Accurate and Economical Traveling-Wave Fault Locating Without Communications

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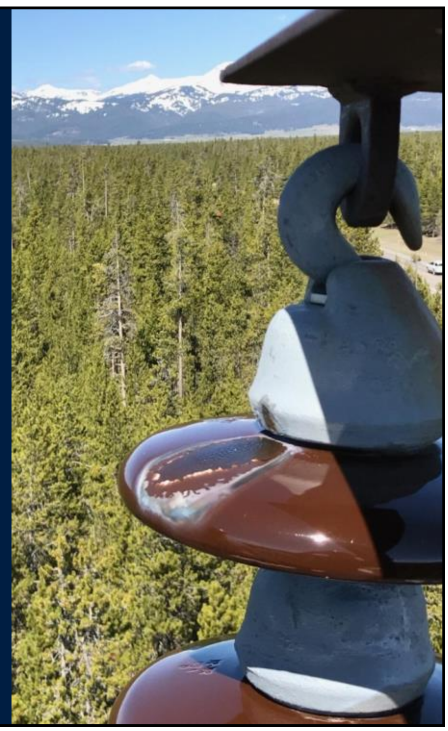
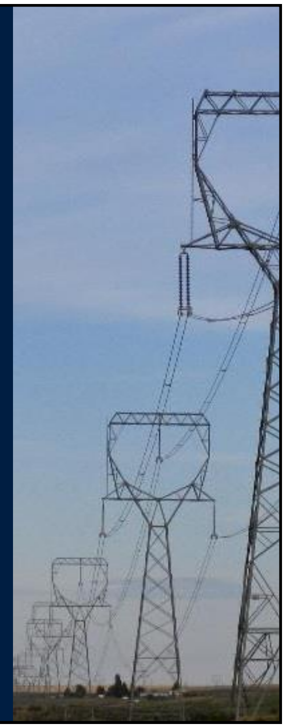
Fault Locating Is Important

- Expedite service restoration
- Reduce outage time
- Identify insulator problems
- Prevent potential recurring faults



Fault-Locating Technology

- Single-ended impedance (SEZFL)
- Double-ended impedance (DEZFL)
- Double-ended traveling wave (DETWFL)
- Single-ended traveling wave (SETWFL)



Fault Launches Traveling Waves

Fault at 47 mi (75 km) From Terminal L

TW line propagation time: 1 ms

Line length (LL): 186 mi (300 km)

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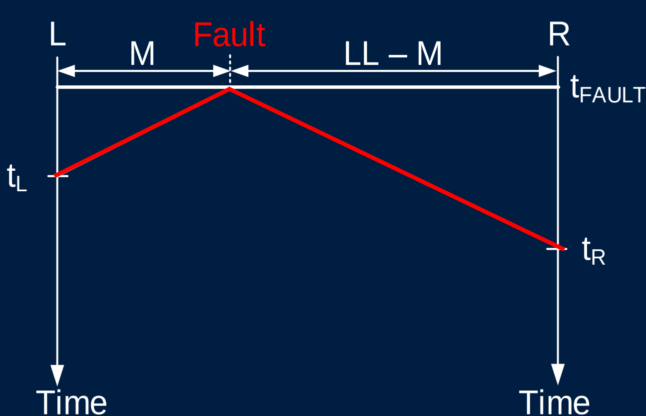
Double-Ended TW Fault Locator



$$\frac{M}{LL} = \frac{t_L}{TWLPT}$$

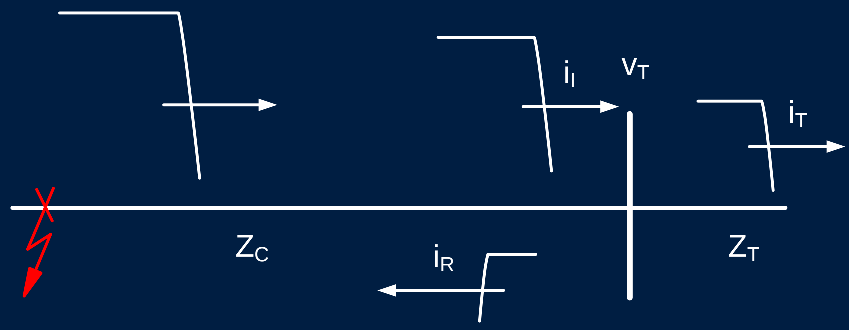
$$\frac{LL - M}{LL} = \frac{t_R}{TWLPT}$$

$$M = \frac{LL}{2} \cdot \left(1 + \frac{t_L - t_R}{TWLPT}\right)$$

M fault location in mi or km

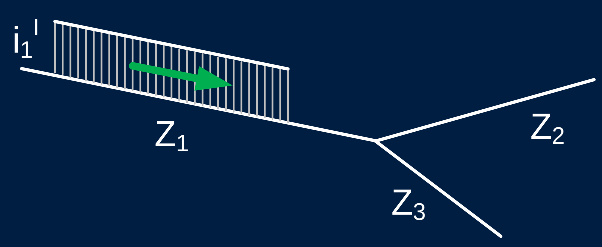
TW line propagation time (TWLPT)

Reflected TW Depends on Termination Impedance

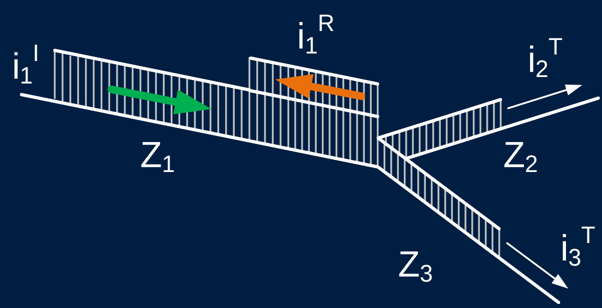


$$i_R = \frac{Z_C - Z_T}{Z_C + Z_T} i_I$$

TW Approaching a Fault Point



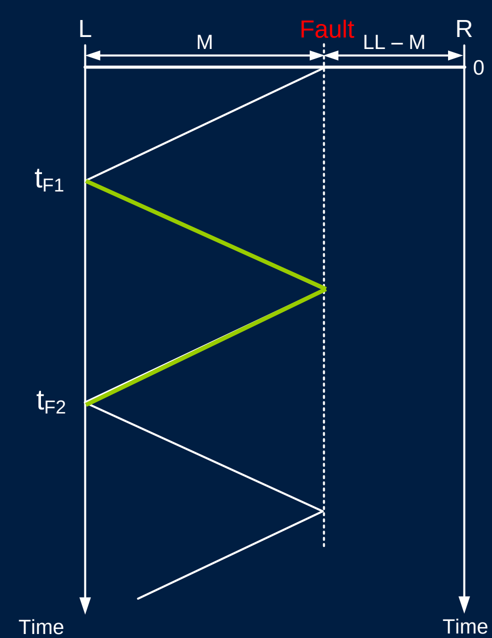
Reflected TW at Fault Point Provides Valuable Information for FL



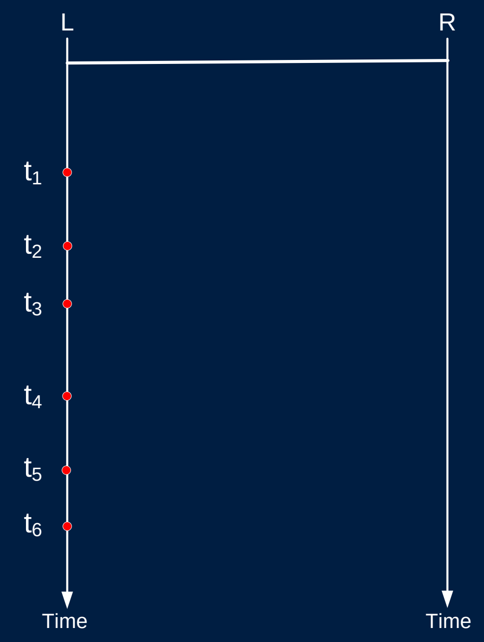
Single-Ended TW Fault Locator

$$\frac{2 \cdot M}{LL} = \frac{t_{F2} - t_{F1}}{TWLPT}$$

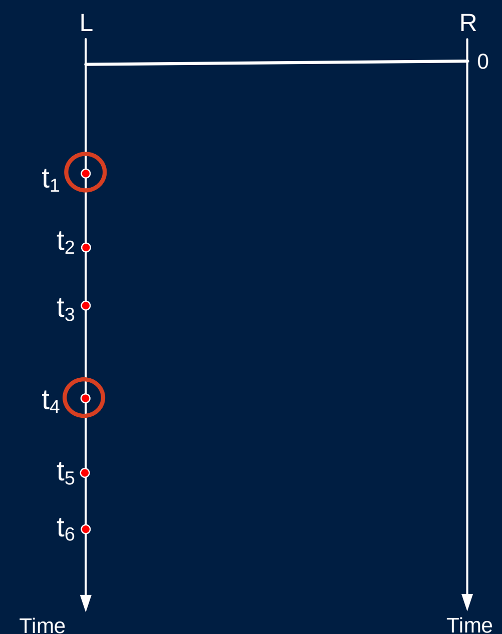
$$M = \frac{LL}{2} \cdot \frac{(t_{F2} - t_{F1})}{TWLPT}$$



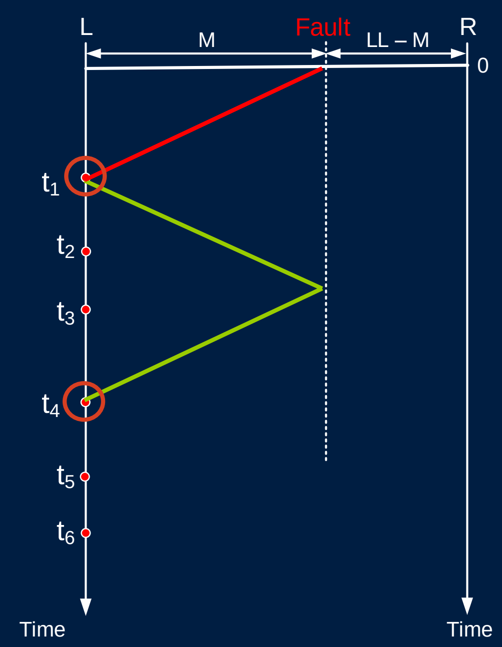
Identifying the First Reflection From the Fault Is Challenging



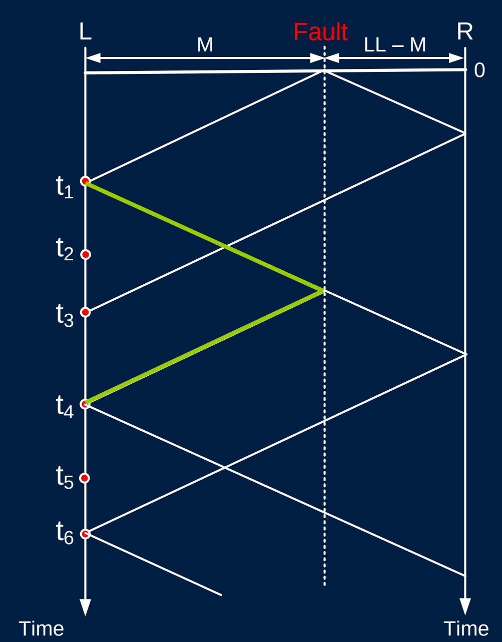
Assume a Fault Location



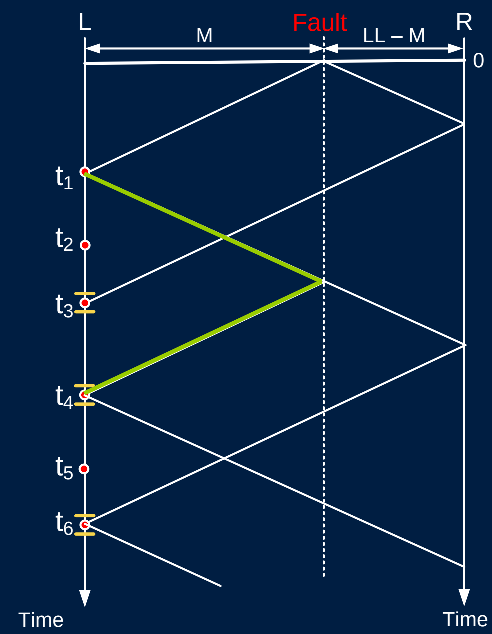
Assume a Fault Location



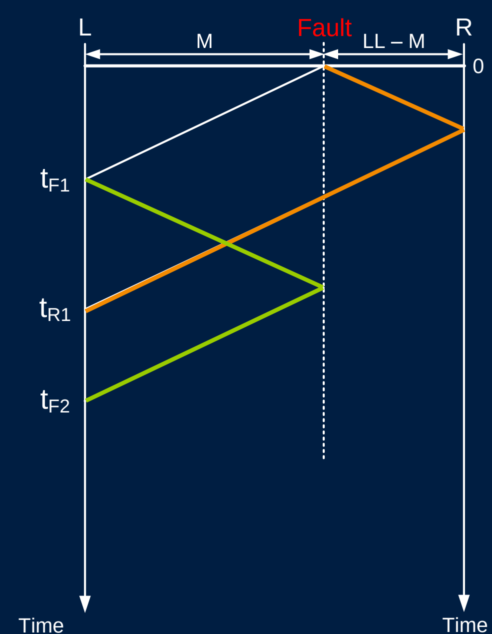
Build a Bewley Diagram



Count the Number of Expected Time Matches

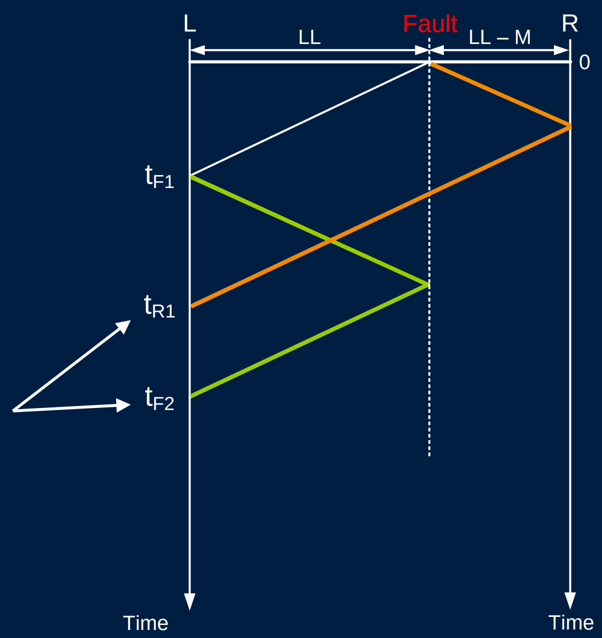


Reflection From the Remote Terminal Also Provides Valuable Information

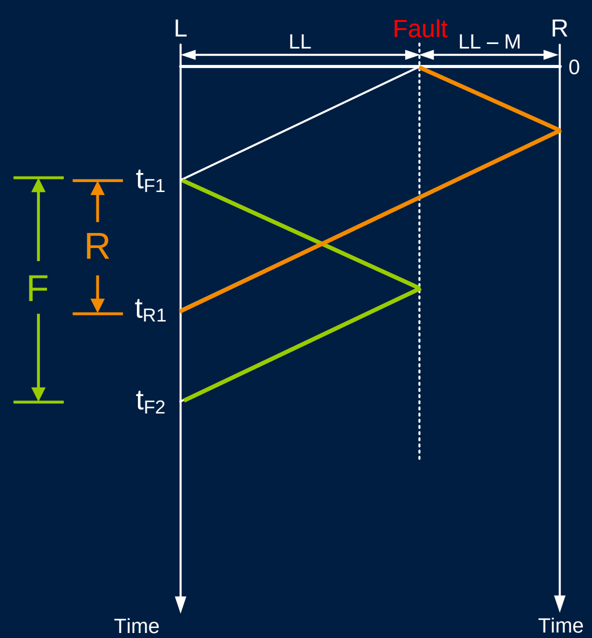


Companion TWs

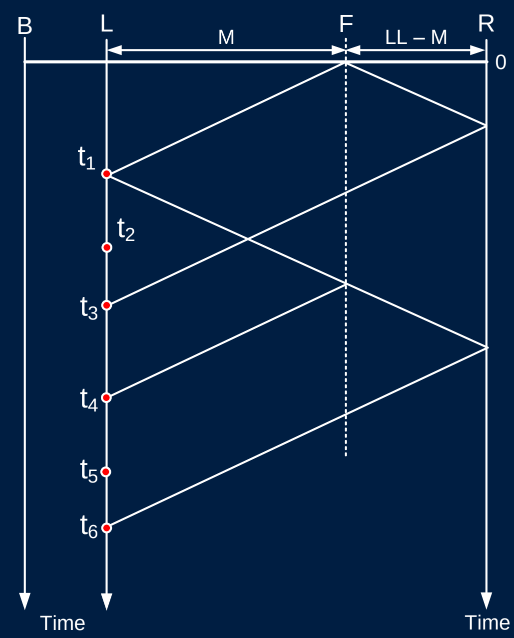
Companion TWs that meet a known relative timing criterion



Use Reflections as Time References



Use Reflection From Behind as a Test Signal



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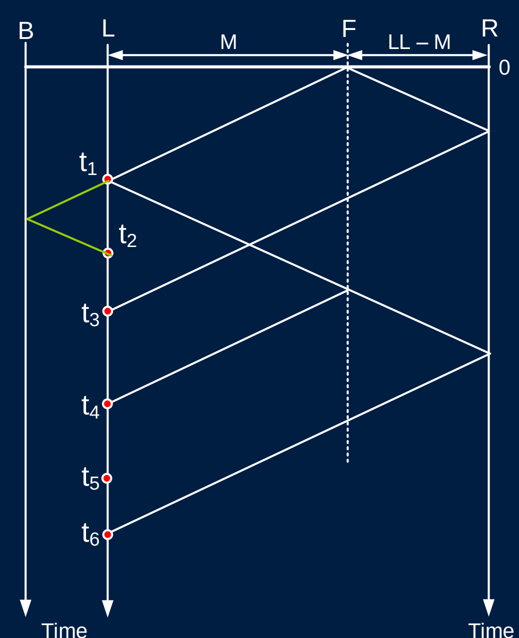

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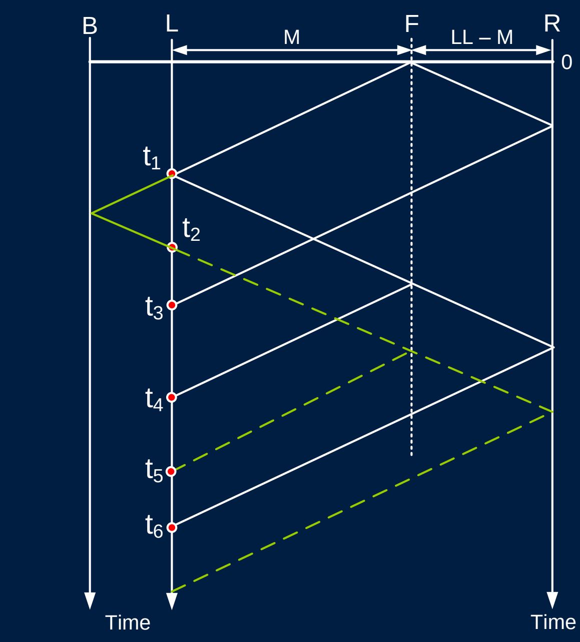
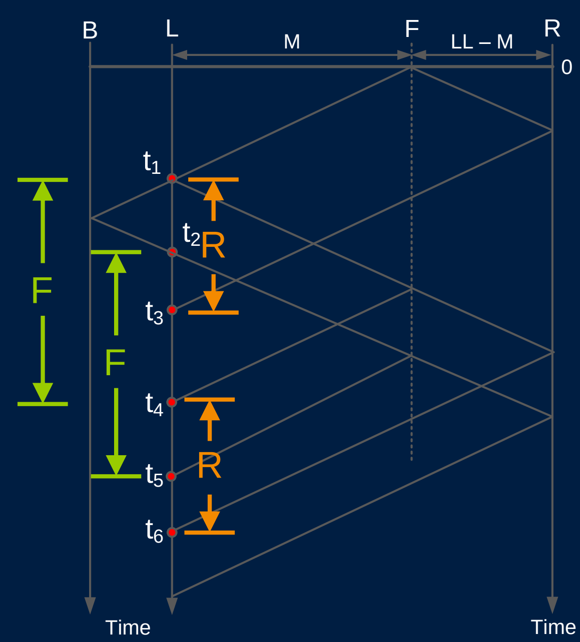


Count Number of Time Reference Matches

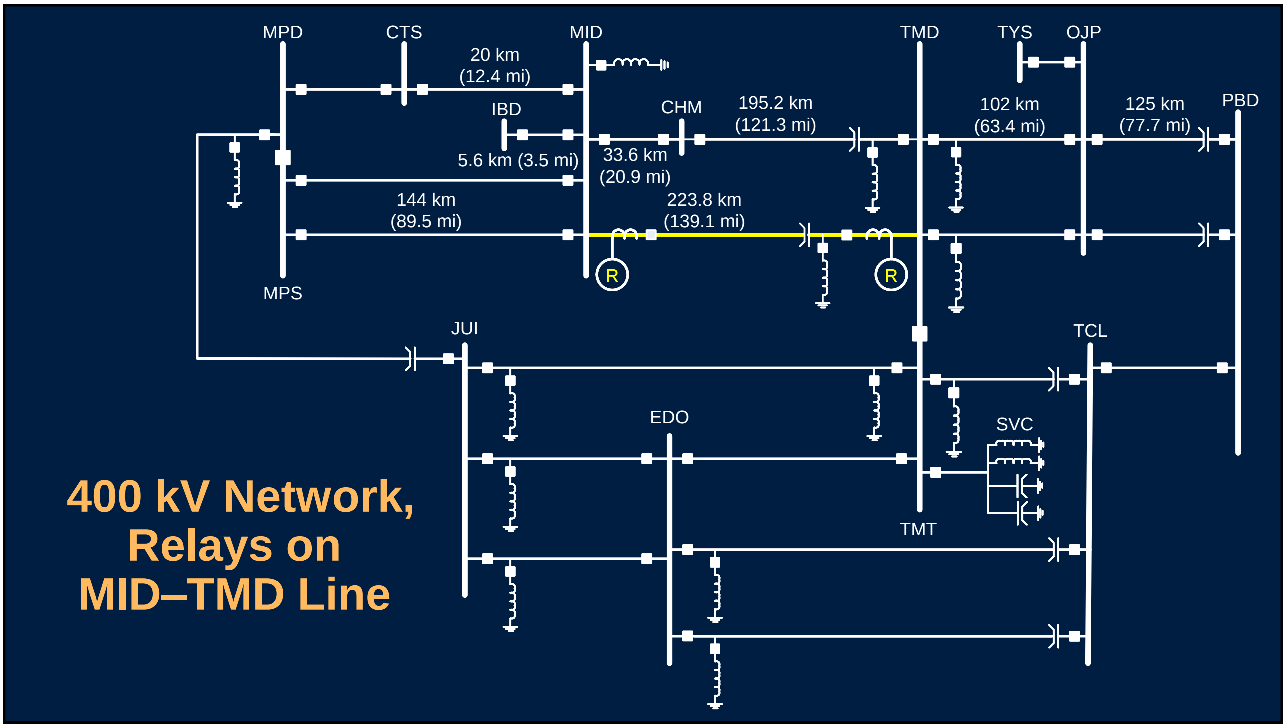


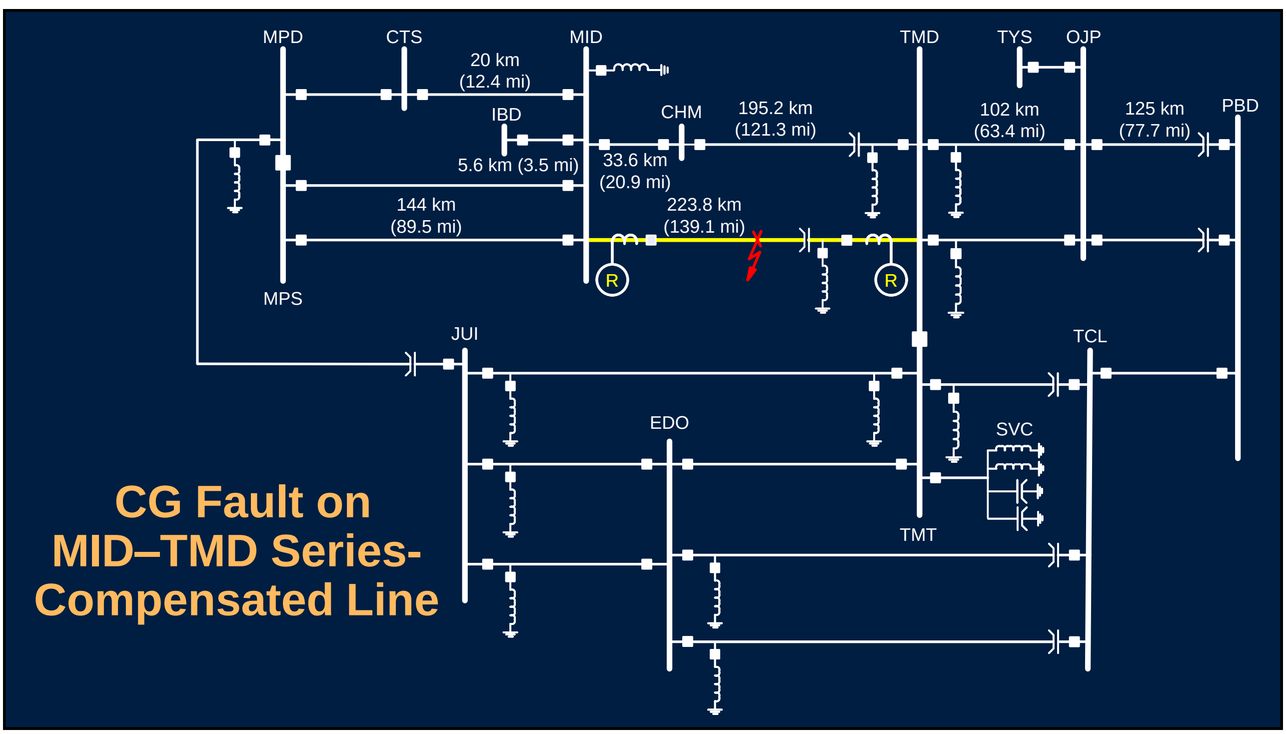
Identify All Possible Fault Locations

- Determine possible fault locations using measured TW arrival times
- Compare possible fault locations with results from DETWFL, DEZFL, and SEZFL methods
- Evaluate how expected TW patterns fit measured TW arrival times and time references
- Rank fault location alternatives on how they fit the measured TW pattern

Selecting the Best Fault Location Result

- Double-ended TW-based: highest
- Single-ended TW-based: second
- Double-ended impedance-based: third
- Single-ended impedance-based: lowest


MPD
CTS
20 km
(12.4 mi)
MID
TMD
TYS
OJP
IBD
CHM
195.2 km
(121.3 mi)
102 km
(63.4 mi)
125 km
(77.7 mi)
PBD
5.6 km (3.5 mi)
33.6 km
(20.9 mi)
144 km
(89.5 mi)
223.8 km
(139.1 mi)
R
R
MPS
JUI
TCL
EDO
SVC
TMT
400 kV Network,
Relays on
MID–TMD Line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R
R
MPS
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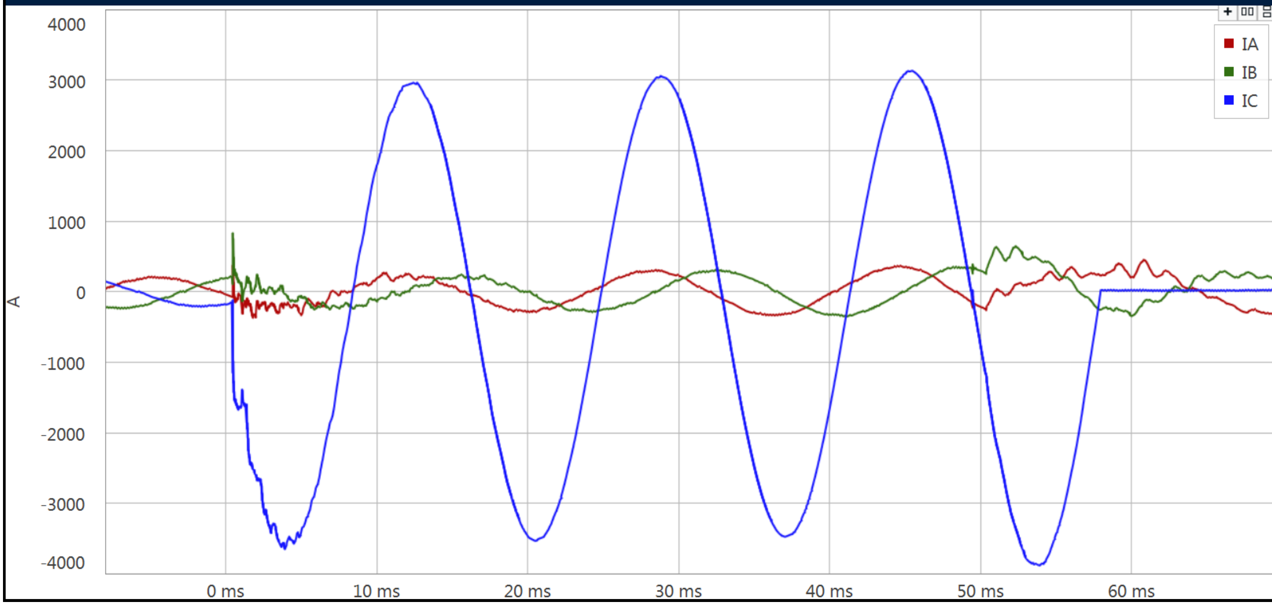
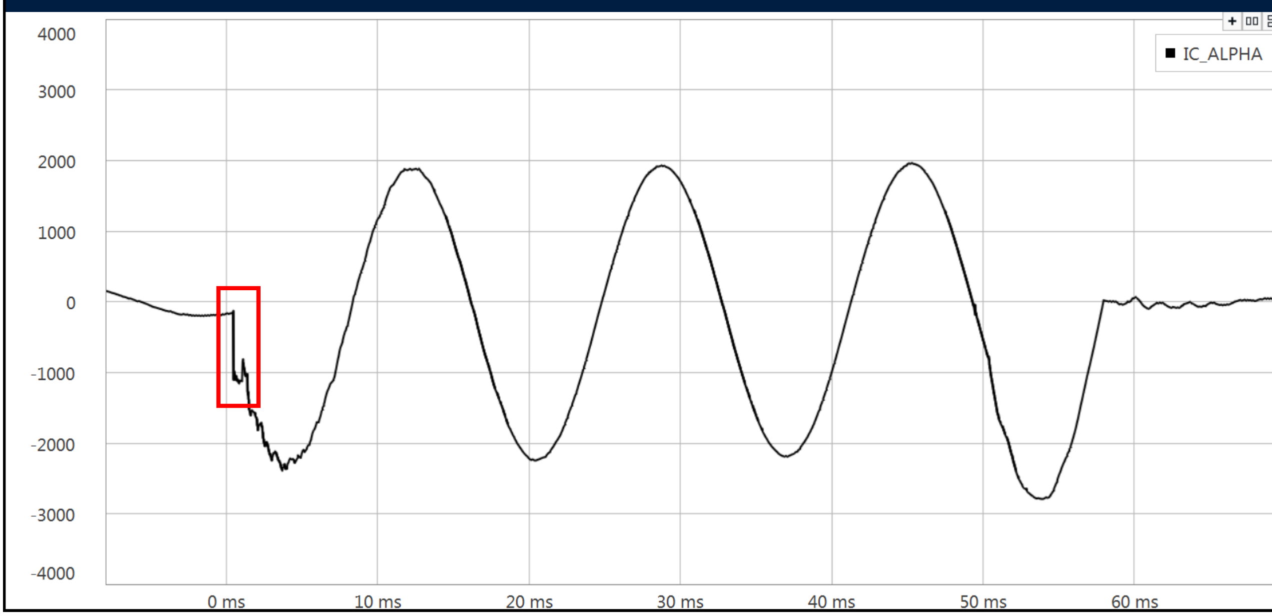
TCL
EDO
SVC
TMT
CG Fault on
MID–TMD Series-
Compensated Line

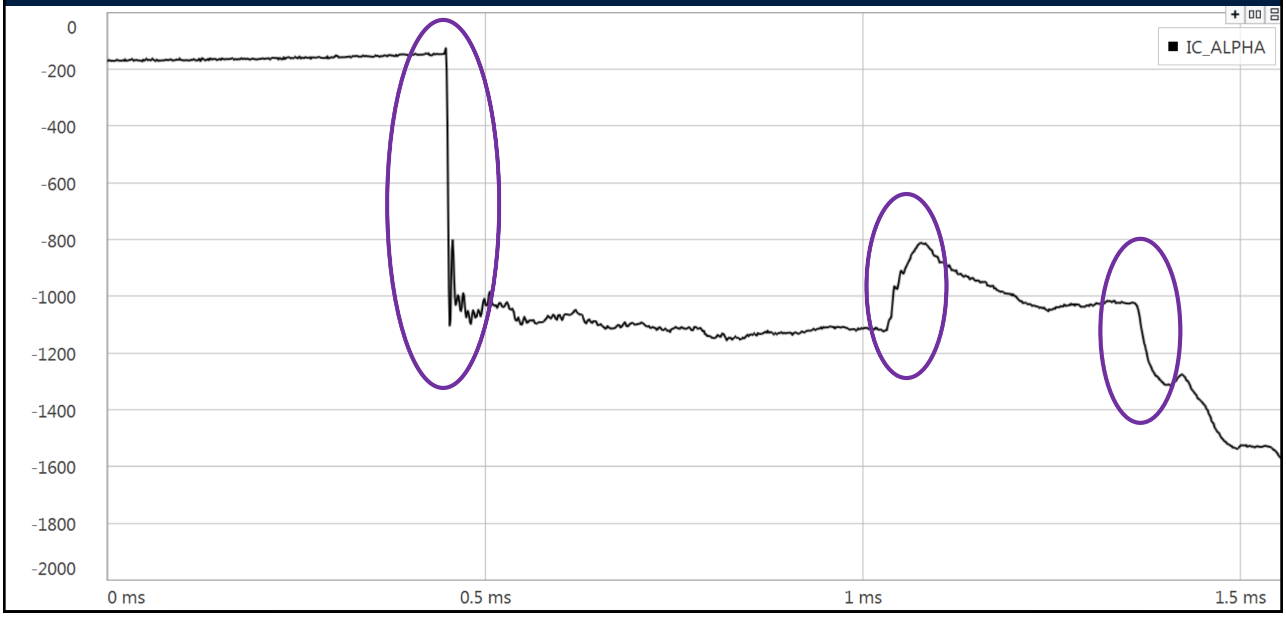
Phase Currents at MID for CG Fault



Alpha-C ($i_C - i_0$) Current at MID for CG Fault

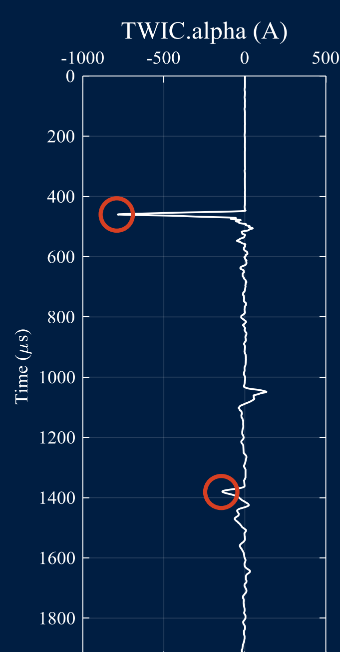


Extract Traveling Wave Information



Identify the Proper Reflections

Alpha-C Current TW at MID

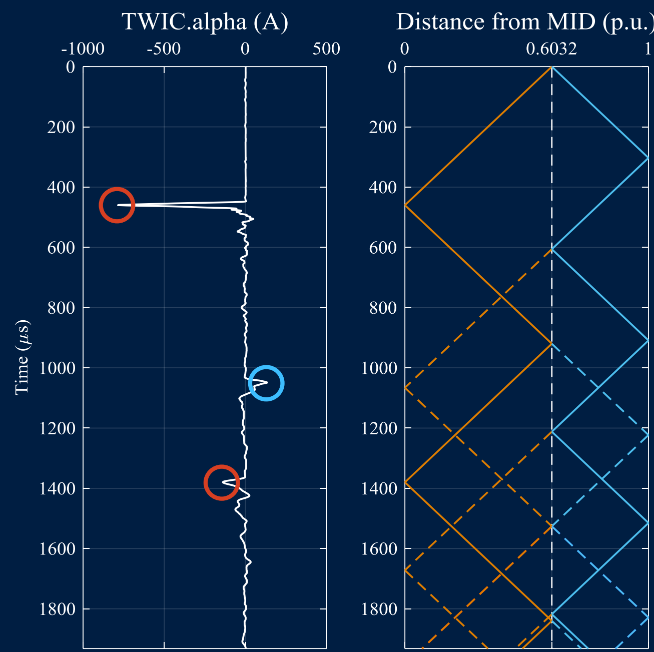


Identify the Proper Reflections

Alpha-C Current TW at MID

FL result: 135.03 km (89.90 mi)

Line patrol: 135 km (89.89 mi)



Single-Ended TWFL Method Highlights

- Uses information from all arriving TWs to identify first refection from fault
- Can be applied using high-resolution oscillography records
- Has been implemented in a protective relay and provides results in real time
- Provides accuracy within one tower span without communications