Utility Experience with Traveling Wave Fault Locating on Lower Voltage Transmission Lines

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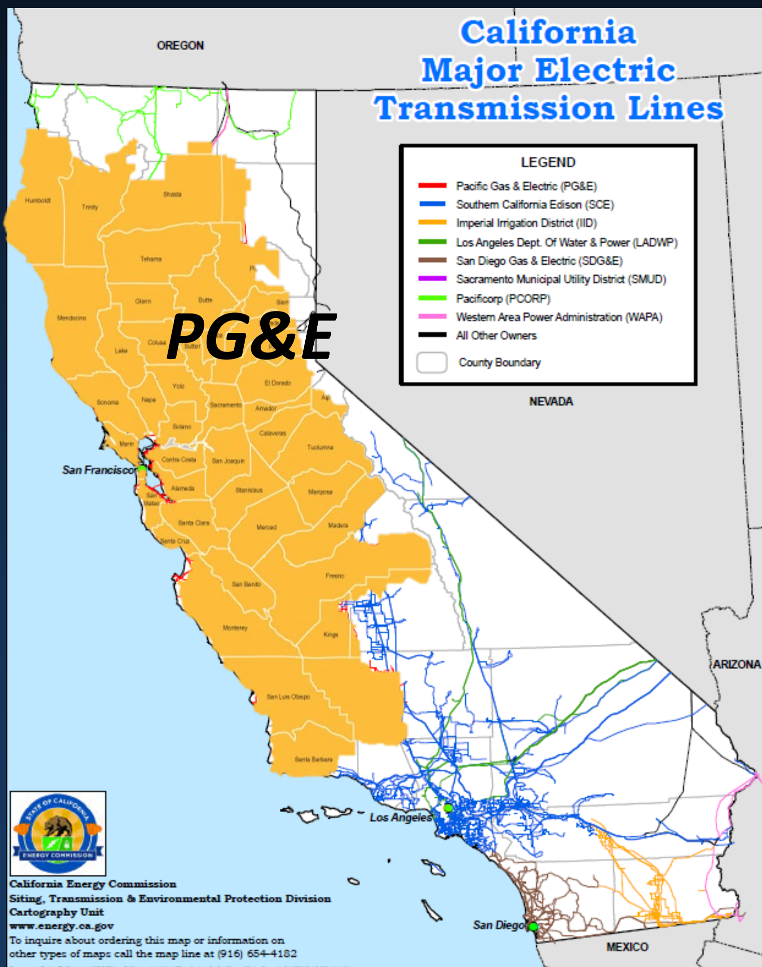
Pacific Gas and Electric Company

PG&E at a glance



- Customers: 5.4 Million electric , 4.4 Million natural gas
- Service Area: 70K square-mile
- Electric Lines 106K miles of Distribution, 18K miles of Transmission
- 1 Million Transformers
- Last Operating Nuclear Generator in CA.
- 67 Hydroelectric Powerhouses
- 924 Automated Self Healing Circuits (FLISR)
- 5.4 Million Electric SmartMeters
- 35,000 Protective Relays

Overview

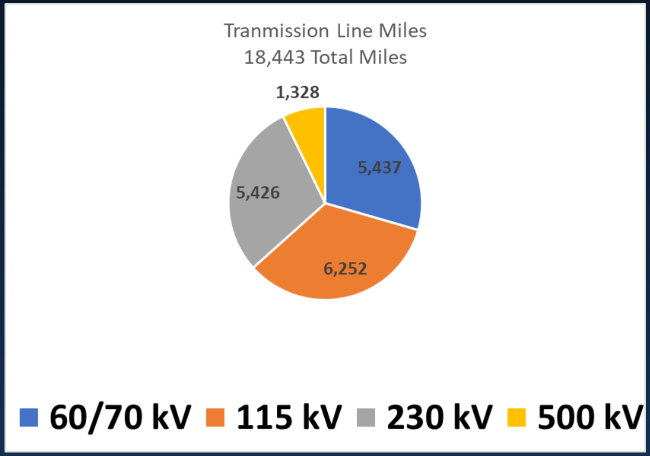
- Traveling Waves – An Introduction
- Single Ended Traveling Wave Fault Location (TWFL)
- TWFL for Complex Line Topologies
- Results : Not Valid → Experience → Very Accurate
- Conclusion – Education, Software, Experience

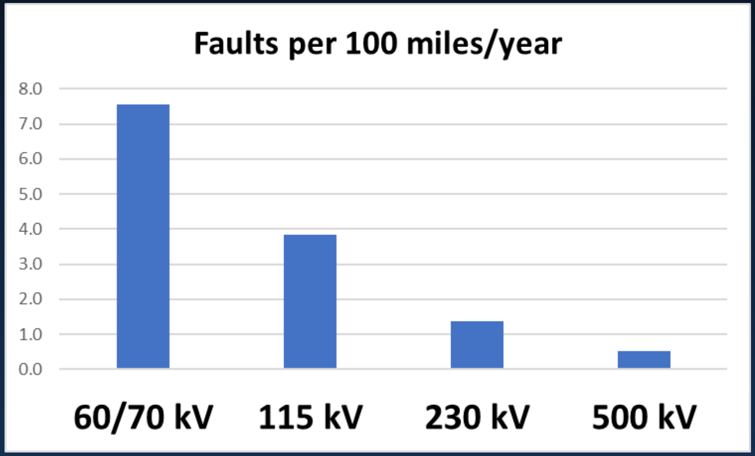
Traveling Waves

- Traveling Waves are Created by Switching and Fault Initiation
- Documented by LV Bewley in Papers in 1929, 1931 and a 1933 Book. Primary interest was effects of lightning
- Traveling Waves move at near the Speed of Light
- Useful for Fault Locating and now Tripping Relays
- Many Papers on Applications on EHV lines
- How Fast are Traveling Waves in Overhead Lines?
  - ~ 0.98 times the speed of light
  - 663 million miles per hour
  - 186 miles in 1 millisecond

Traveling Waves

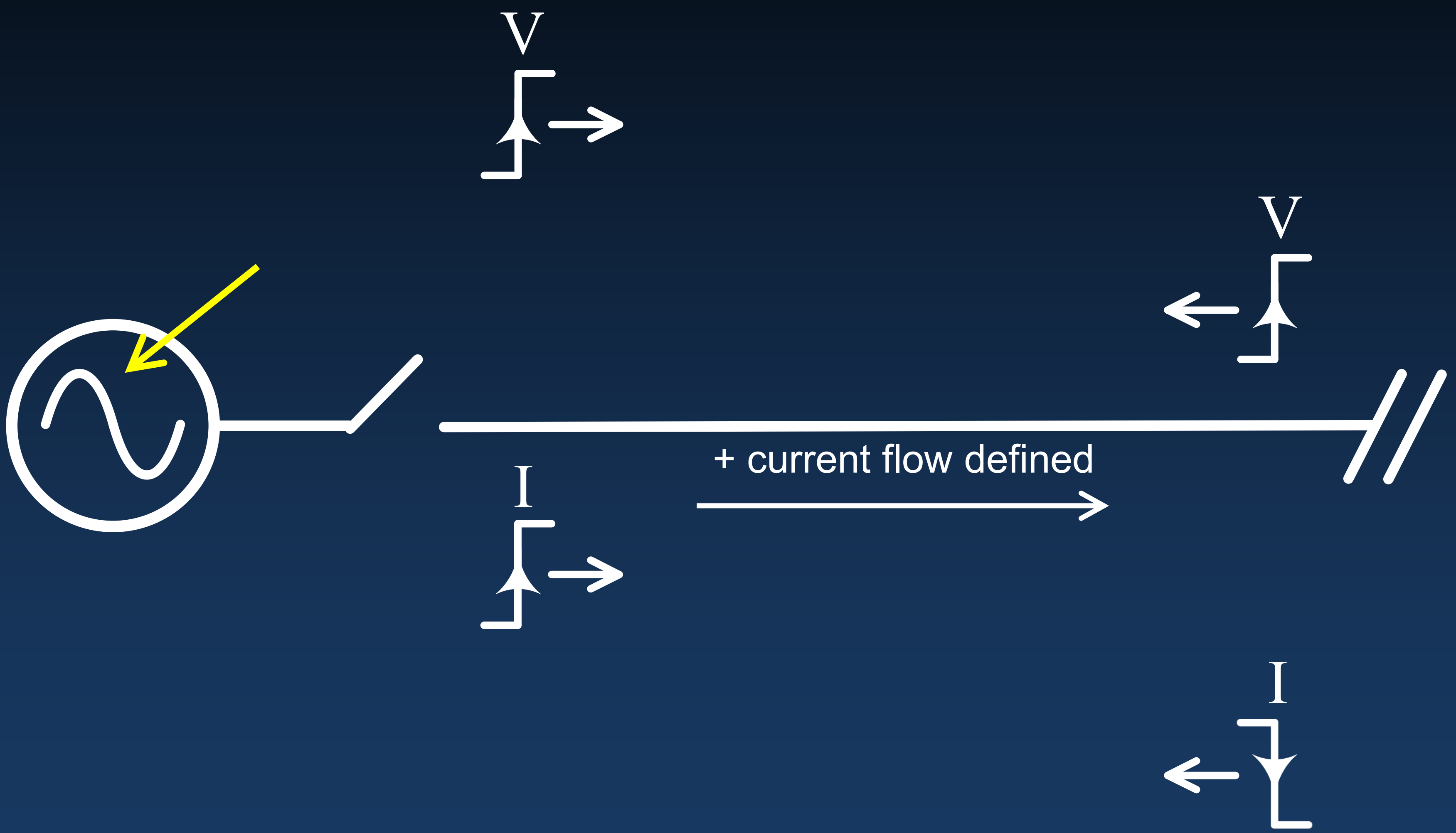
- More Faults/Customers on Lower Voltage Transmission Lines.



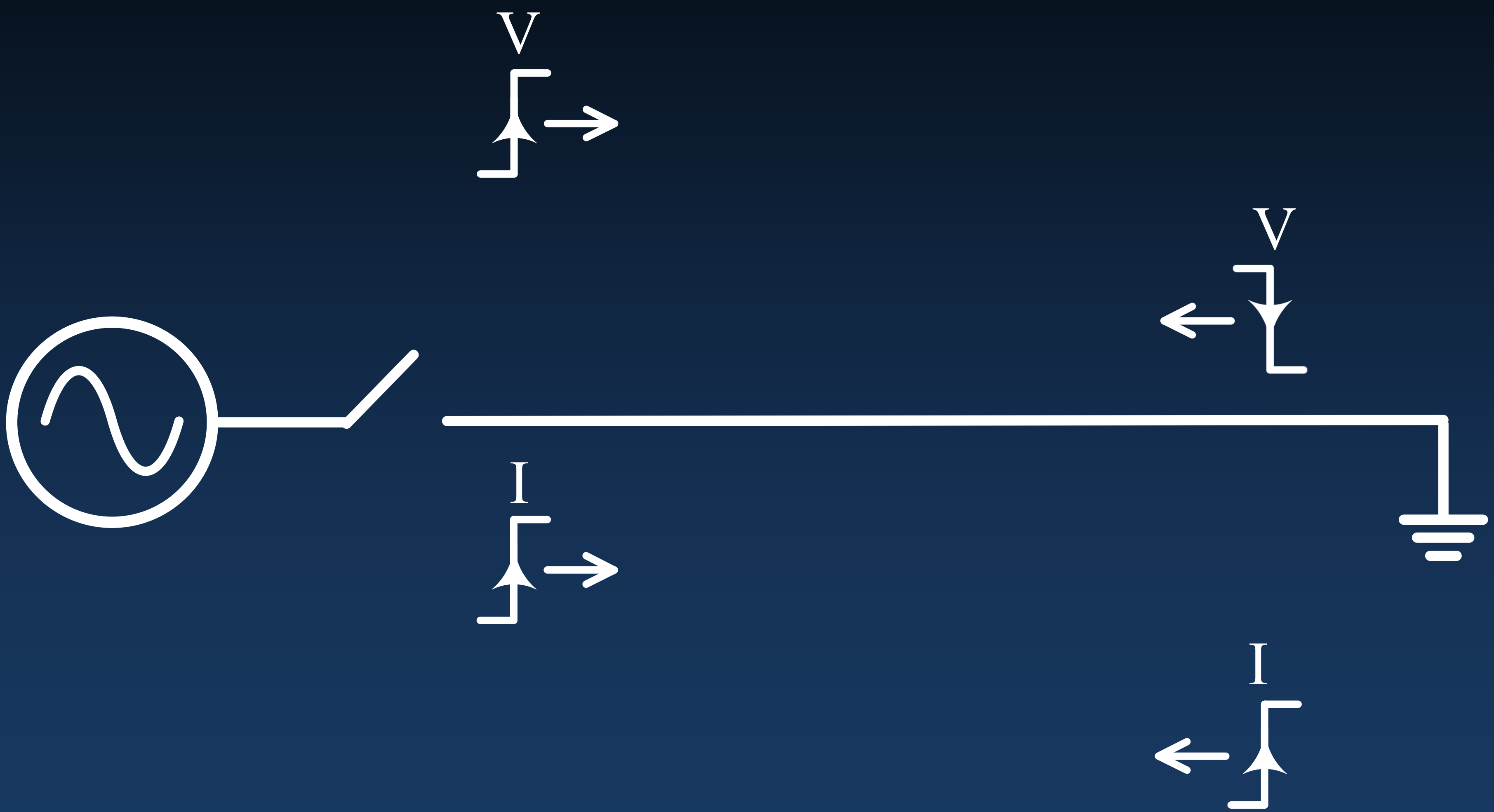


- Complex Topologies make Impedance Based Fault Locations difficult.
- PG&E Transmission Line Standard Uses Relays with this option
- Experiences with Traveling Wave Fault Location on Lower Voltages

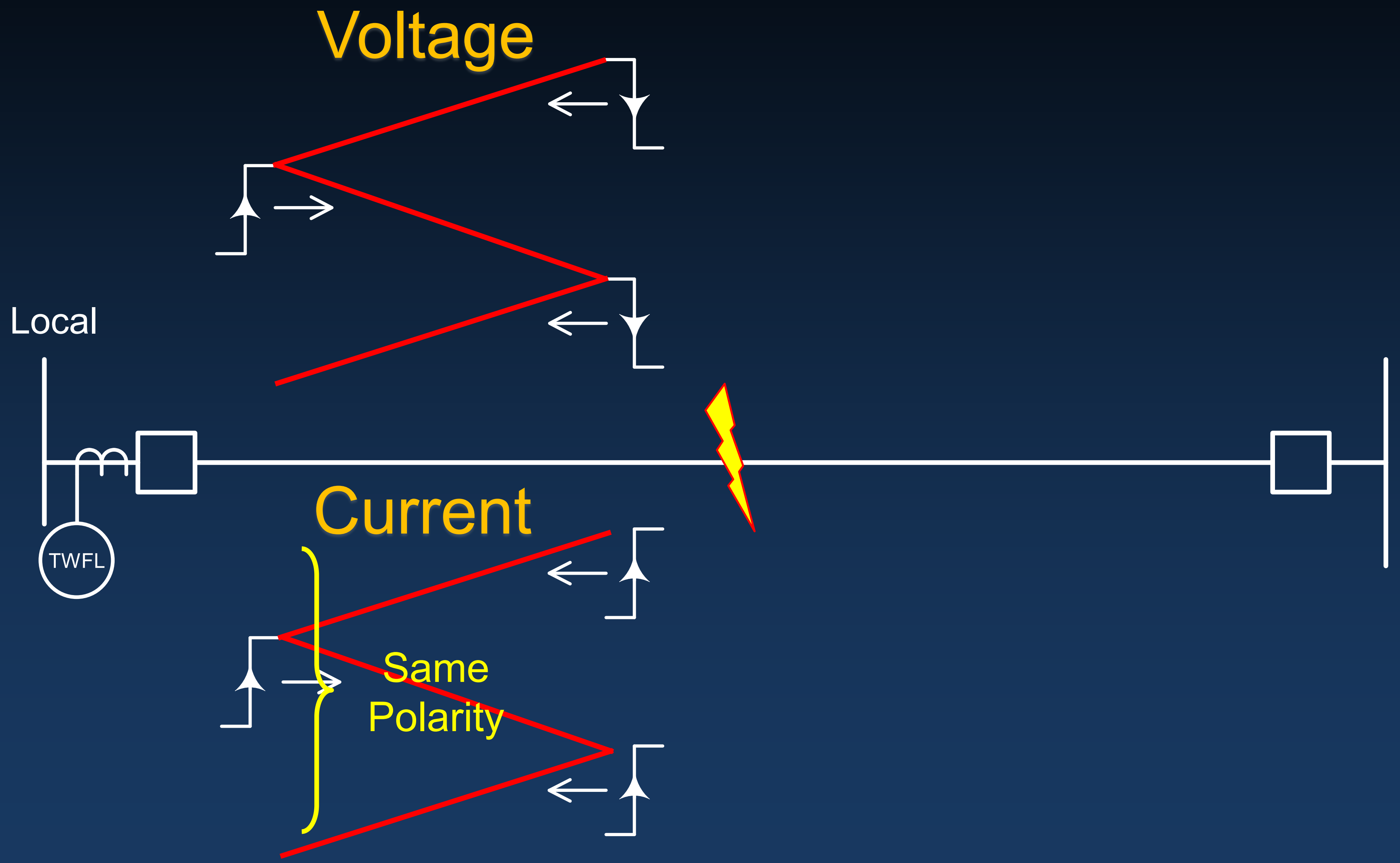
TW Reflections - Open



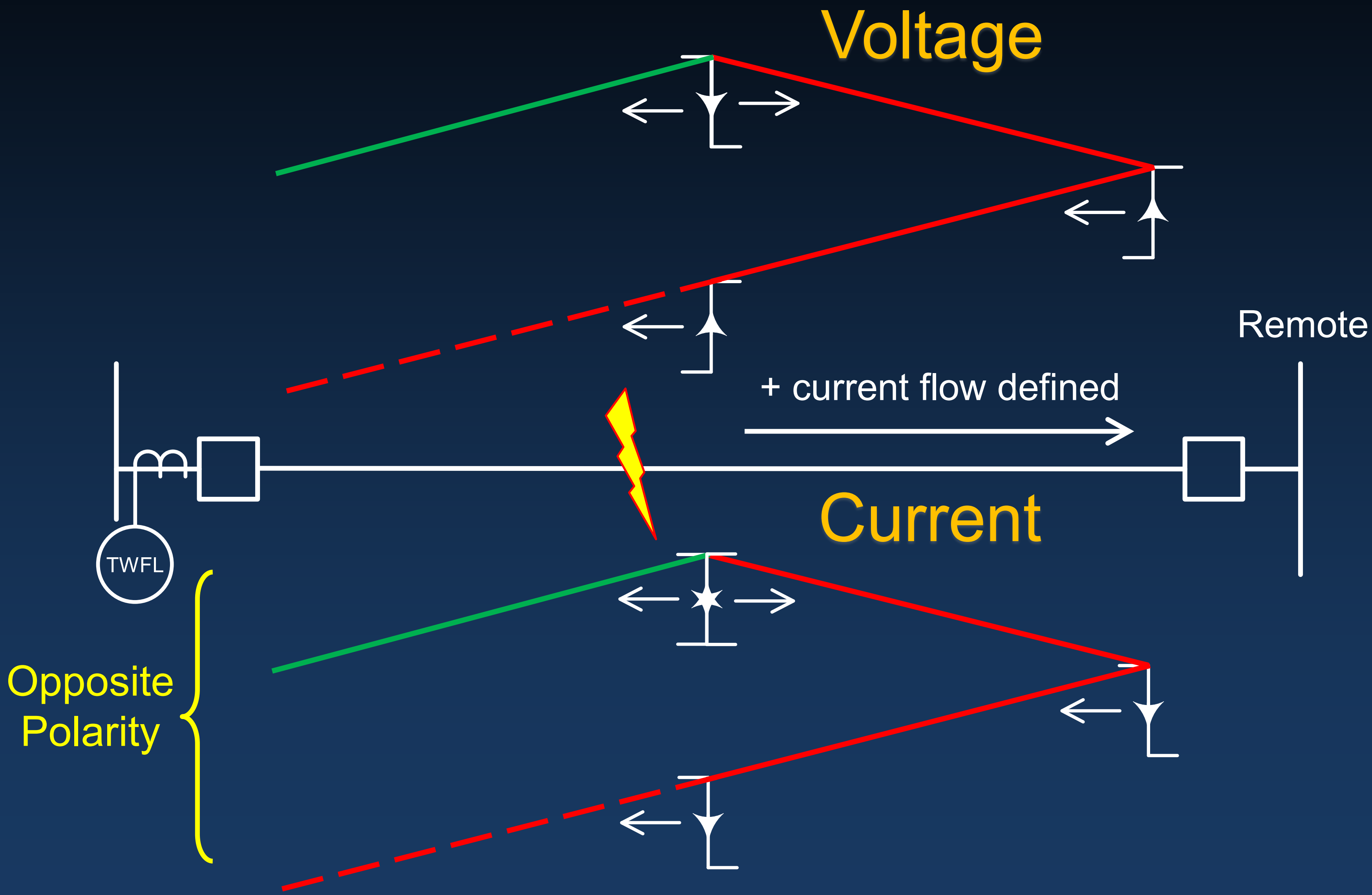
TW Reflections - Short



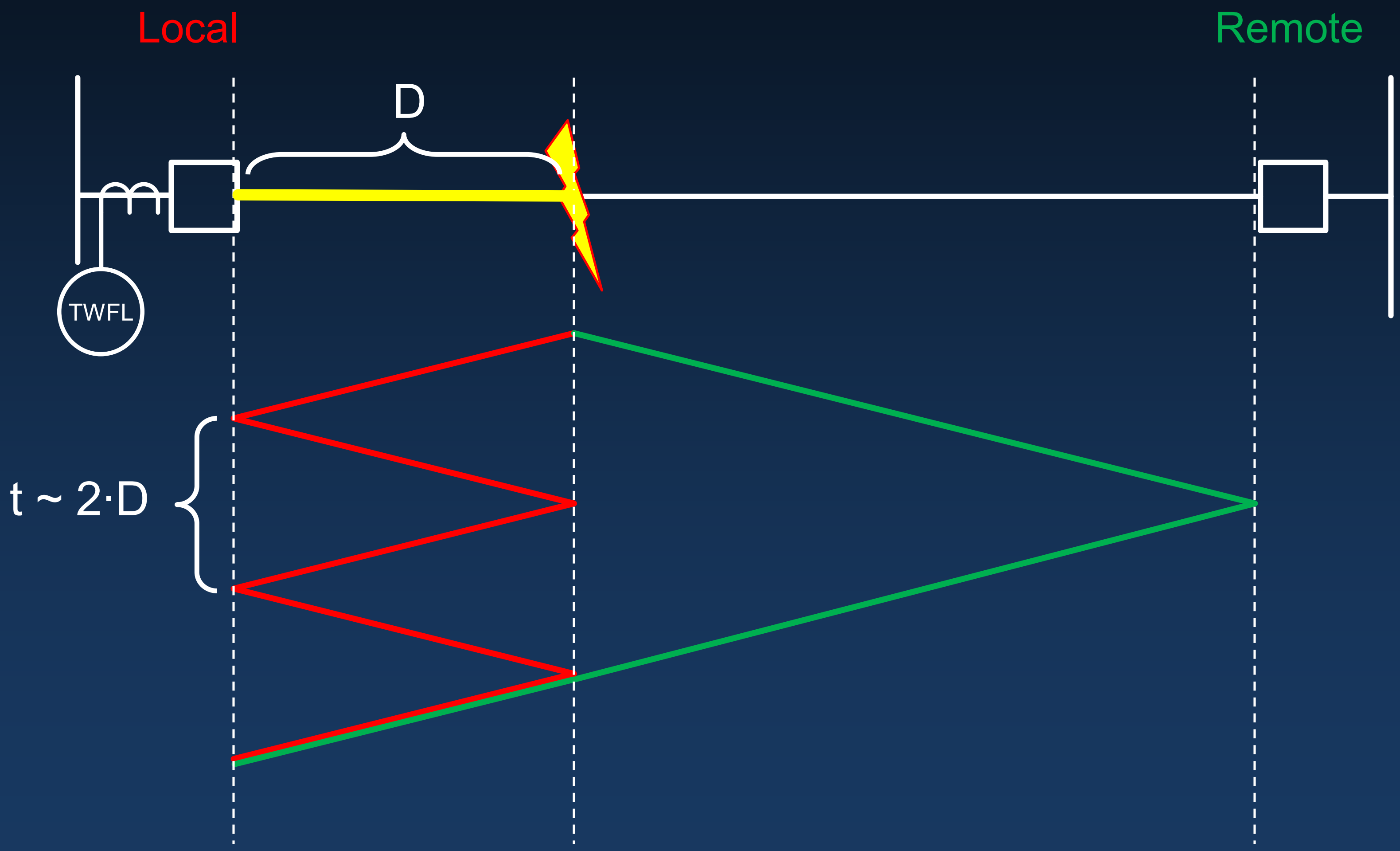
Single-Ended Local TW Reflections



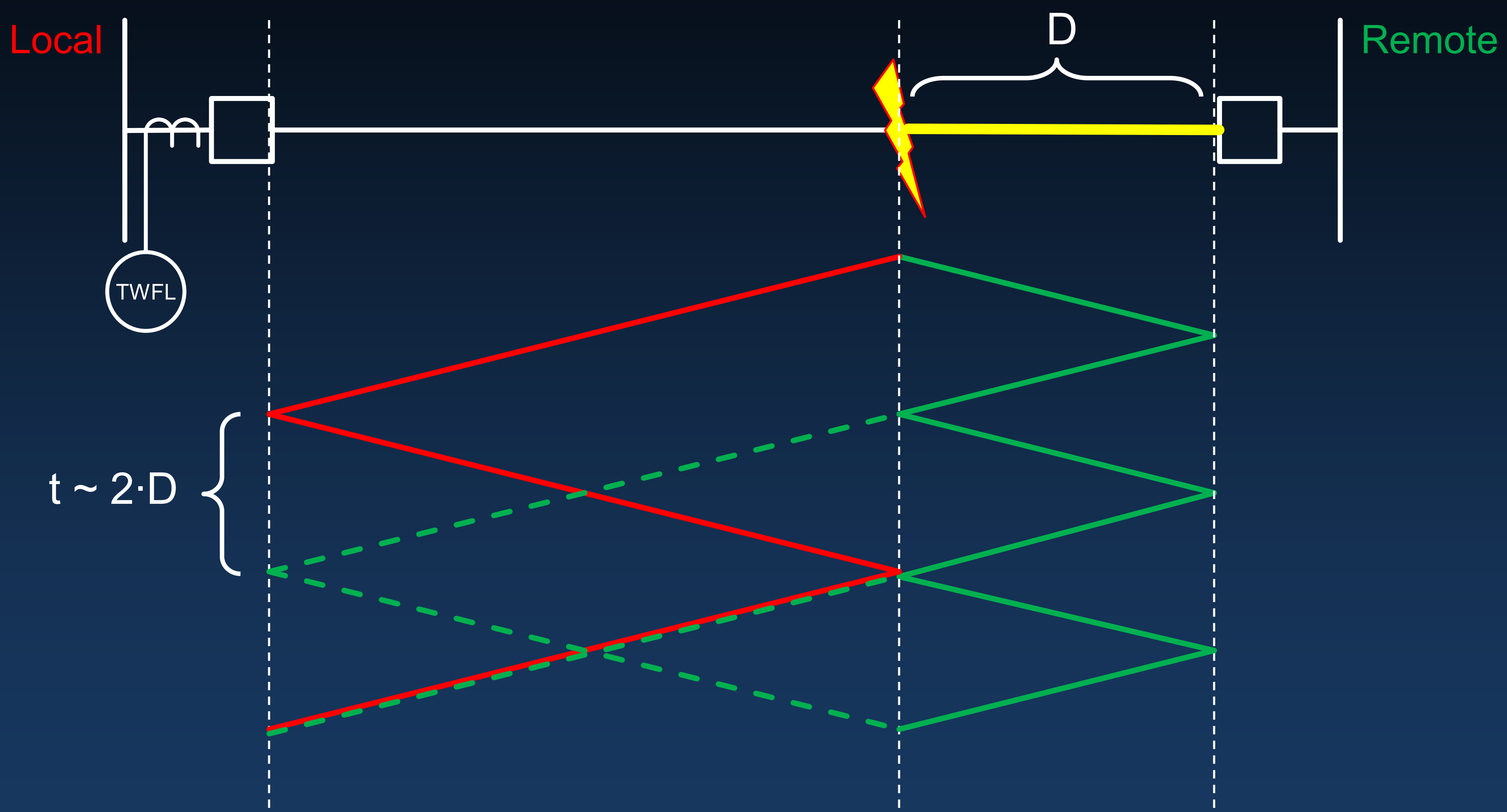
Single-Ended Remote TW Reflections



Fault near Local Terminal (1/3 Line)



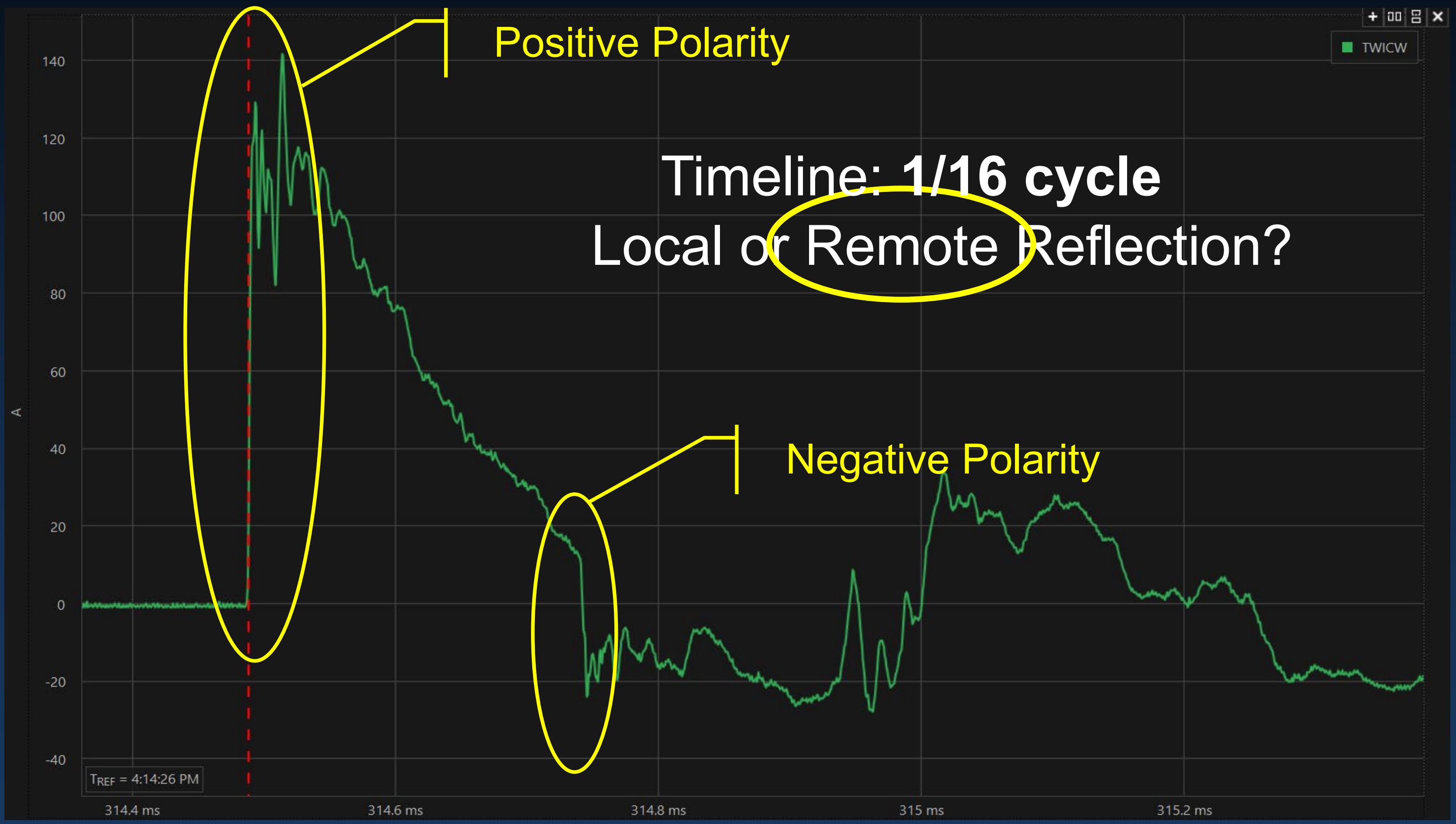
Fault near Remote Terminal (2/3 Line)



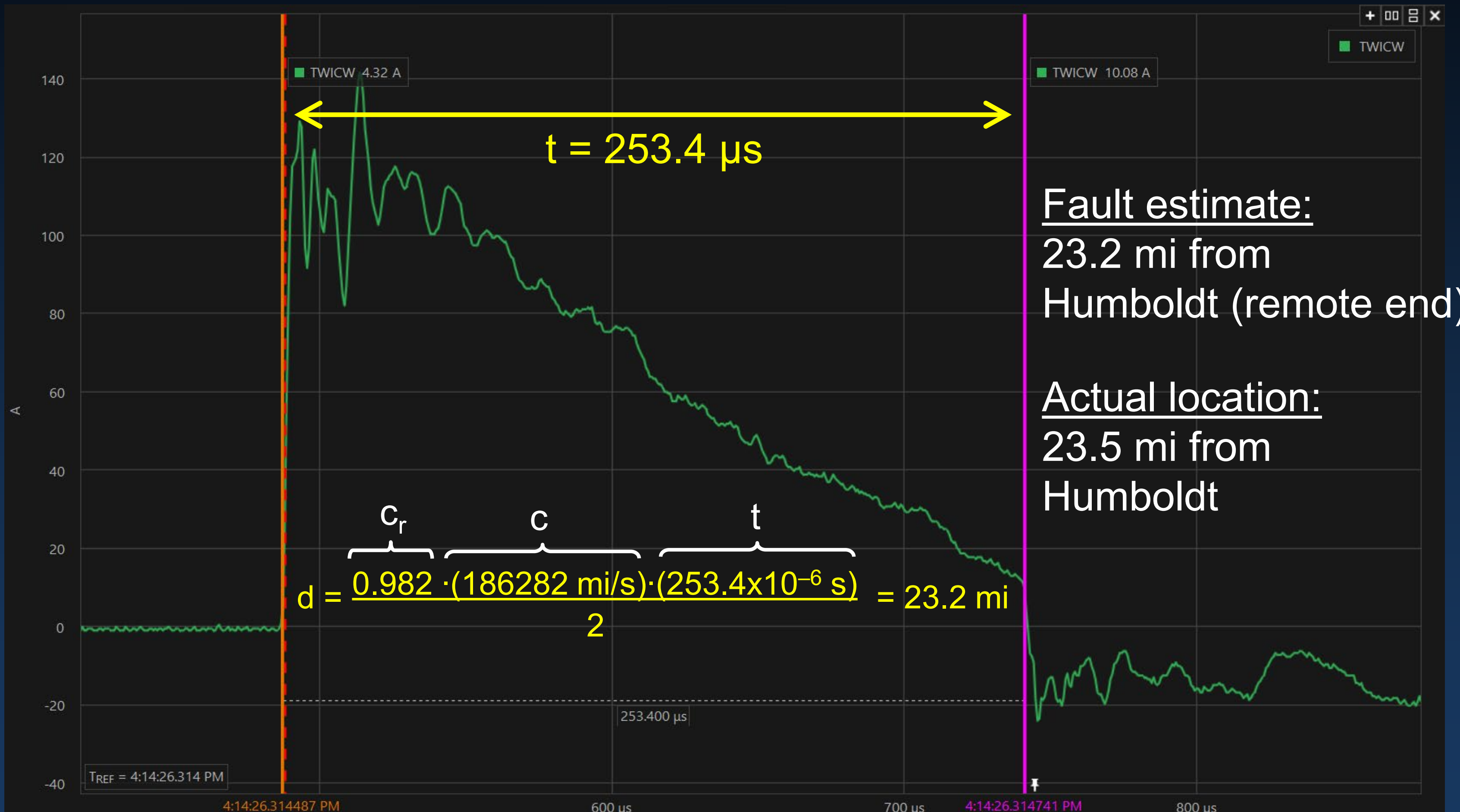
Example: Humboldt-Trinity 115kV Line

Line Length = 68.9 miles

Example: Humboldt-Trinity 115kV Line

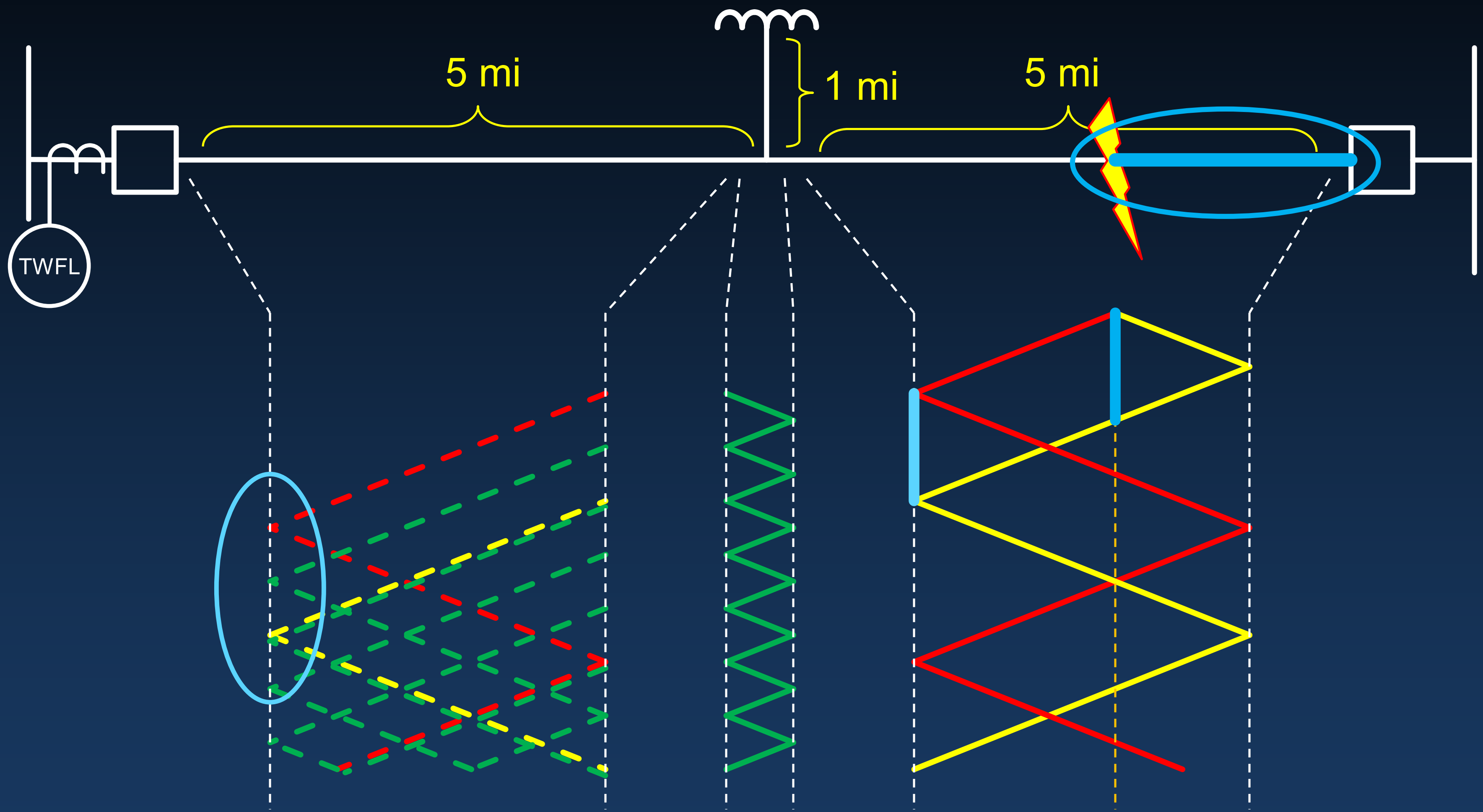


Humboldt-Trinity 115kV Line Remote Reflection

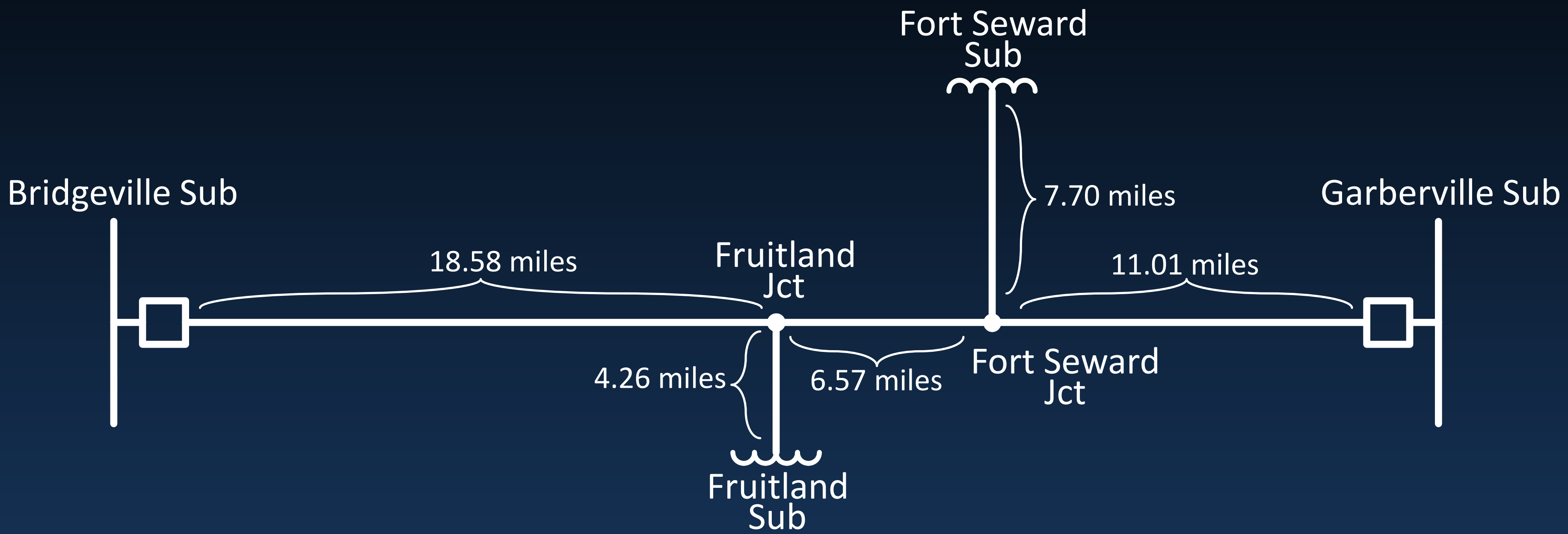


Humboldt-Trinity 115kV Line
Local Reflection

TW for Complex Line Topologies



Bridgeville-Garberville 60kV Line



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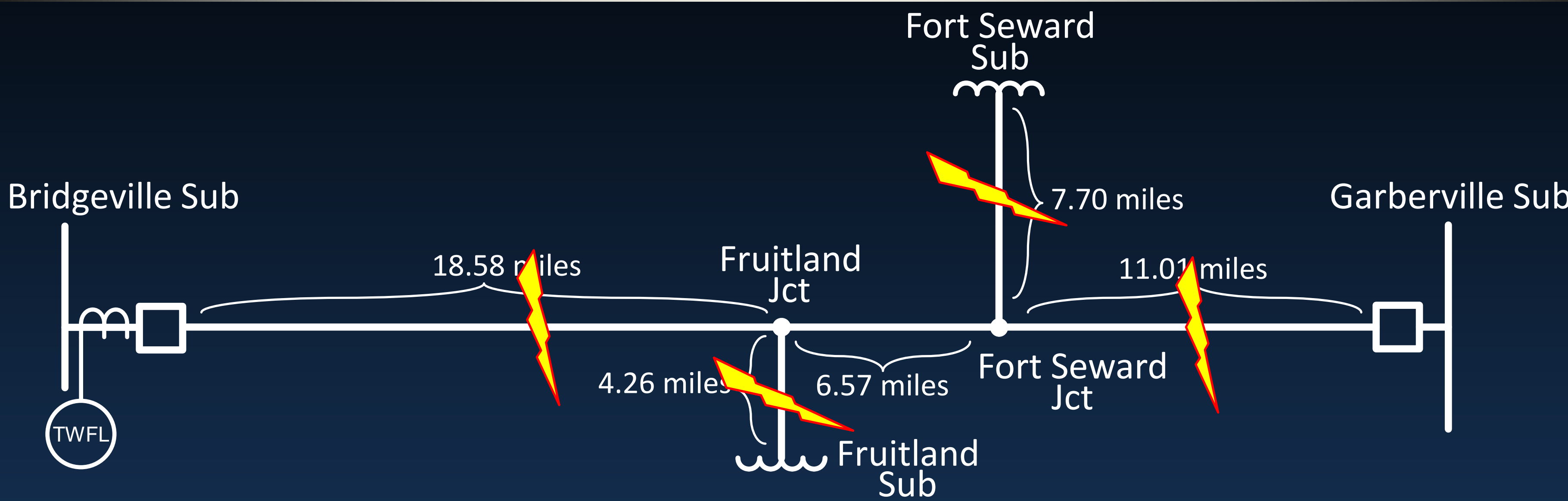
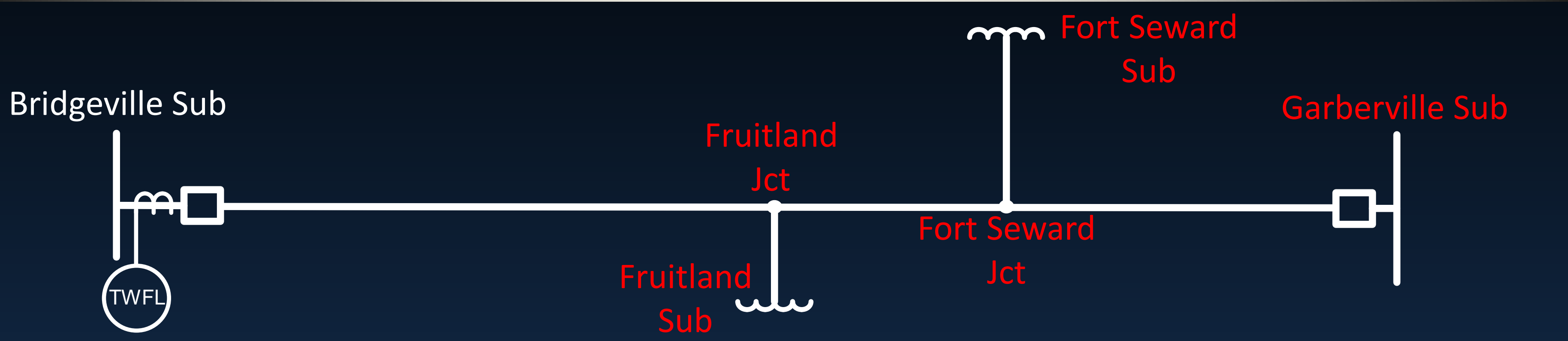
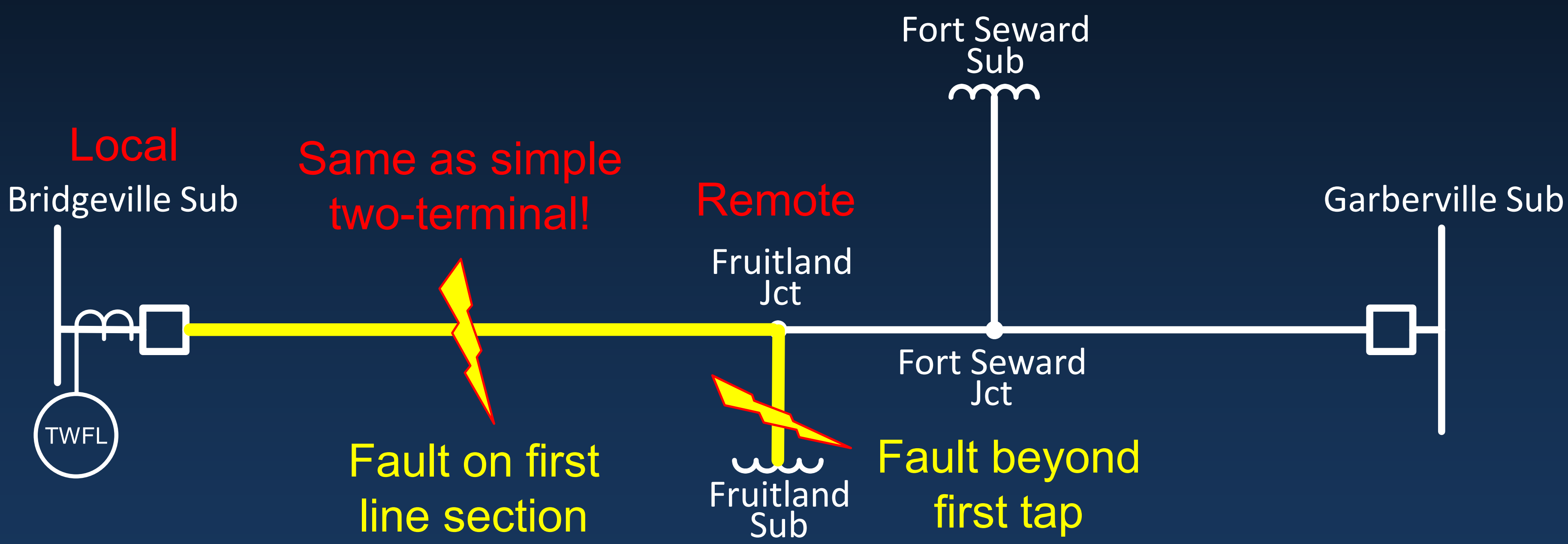


Bridgeville-Garberville 60kV Line Energization



Where are the sources of reflections?

Single-Ended TWFL – Complex Topology



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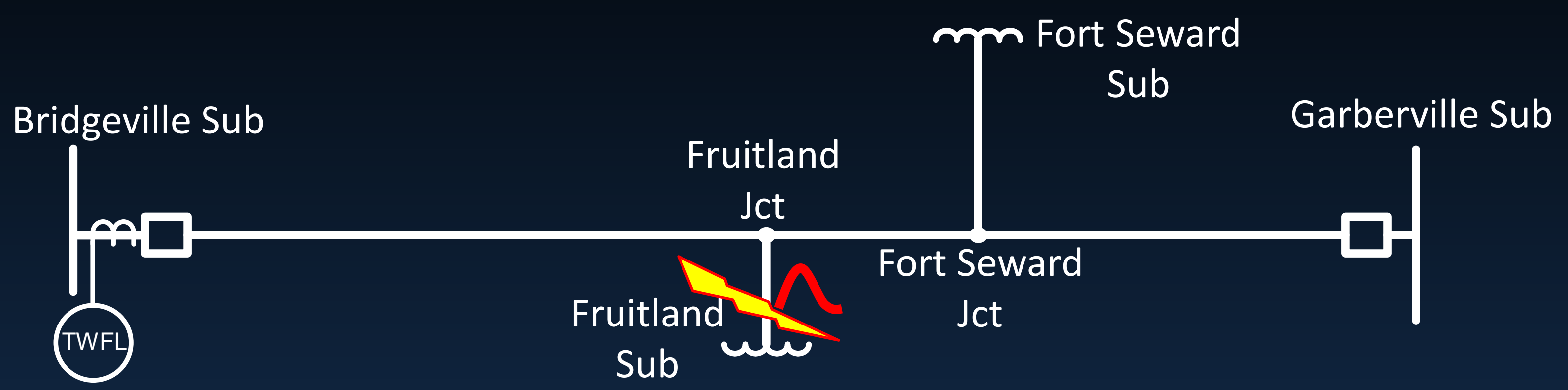

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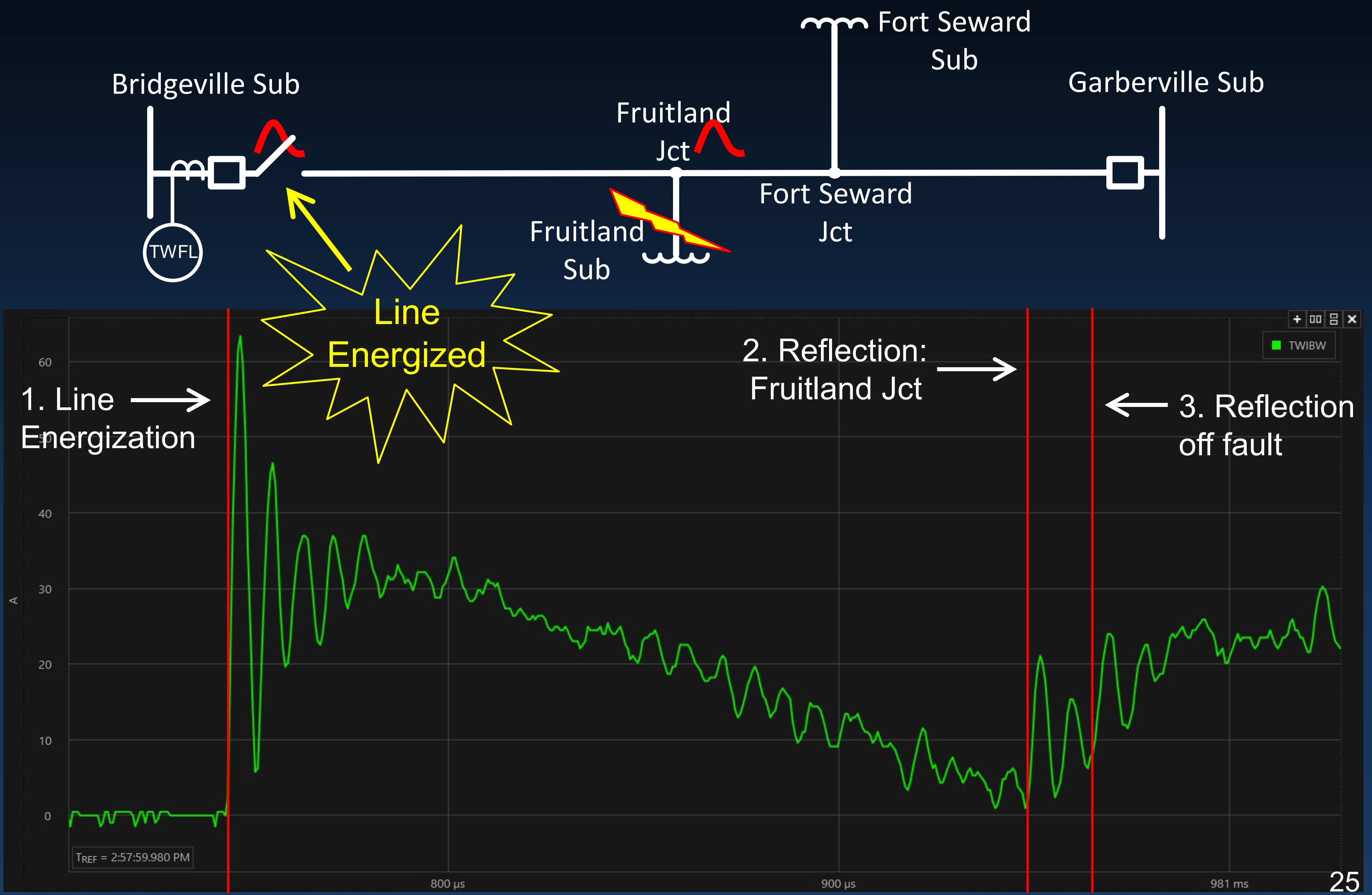
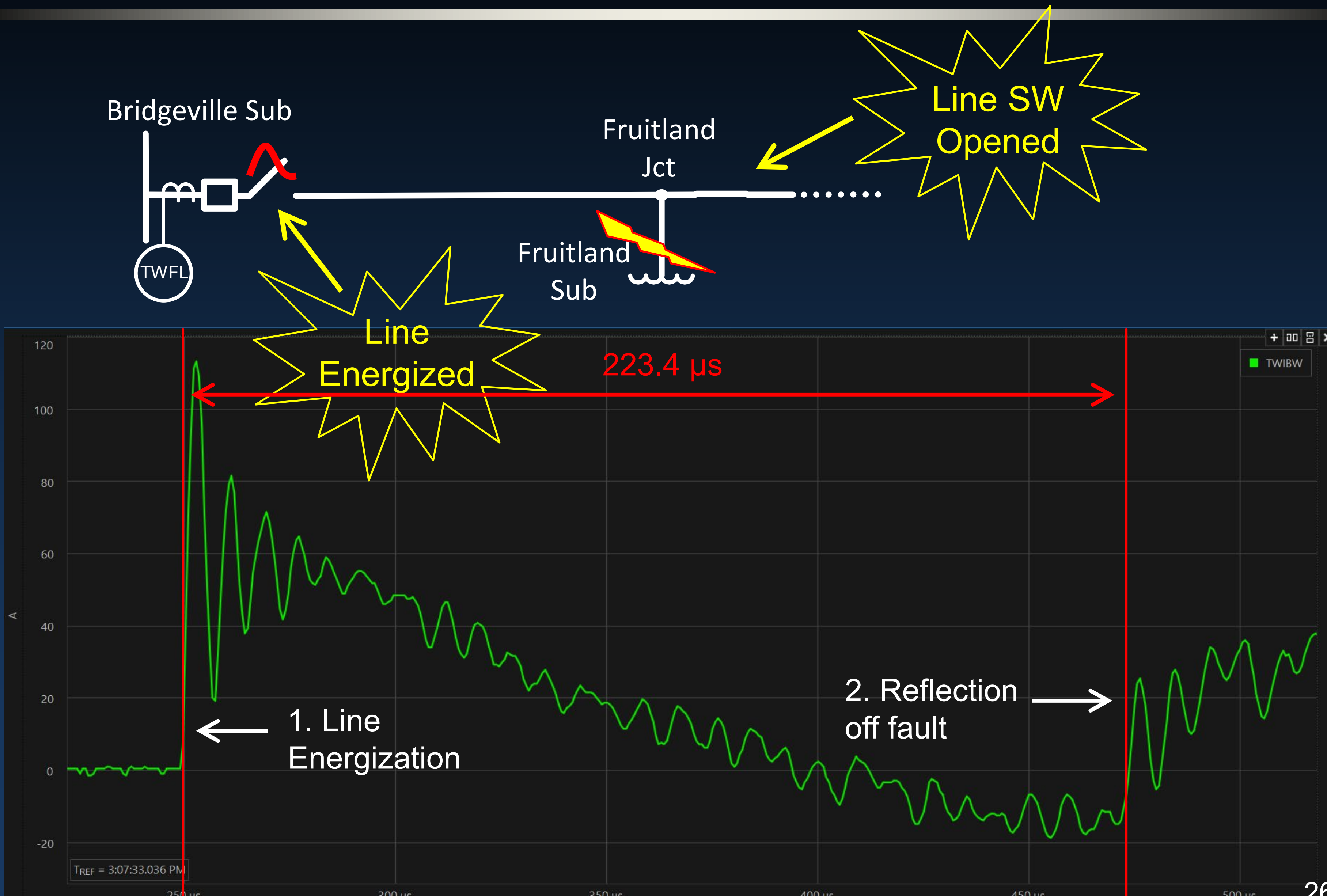


Single-Ended TWFL – Complex Topology

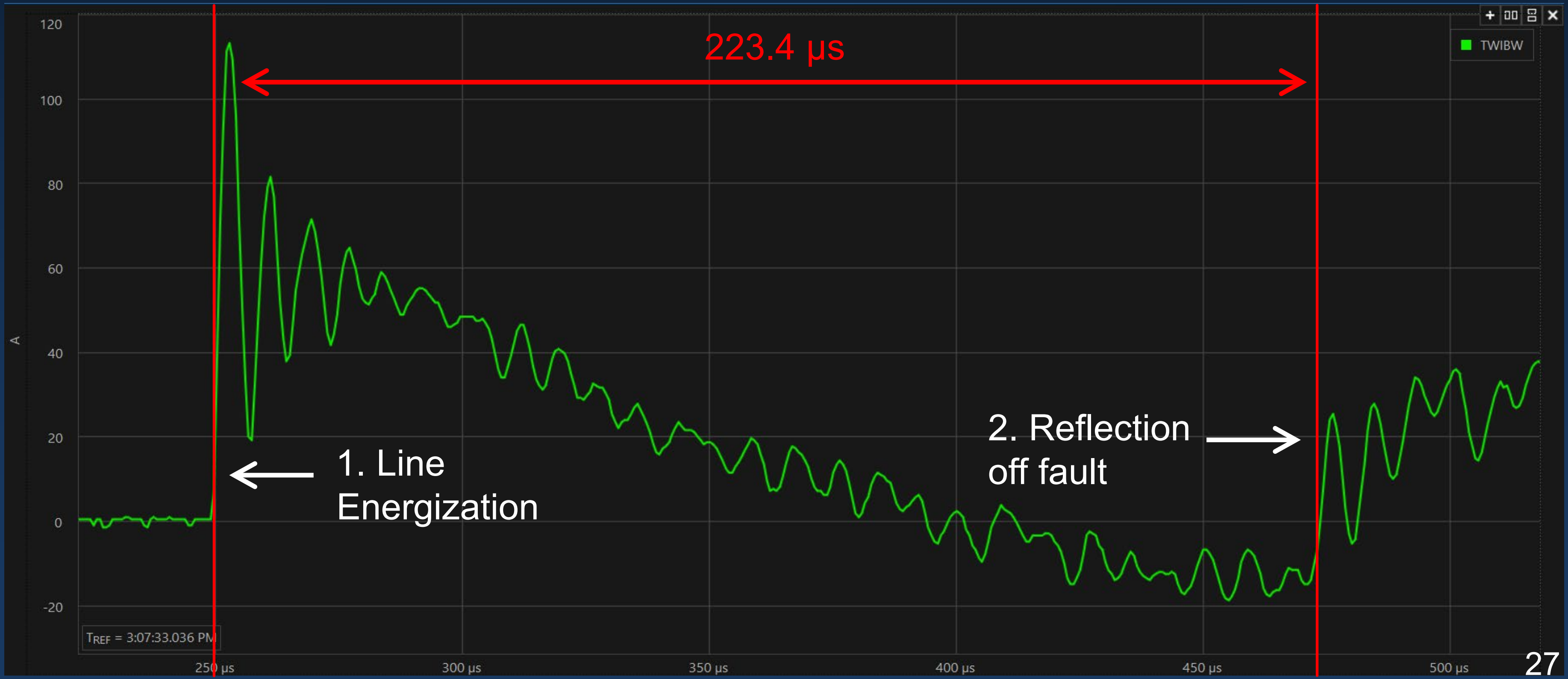


Single-Ended TWFL – Complex Topology

$$d = \frac{0.974 \cdot (186282 \text{ mi/s}) \cdot (223.4 \times 10^{-6} \text{ s})}{2} = 20.27 \text{ mi}$$

20.27 mi corresponds to **pole 001/008**

Field report: **Tree removed between poles 001/008** & 001/009



Results

Humboldt-Trinity 115kV Line				
Single-ended TWFL	**Estimated Location from TW event**		**Field Found Actual Fault Location**	
Date	Miles	Structure #	Miles	Structure #
9/10/2015	50.86	**96/4**	50.69	**96/4**
3/5/2016	45.47	**91/0**	45.36	**90/10**
1/2/2017	41.26	**86/7**	40.98	**86/4**

Error due to CT lead length:
+ 0.19 miles

Adjusting for offset, average error is:
+/– 0.06 miles or +/– 300 ft!

Bridgeville-Garberville 60kV Line				
Single-ended TWFL	**Estimated Location from TW event**		**Field Found Actual Fault Location**	
Date	Miles	Structure #	Miles	Structure #
1/2/2017	16.84	**16/10**	16.71	**16/8**
2/5/2017	16.55	**16/6**	16.53	**16/6**
4/6/2017	15.92	**15/9**	15.84	**15/8**
4/8/2017	7.37	**7/6**	7.38	**7/6**
11/6/2017	20.27	**1/8**	20.26	**1/8**
2/19/2018	6.03	**6/1**	5.88	**5/18**

Error due to CT lead length:
+ 0.06 miles

Correction Factors

- CT lead length
- Line modeling errors
- Conductor sag
- Elevation changes

- Factored into relative speed of light constant c_r

Conclusion

- Single Ended TWFL is Complicated
- Can be Extremely Accurate +/- 1 pole
- Requires Training
- Requires New Software
- Requires Experience
- TWFL on Complex Lines has Gaps

Questions