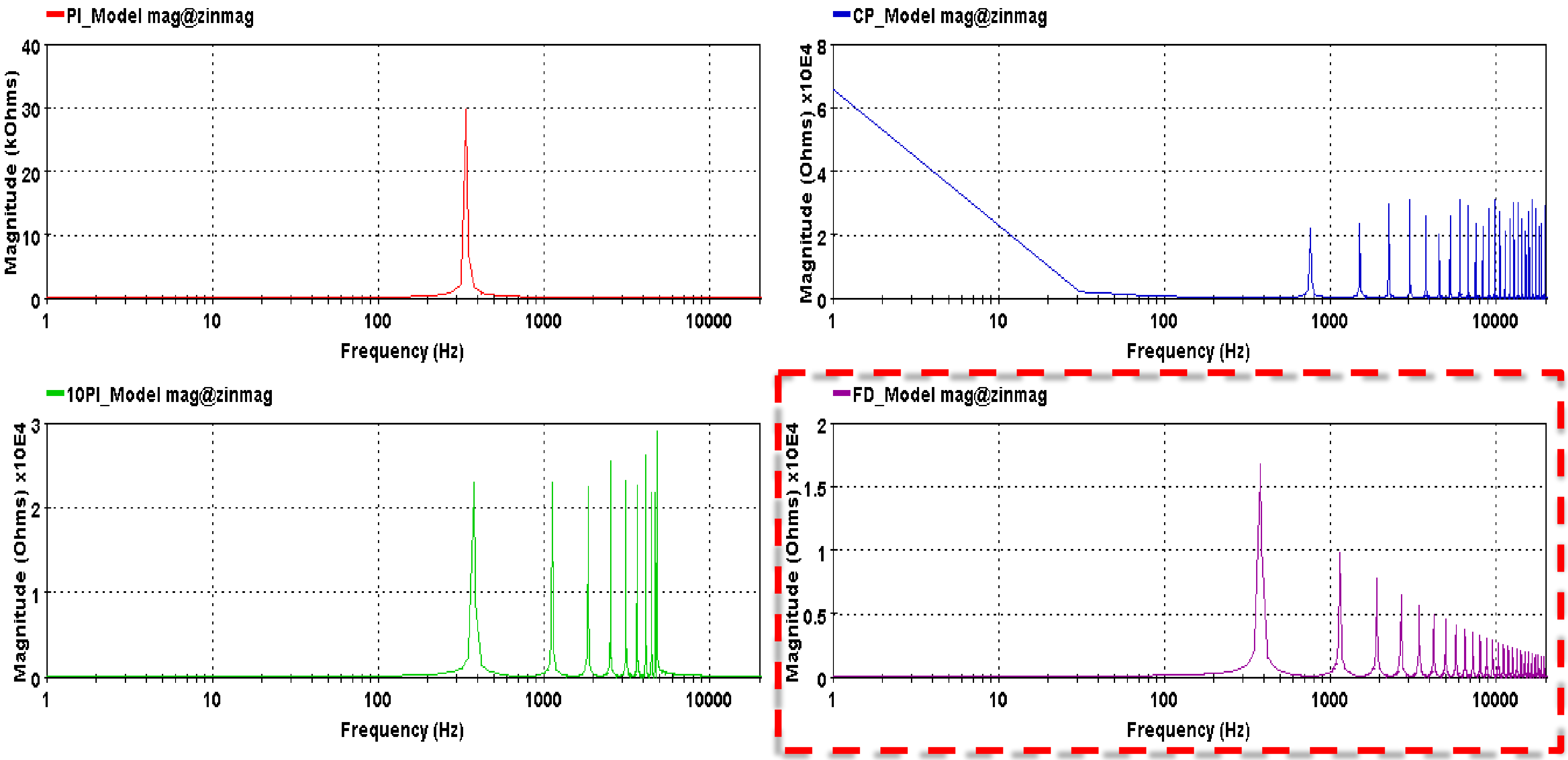
Traveling Waves Simulation



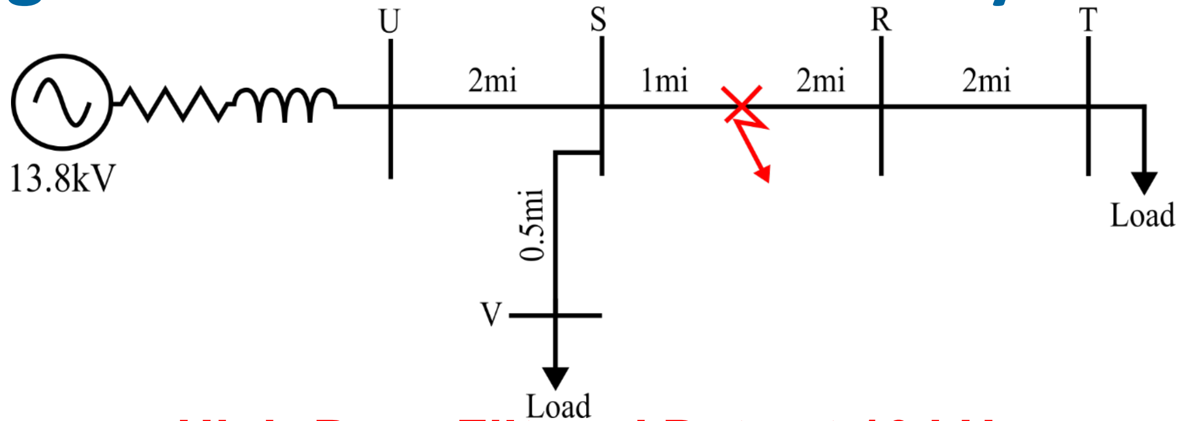
- Frequency-dependent system models are crucial for EMTP simulations.
- Transmission and distribution test cases are developed to understand the signature of the transients, and they are simulated in EMTP-RV.
- Ideal CT and PT characteristics are assumed.

Line Models for EMTP

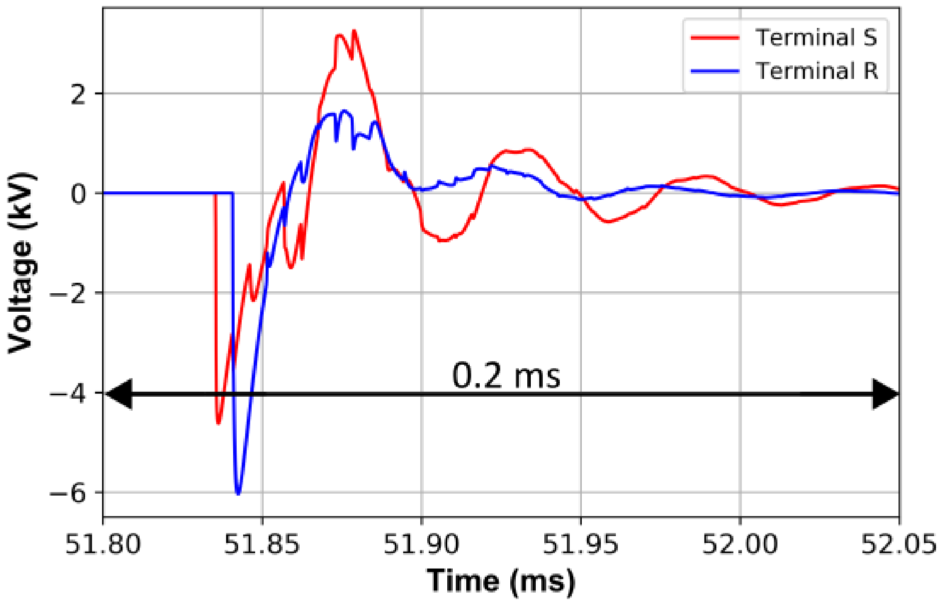


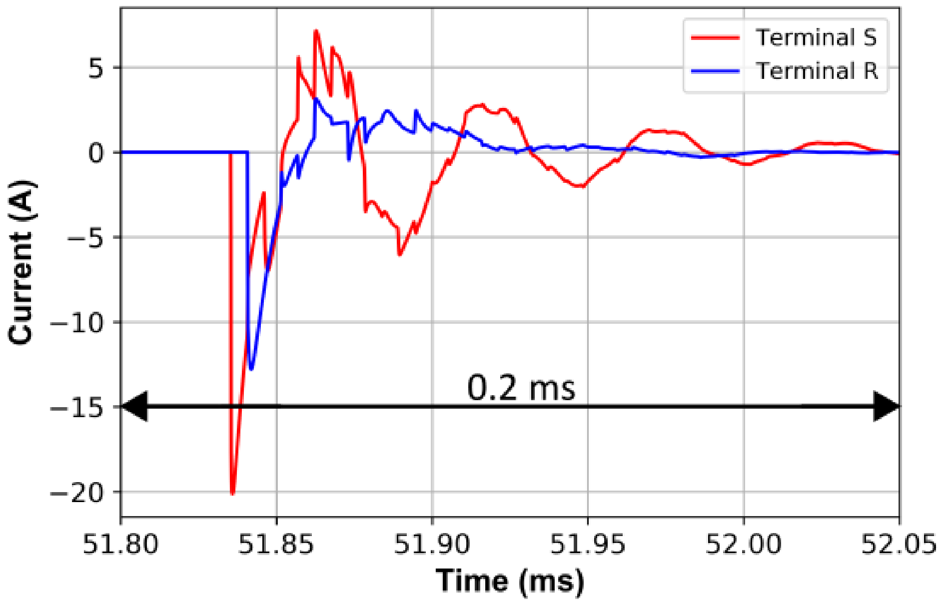
- A frequency-dependent models can be used to study high-frequency transients.

Traveling Waves in the Distribution System



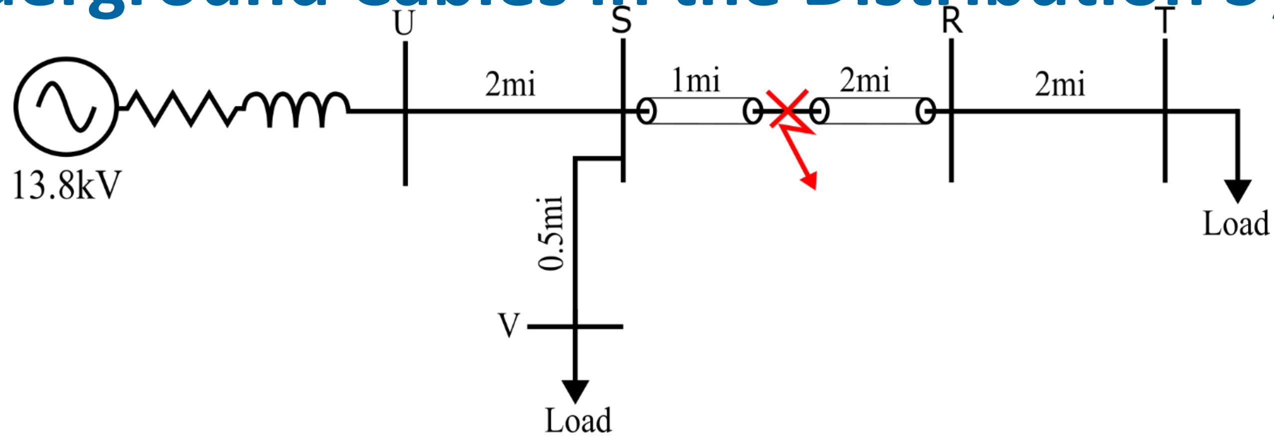
High-Pass-Filtered Data at 10 kHz



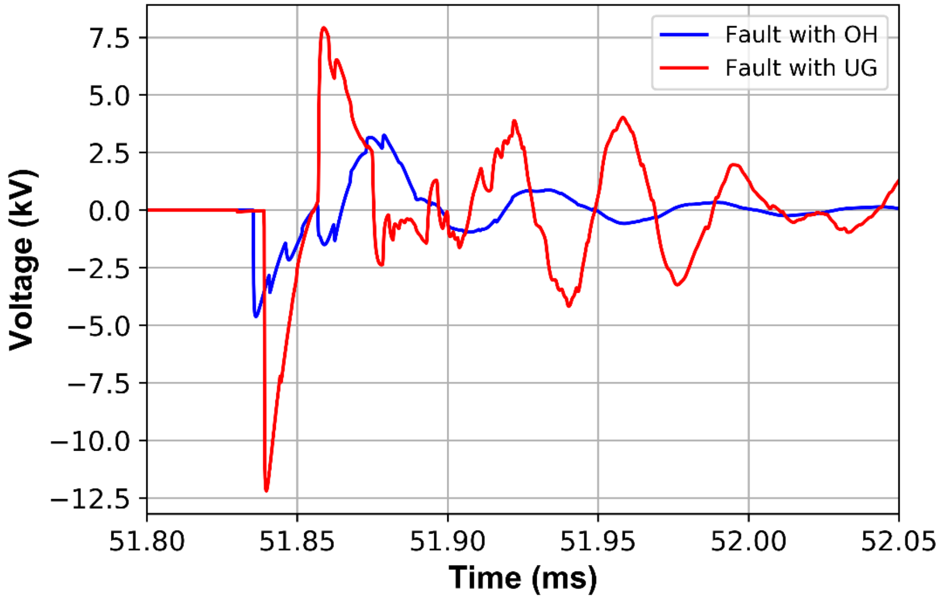


- Short lines, frequent taps, multiple reflections.

Underground Cables in the Distribution System

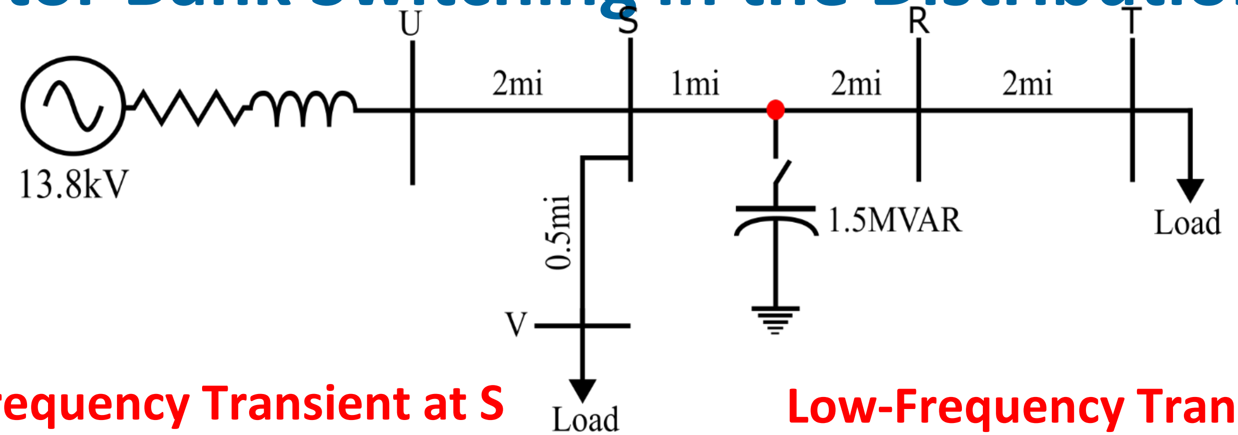


High-Frequency Transient at S

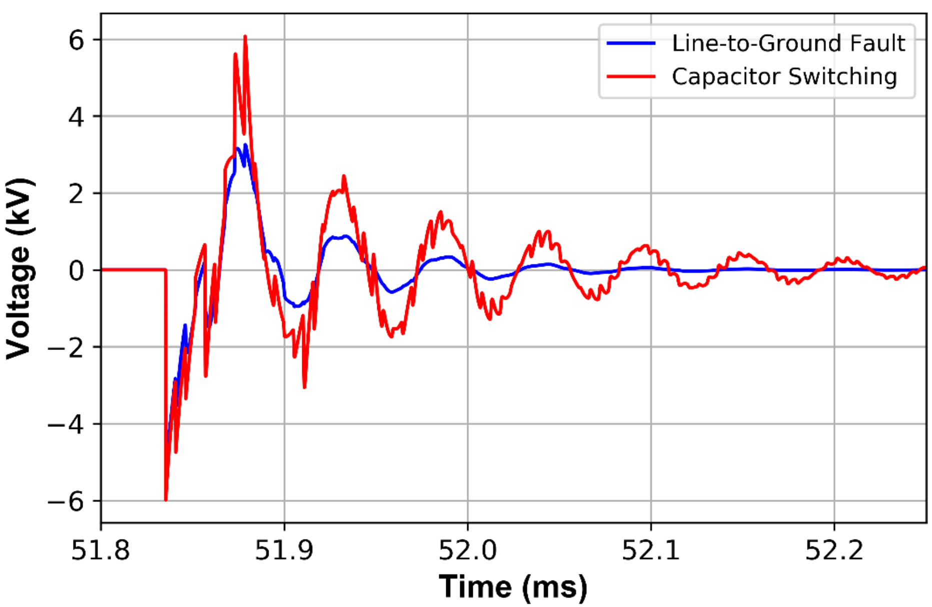


- Wave propagation velocity in underground cables is 50%–60% of overhead.
- Traveling waves move more slowly through the cables due to the permittivity of the medium.

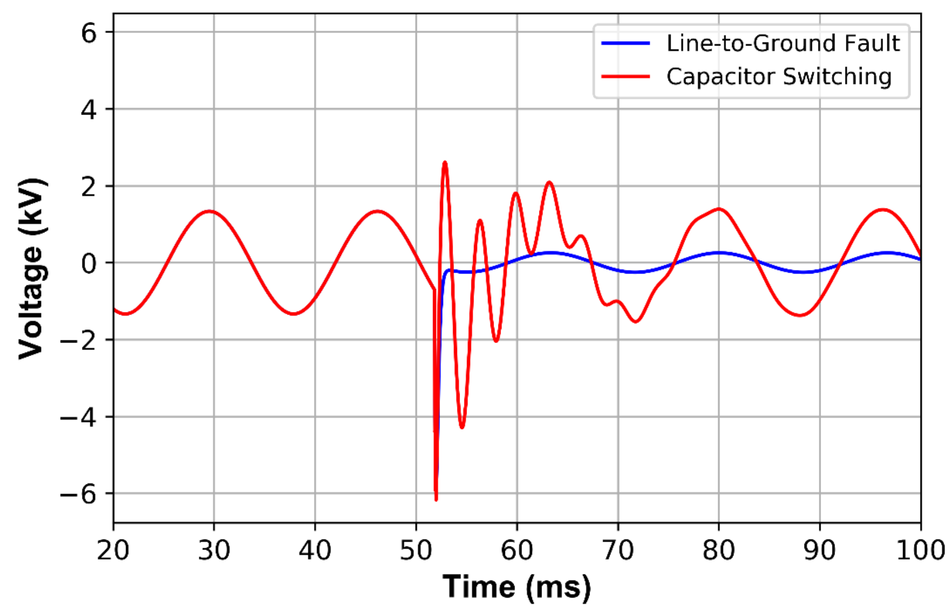
Capacitor Bank Switching in the Distribution System



High-Frequency Transient at S

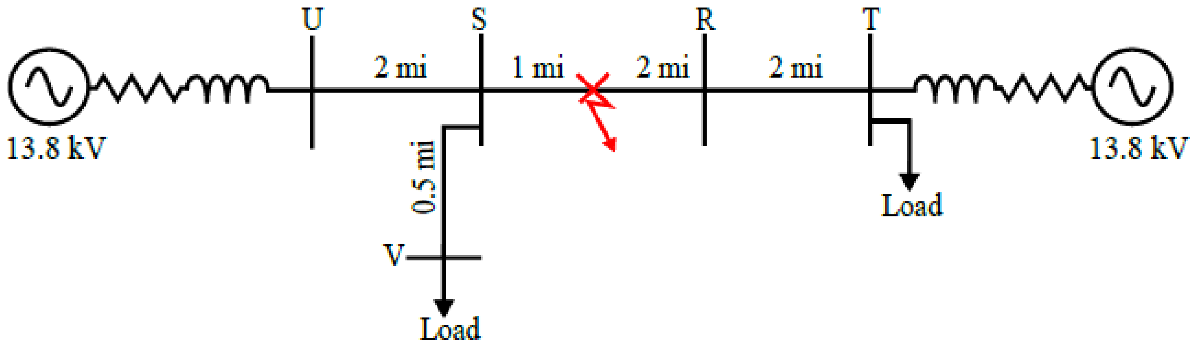


Low-Frequency Transient at S



- The presence of a low-frequency oscillatory transient differentiates the capacitor switching from the fault.

Multiple Sources in the Distribution System



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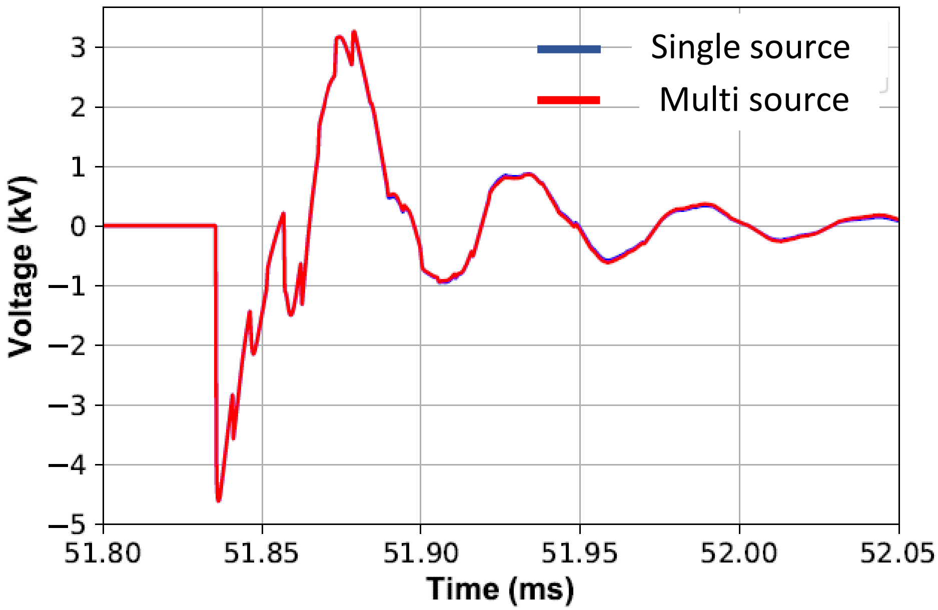
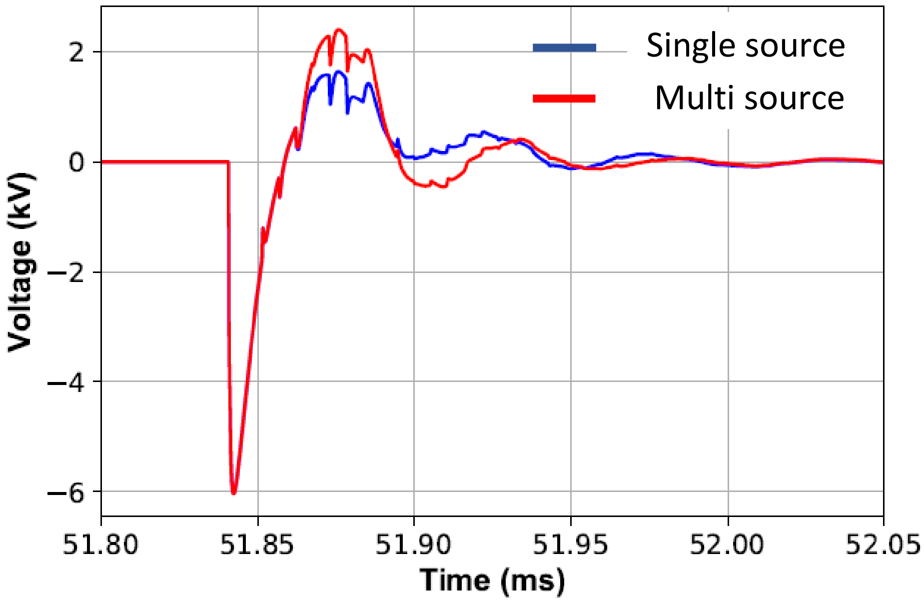


Low-Frequency Transient at S



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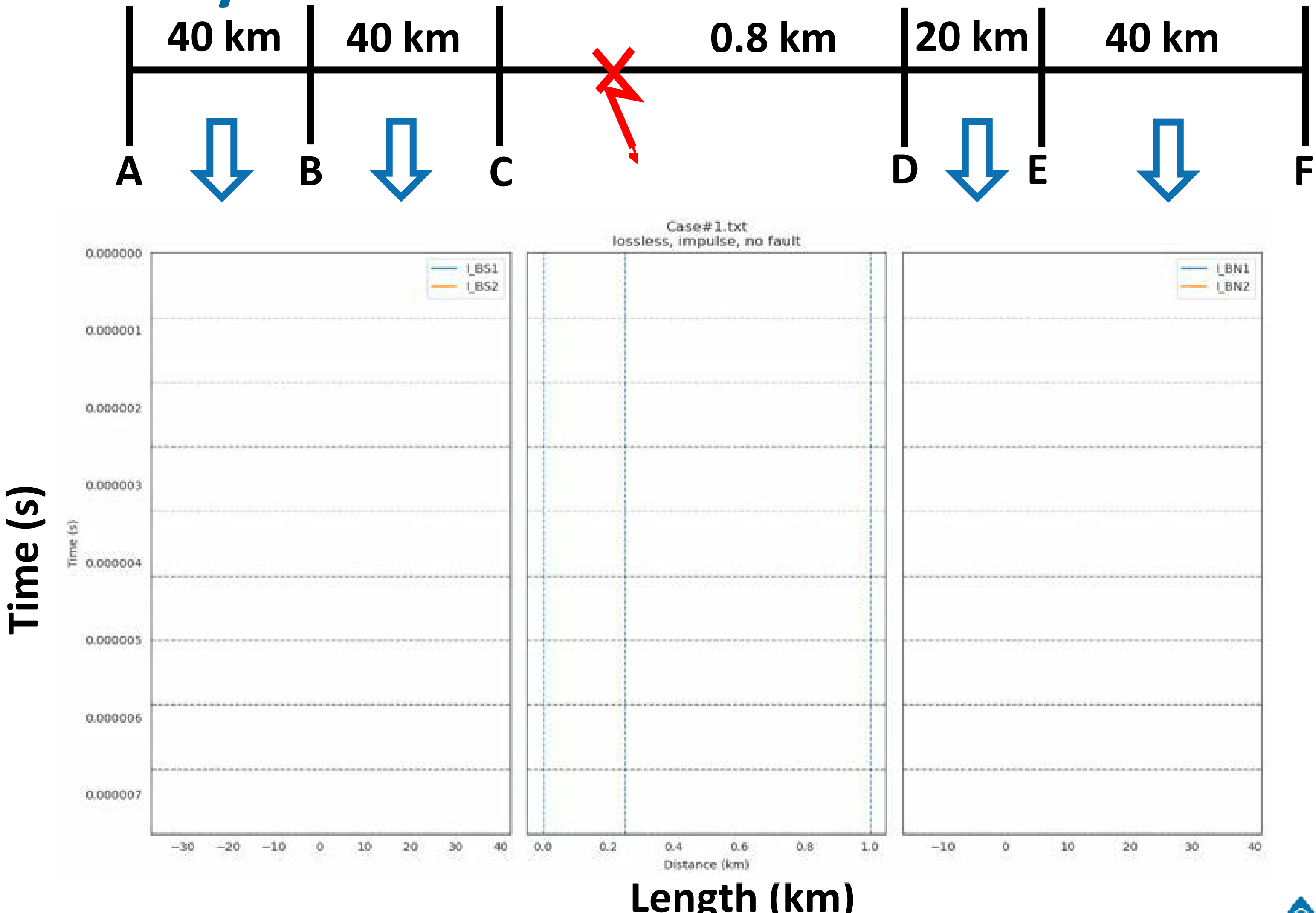
Bewley Lattice Tool



- Bewley lattice visualization tool was developed to visualize waves traveling (available in open-source).

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Future Work

- Utilize modified IEEE 13-bus test system at 13.8 kV to study traveling waves in a complex distribution system.
- Frequency signatures will be developed using advanced signa-processing techniques.
- High-frequency models of transformers and DERs will be developed and validated through testing.
- High-impedance and arcing fault transients will be studied using the Medium-Voltage Outdoor Test Area facility at NREL.
- Field data from utilities needed.

Q&A or Thank You

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