Line Protection at the Speed of Light Improves Power System Stability

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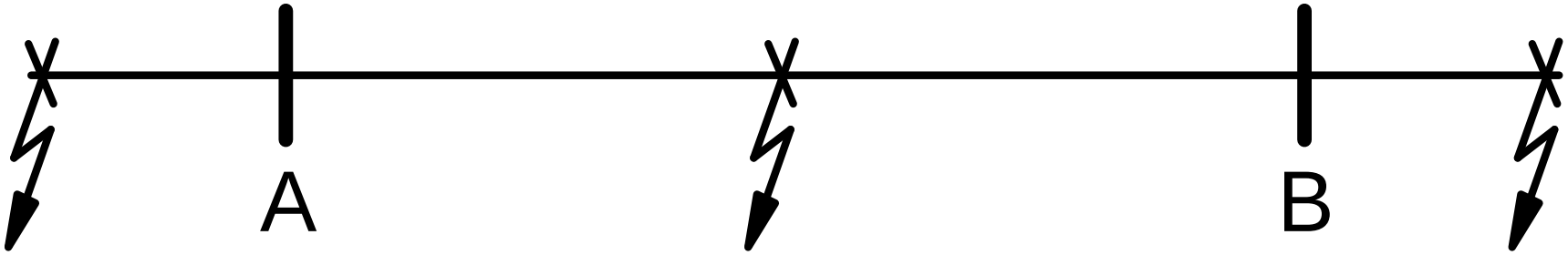
Higher Expectations For Protection

- Reduce fault clearing time for critical lines
- Improve Power Quality
- Protect lines near inverter-based sources
- Protect series-compensated lines with inherent security and dependability
- Avoid human errors and reduce engineering time through simplicity

ASEA RALDA (1976)

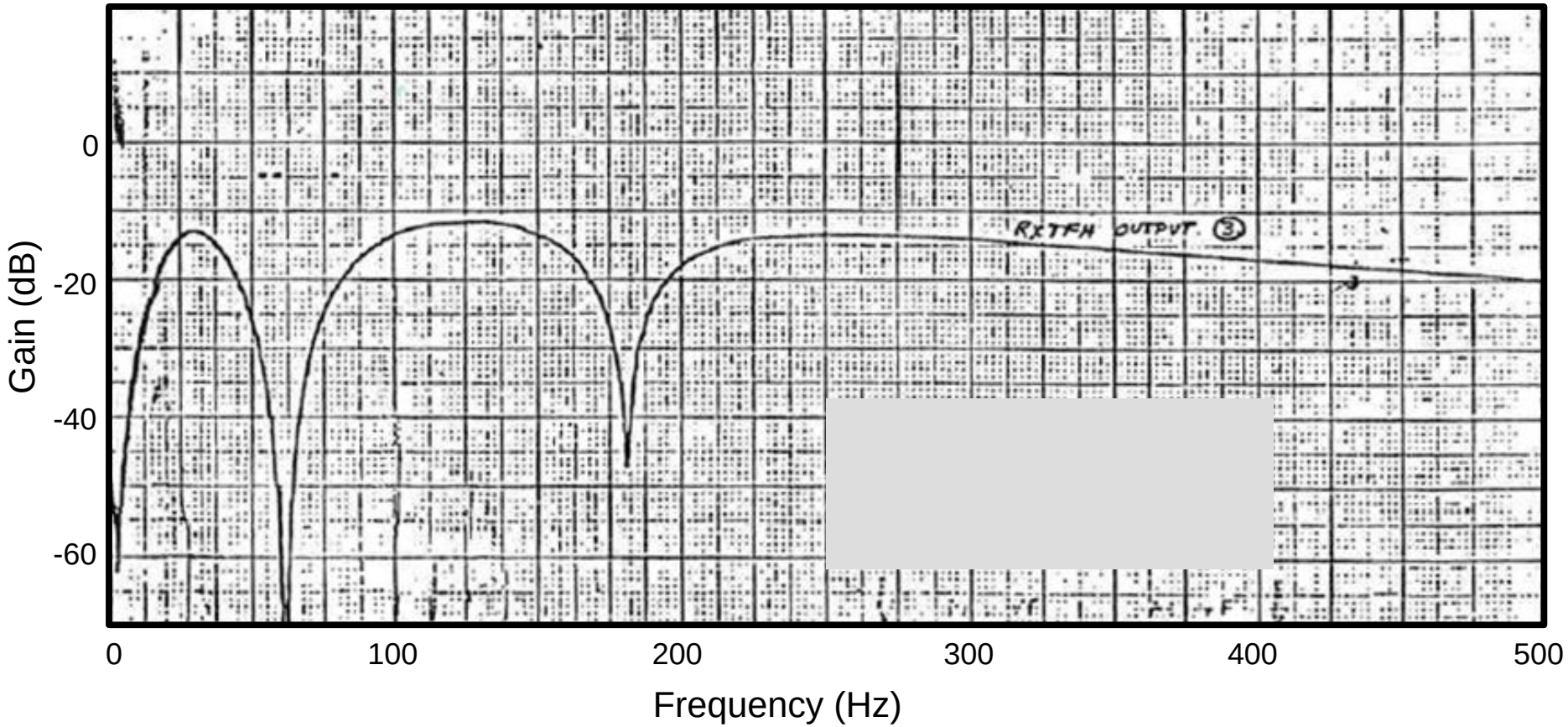
5 ms Directional Wave Relay



Δi	Δv	Δi	Δv
-	-	+	-
+	+	-	+

ASEA RALDA Frequency Bandwidth

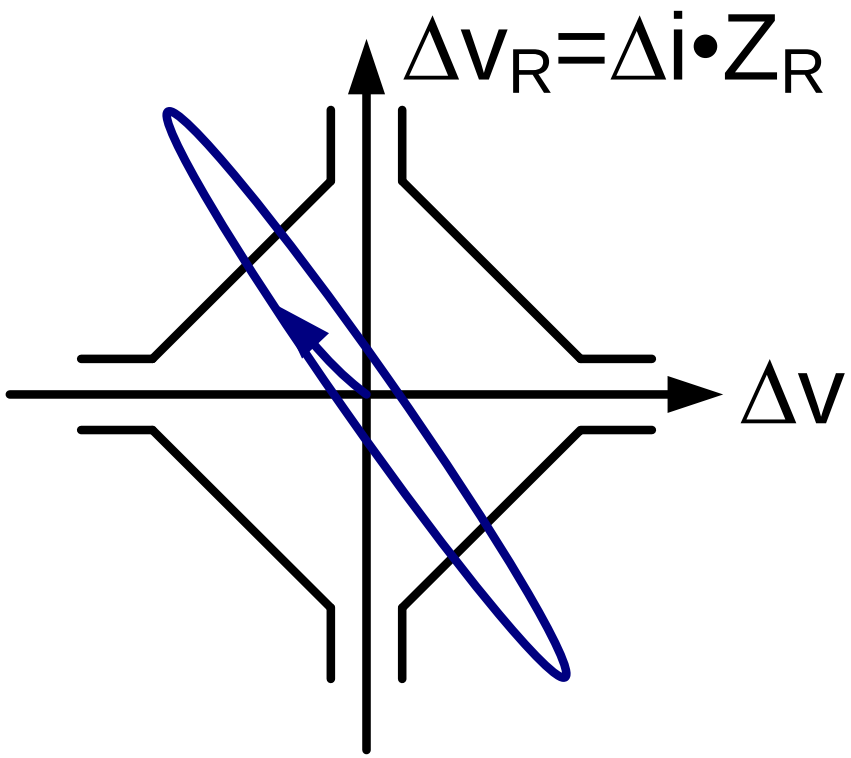
Filtering Attenuates DC, Fund. and 3rd Harm.

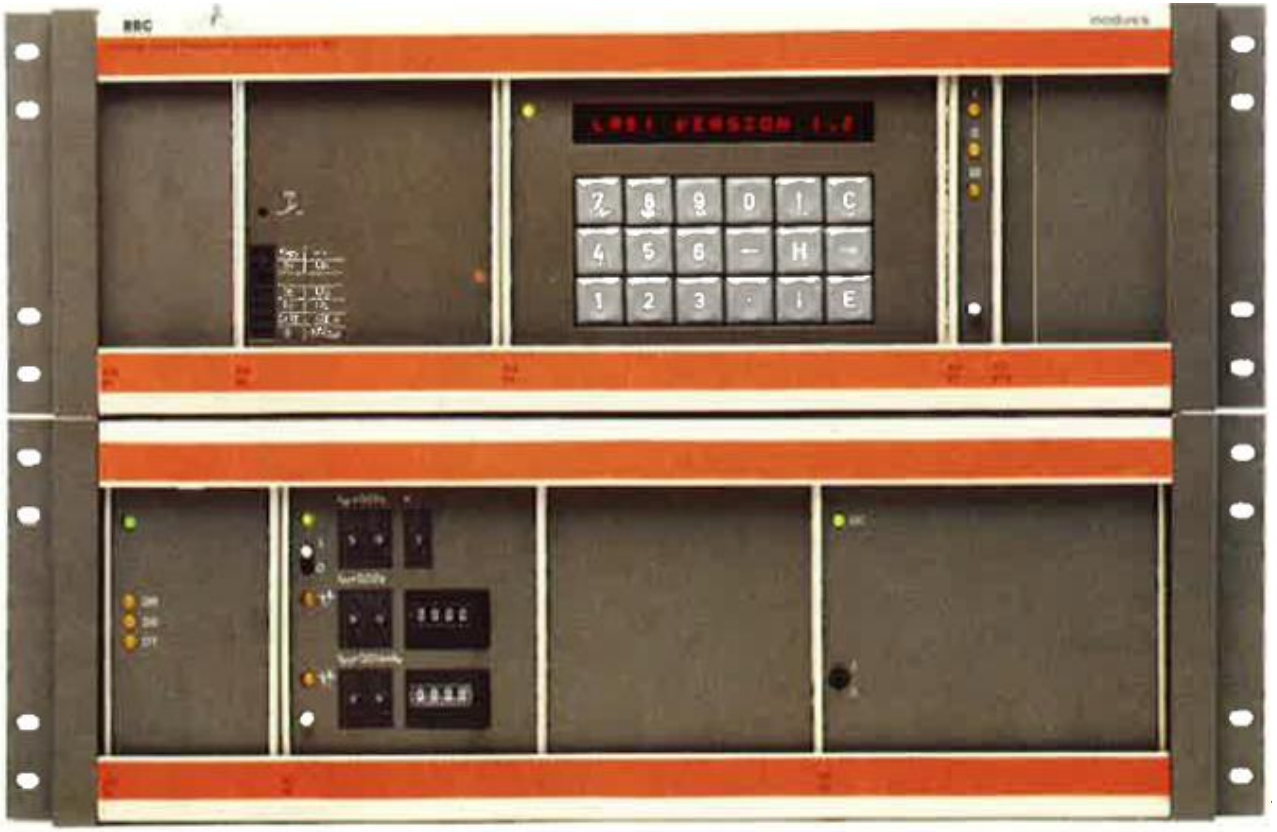


BBC LR-91 (1985)

5 ms UHS Directional Wave Relay

Fault is forward when the operating point enters the 2nd or 4th quadrant

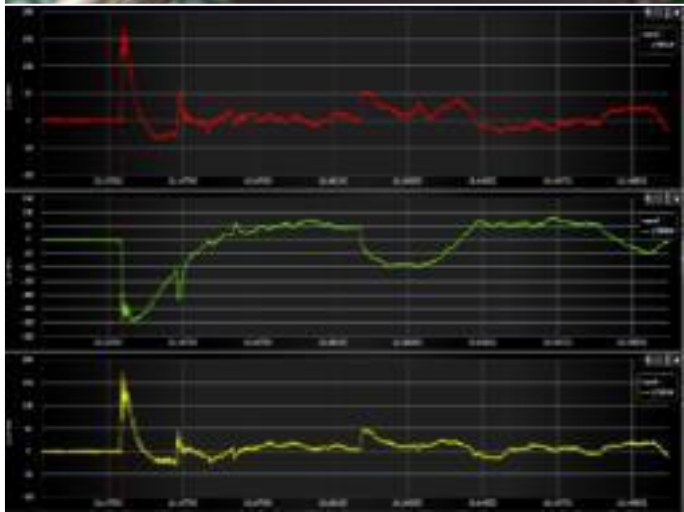




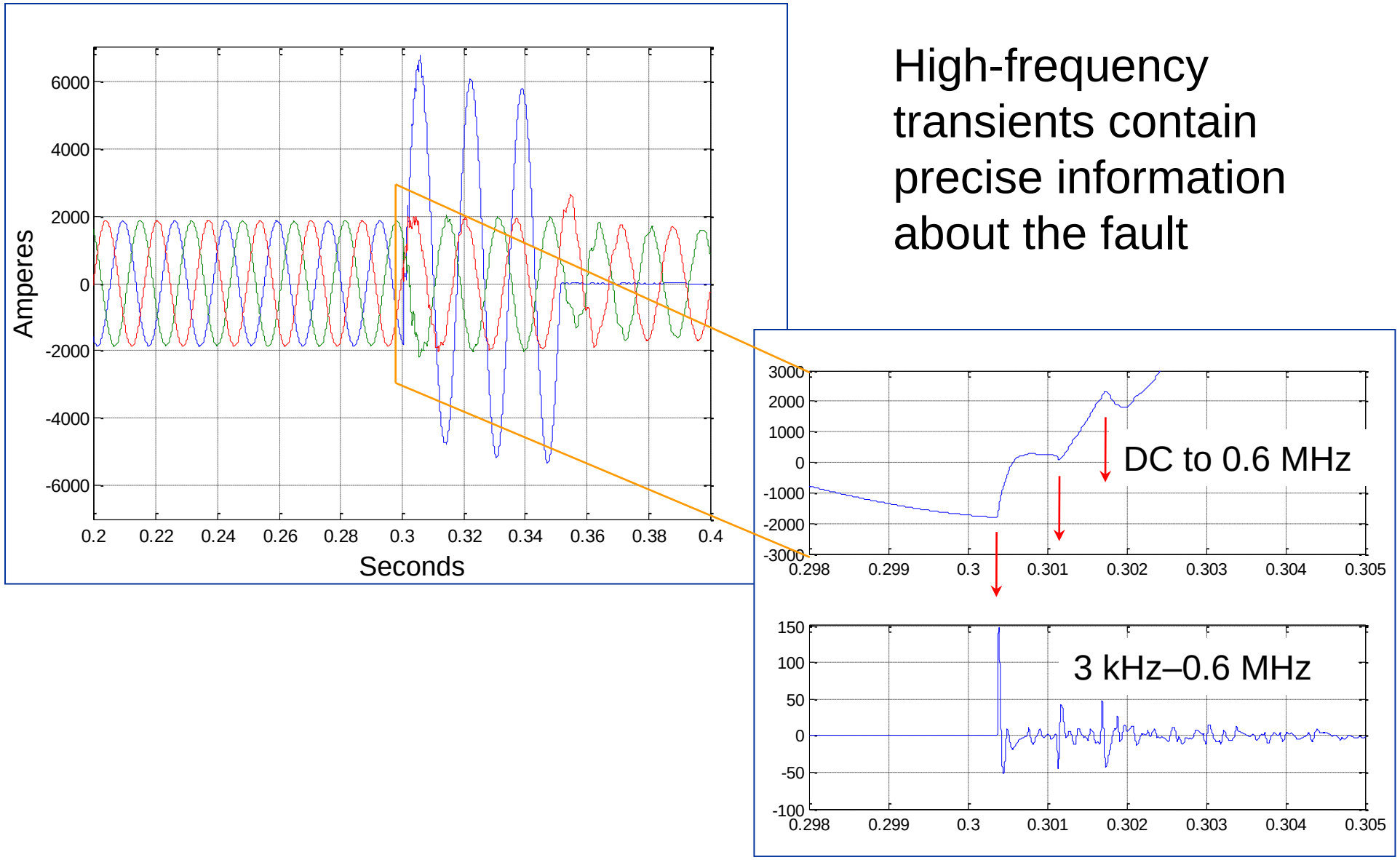
Traveling Waves

Technology and Tools

- Better technology
  - High-speed ADC
  - Processing power
  - High-bandwidth communications
- Advanced simulation tools like EMTP
- MHz records of field events
- TW fault locating experience and new ideas

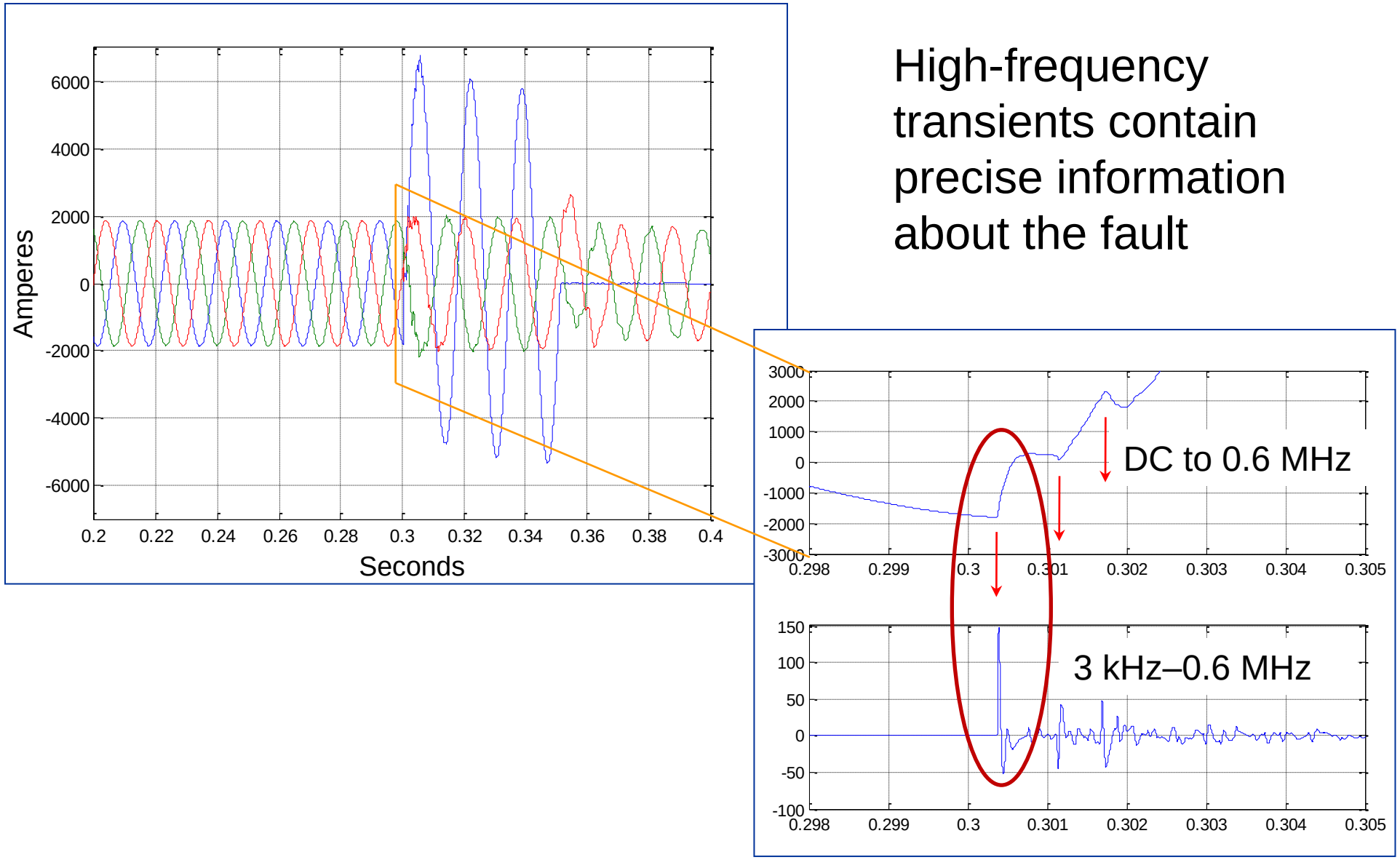


Transients Contain Fault Information



High-frequency transients contain precise information about the fault

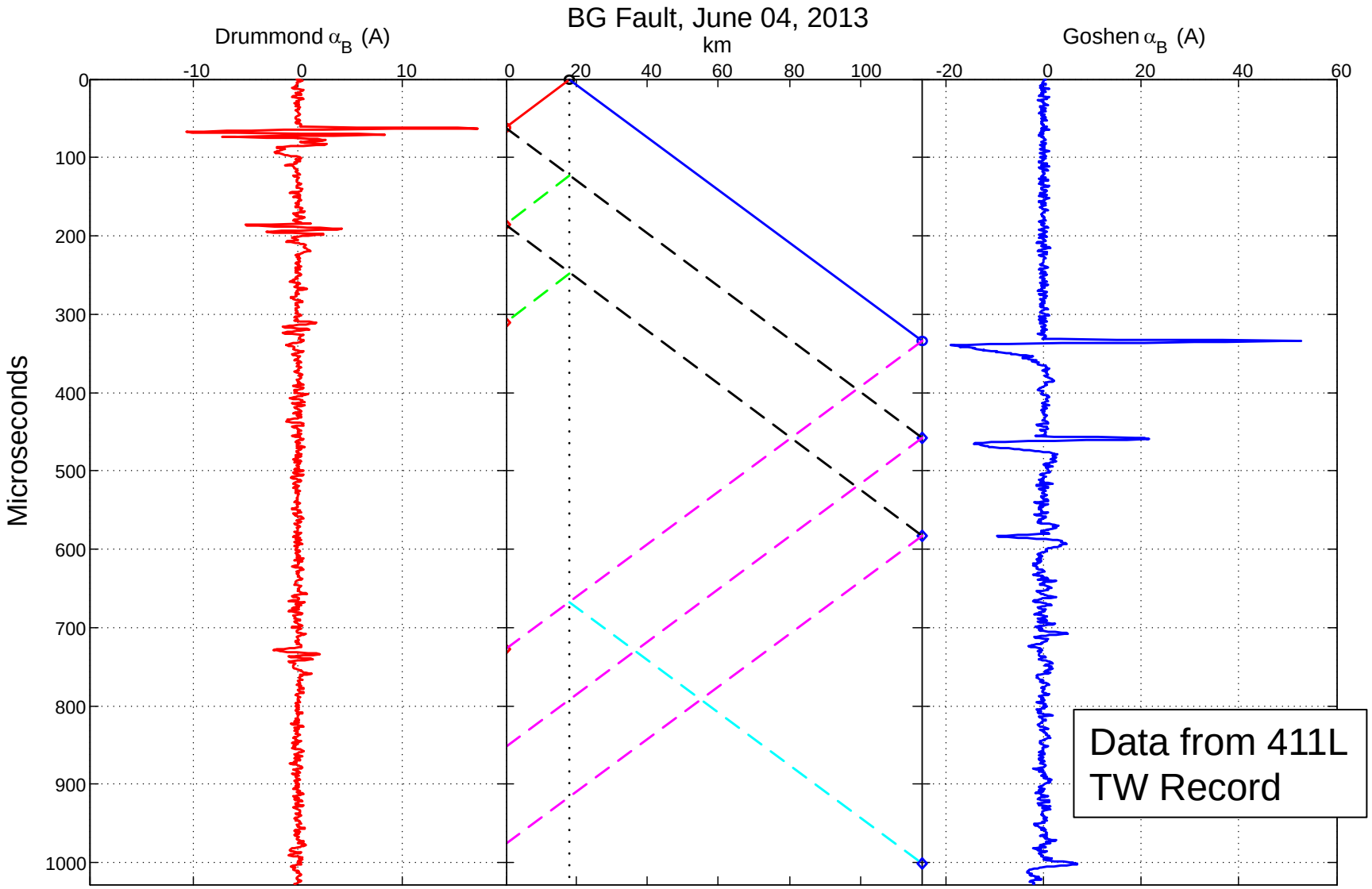
Transients Contain Fault Information



High-frequency transients contain precise information about the fault

Learning From Fault Locating Experience

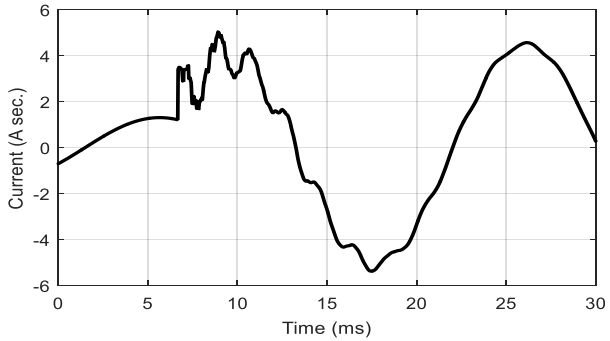
BG Fault at 18.02 km From Drummond



Event Playback to Learn From Field Events

UHS Relay

1.2 Second Events



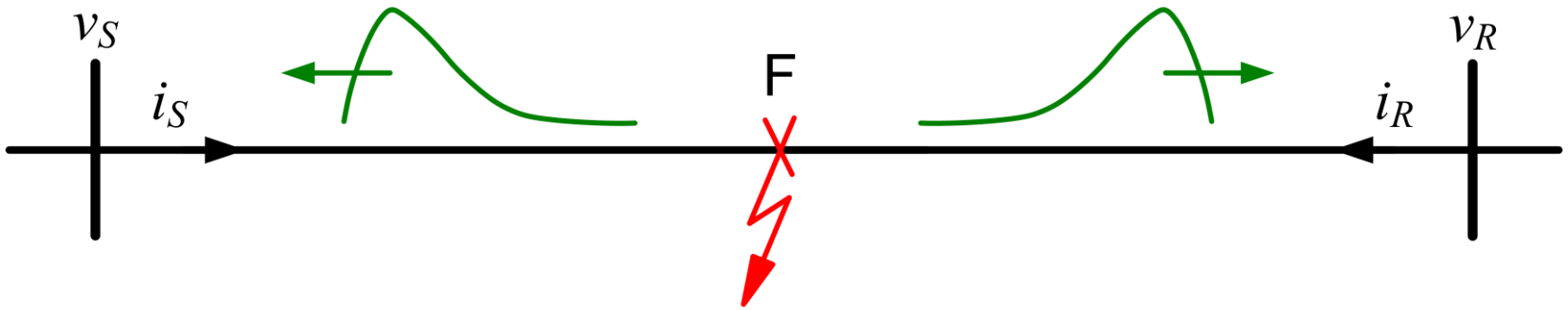
Local and Remote Voltages and Currents

1 MHz Voltages

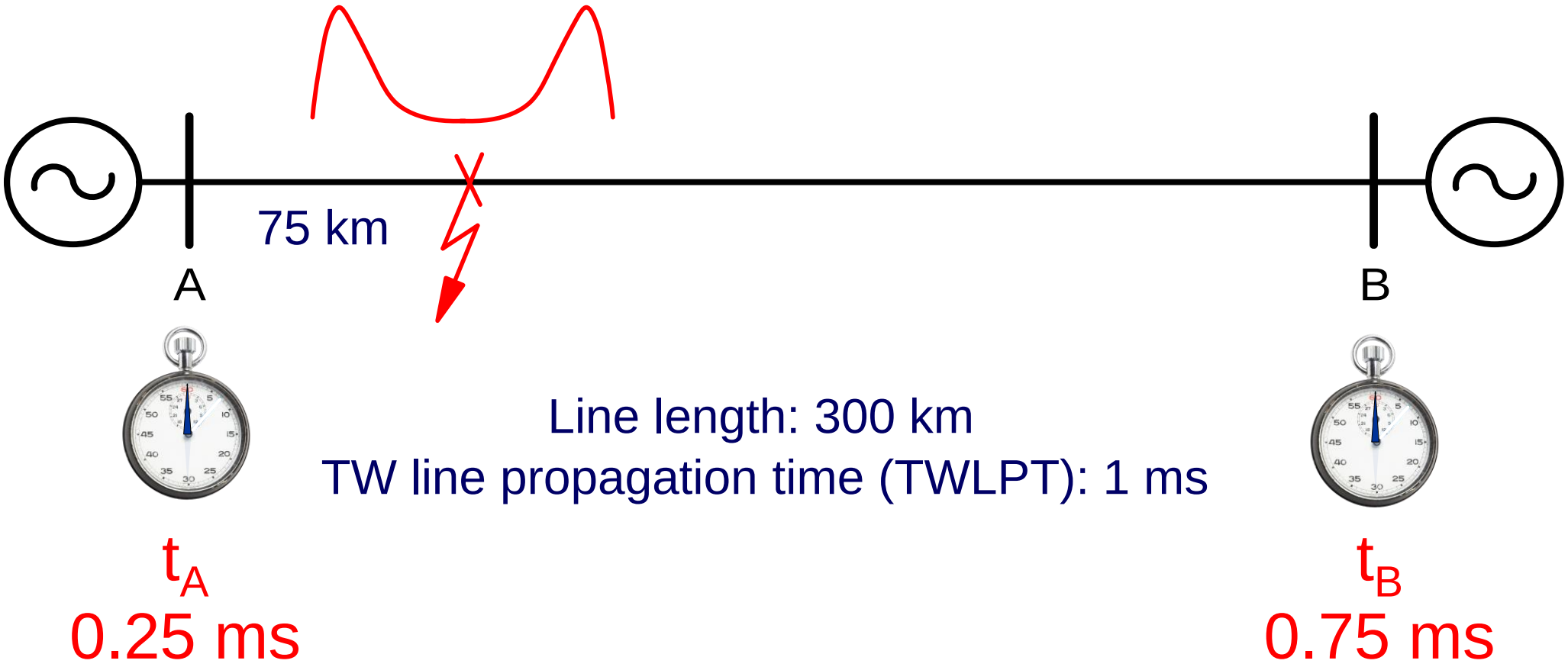
1 MHz Currents

Protection

Faults Launch Waves That Travel Close to The Speed of Light



Wave Arrives First to The Terminal Closest to The Fault

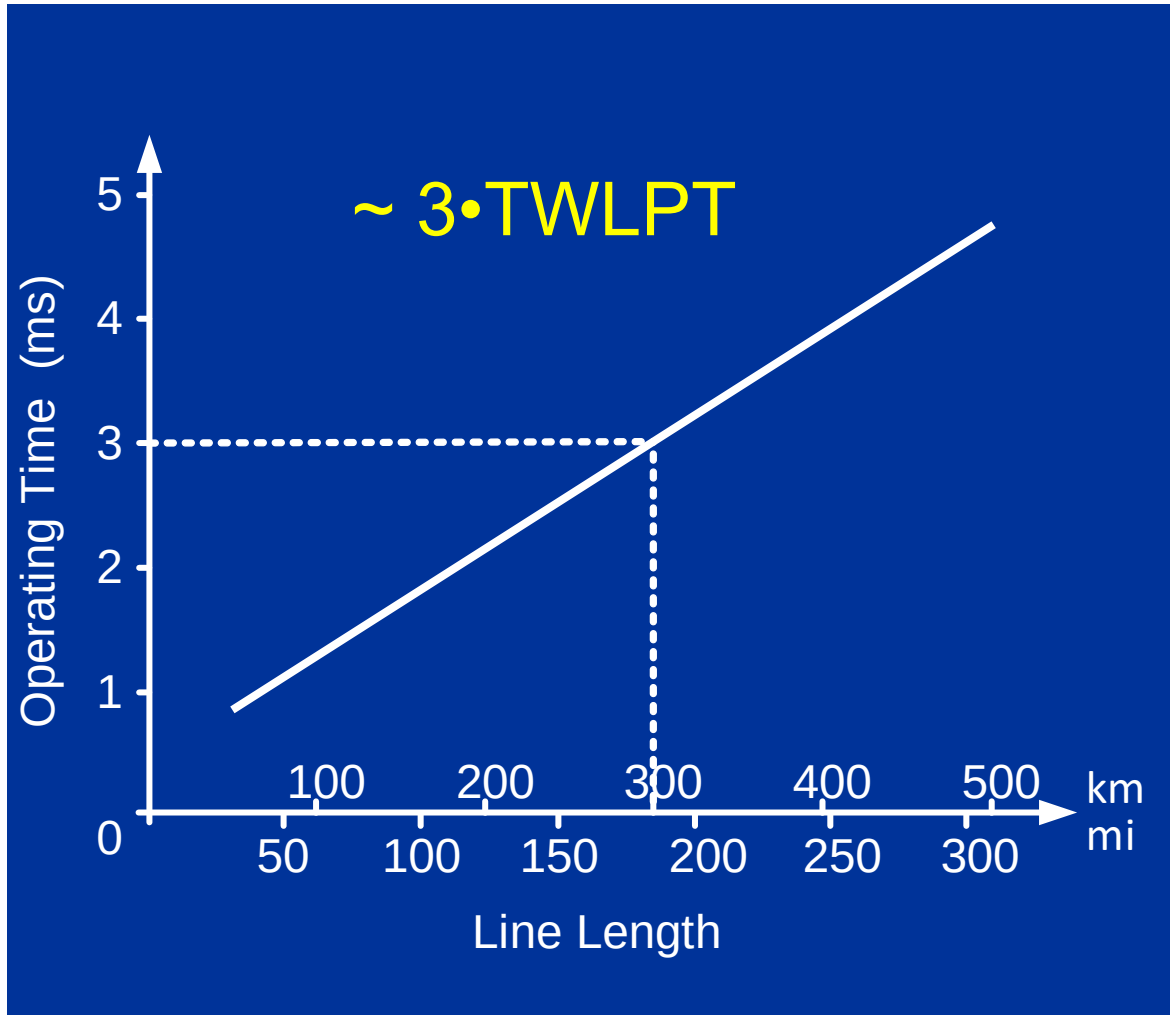


Traveling-Wave Differential Scheme

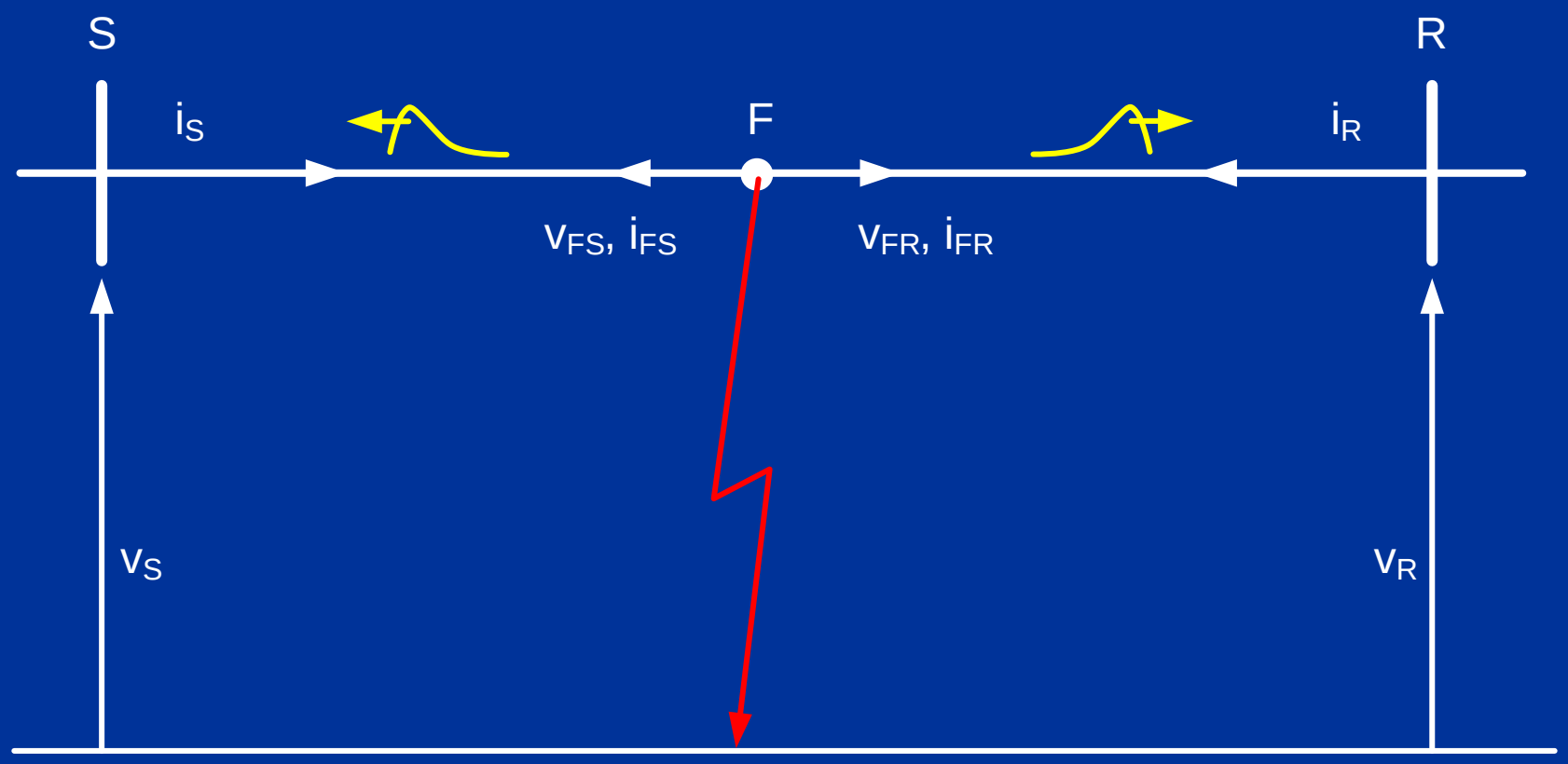
TW87

TW Differential Scheme (TW87)

- Requires point-to-point fiber
- Does not need satellite clocks
- Intended for two-terminal lines
- Can be applied to lines with
  - Series-compensation
  - Multiple terminals
  - Tap lines

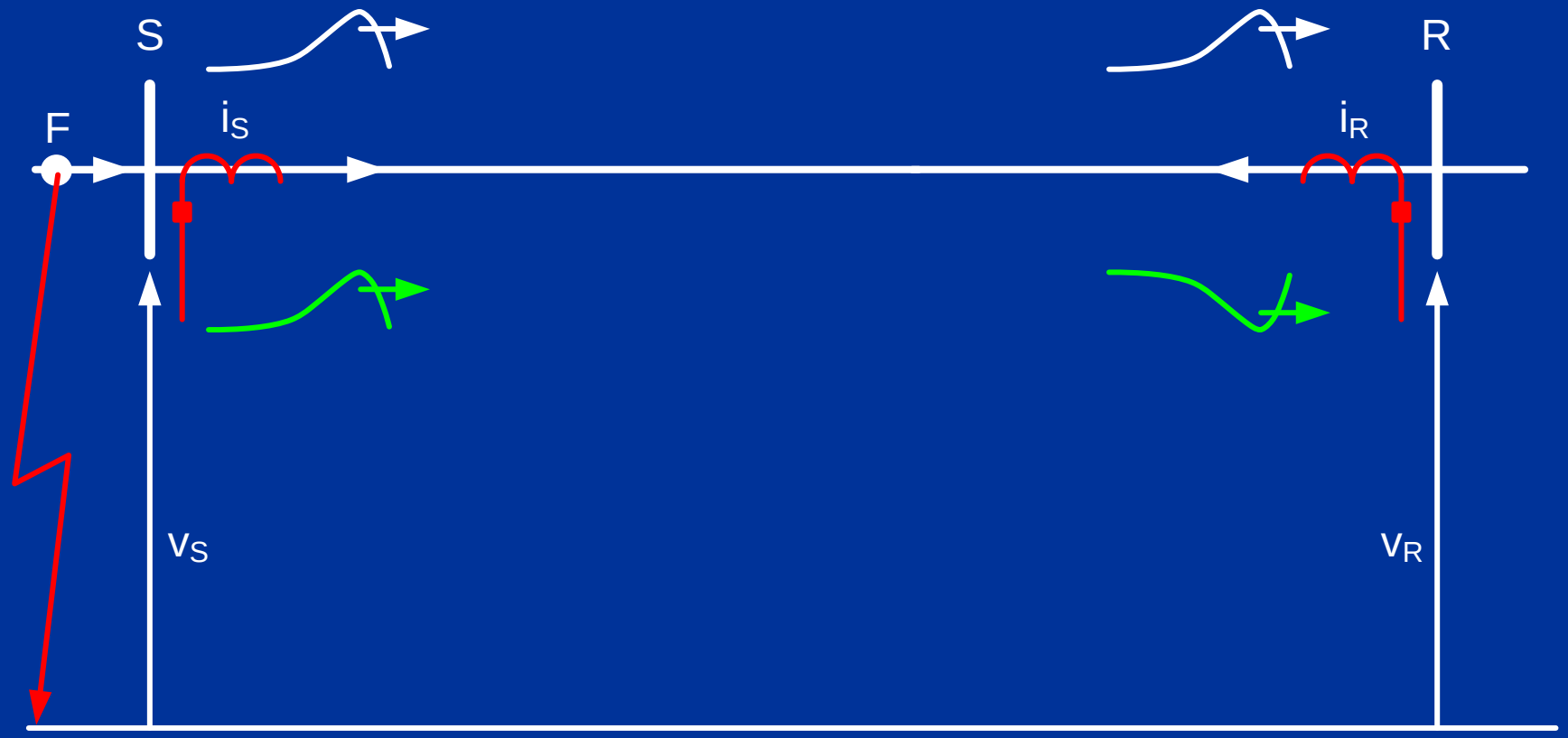


TW87 Operating Quantity



$$i_{OP(t)} = \left| i_{S(t)} + i_{R(t \pm \Delta t)} \right| \qquad \Delta t < TWLPT$$

TW87 Restraining Quantity 1



$$i_{RT1(t)} = \left| i_{S(t-TWLPT)} - i_{R(t)} \right|$$

TW87 Restraining Quantity 2

$$i_{RT2(t)} = \left| i_{R(t-TWLPT)} - i_{S(t)} \right|$$

TW87 Maximum Restraining Quantity

$$i_{RT(t)} = \max\left(i_{RT1(t)}, i_{RT2(t)}\right)$$

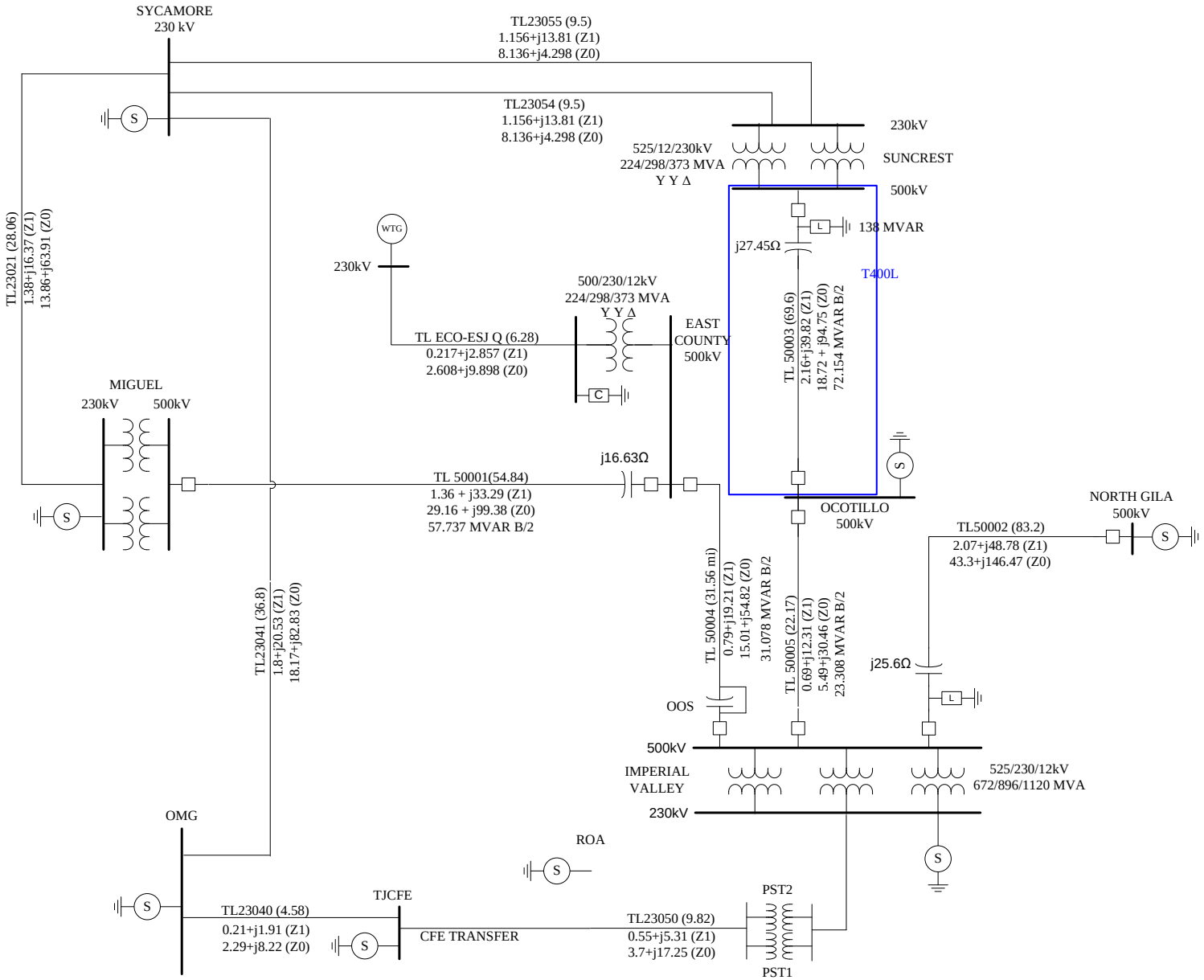
TW Differential Element Principle

- External fault TWs are
  - of opposite polarity
  - spaced one line travel time **TWLPT** apart
- Internal fault TWs are
  - of same polarity
  - spaced less than one line travel time **TWLPT**

Sum of first TWs = OPERATE

*Difference of TWs **TWLPT** apart = RESTRAIN*

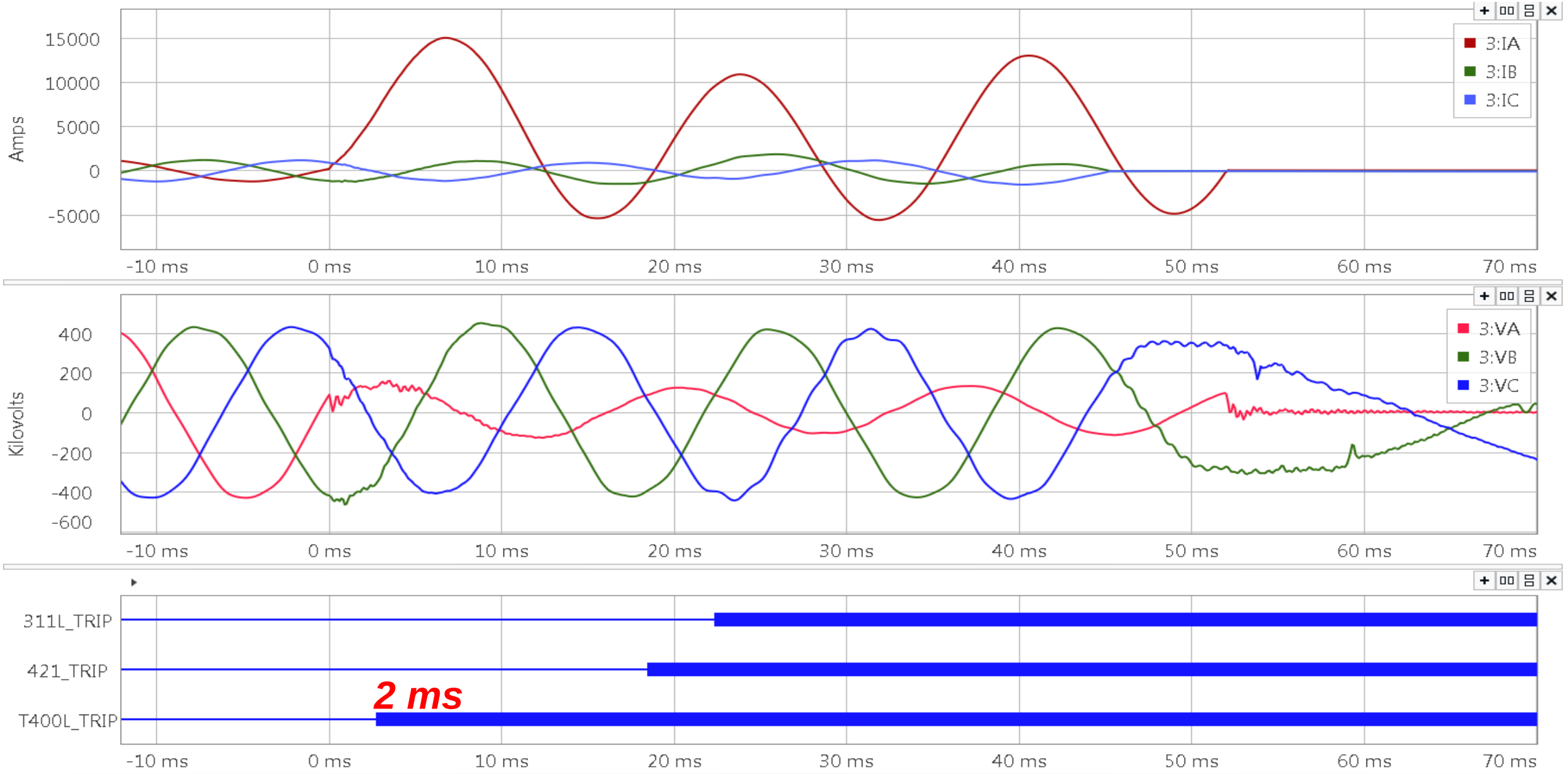
500kV, 69.3 mi, Series Compensated Line



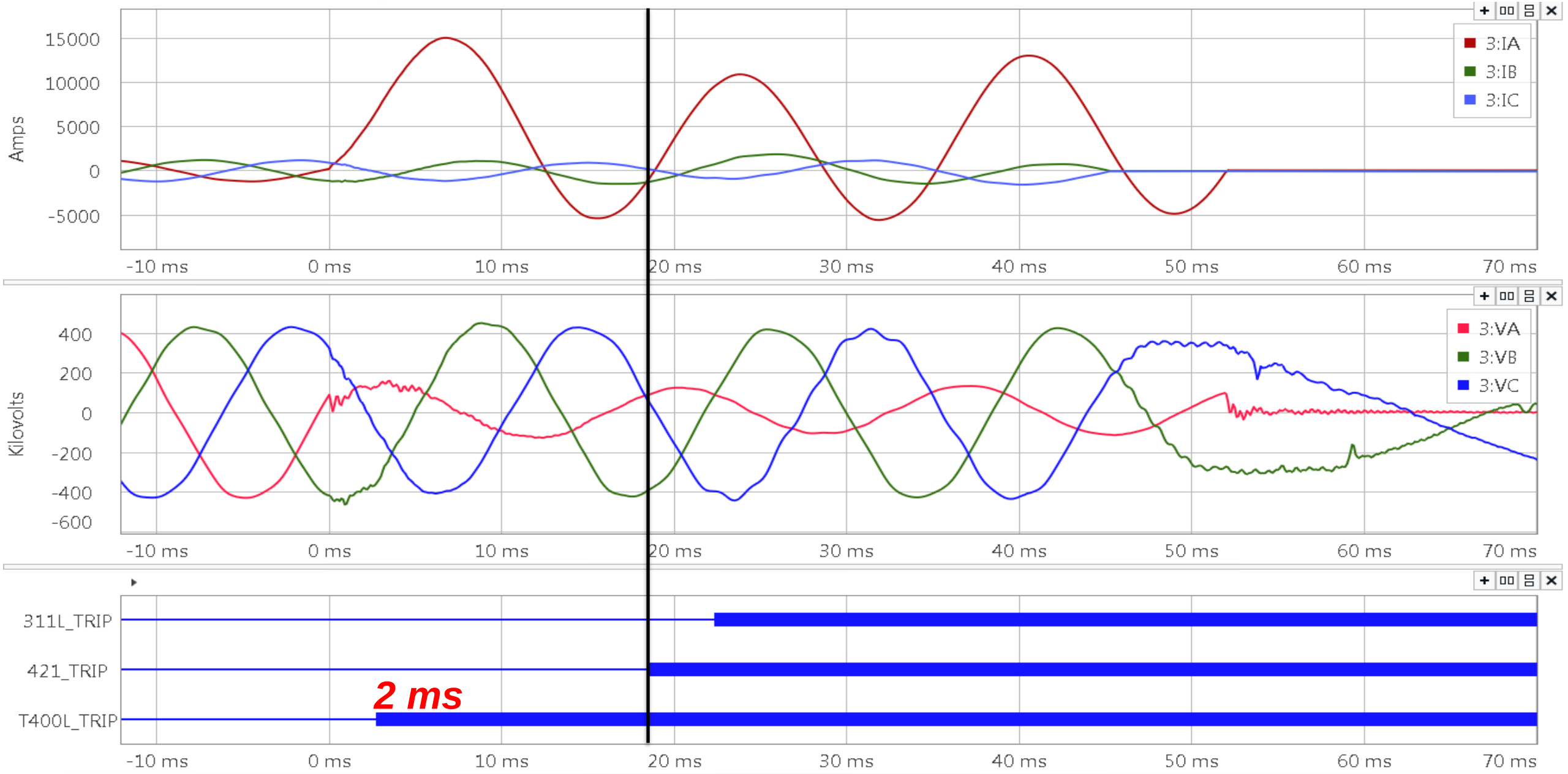
SDGE

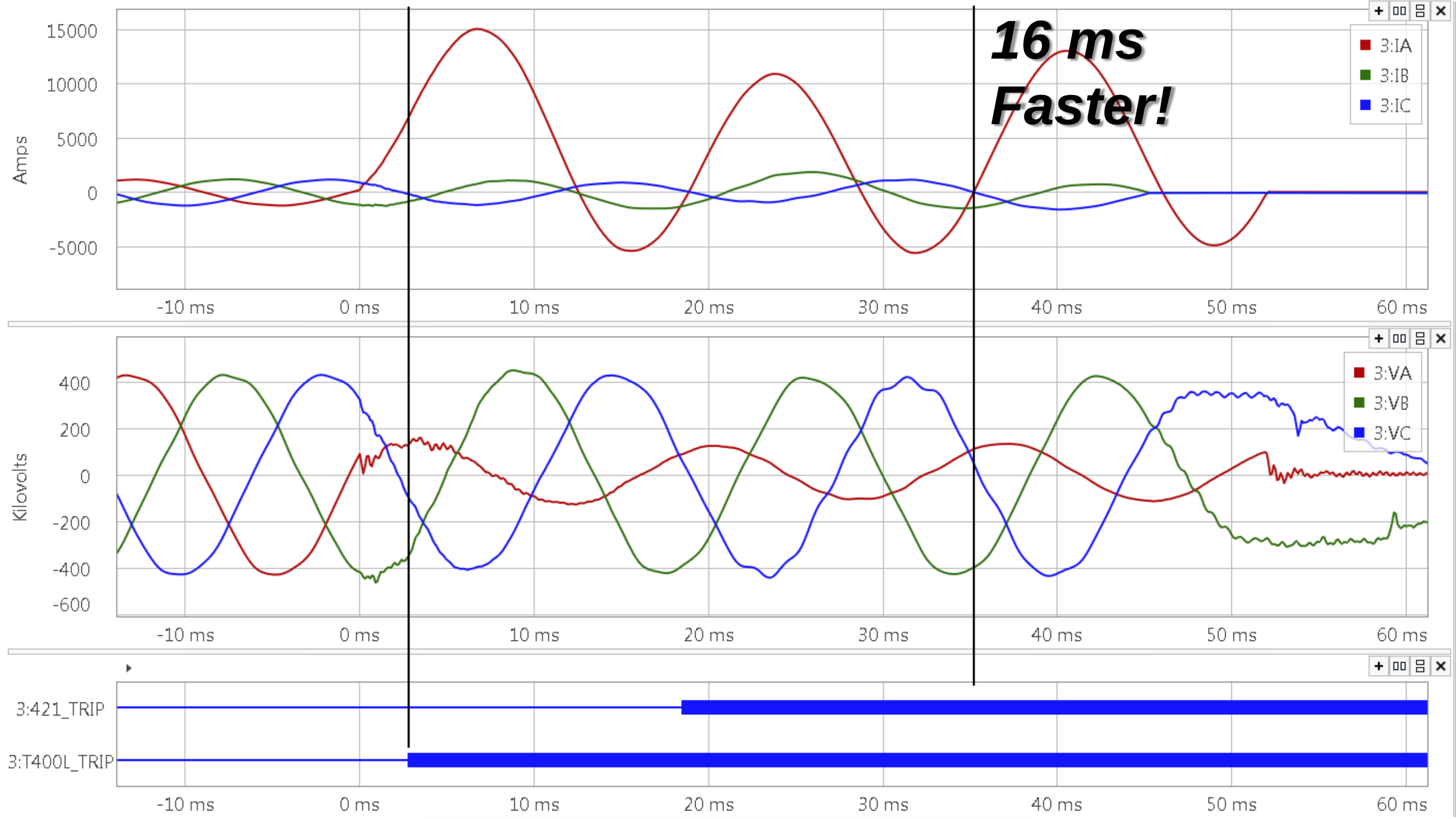
A Sempra Energy utility®

TW87 Operates in 2 ms for an AG Fault

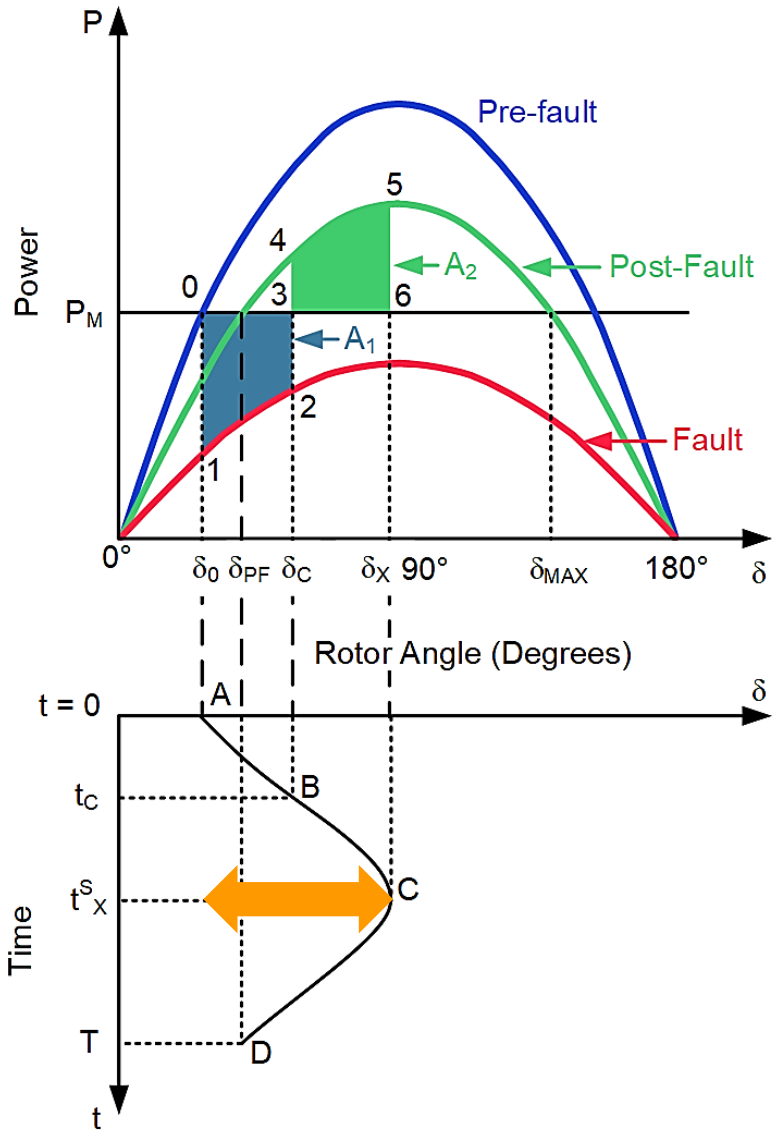


TW87 Operates in 2 ms for an AG Fault




16 ms
Faster!
Amps
15000
10000
5000
0
-5000
3:IA
3:IB
3:IC
-10 ms
0 ms
10 ms
20 ms
30 ms
40 ms
50 ms
60 ms
Kilovolts
400
200
0
-200
-400
-600
3:VA
3:VB
3:VC
3:421_TRIP
3:T400L_TRIP

Faster Fault Clearing Times Reduce Power Angle Oscillations



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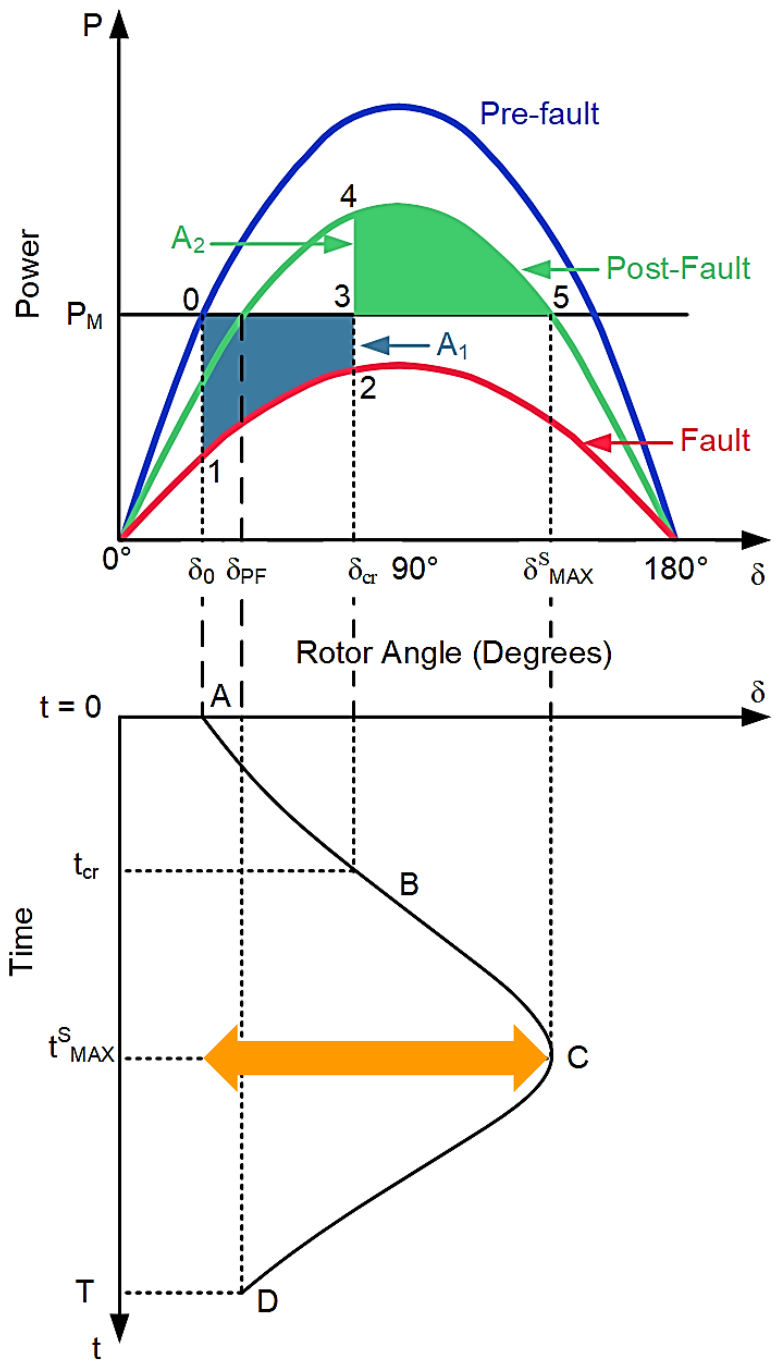

Summary

- Traveling wave differential scheme with direct fiber communications operates in ~ 3•TWLPT
- Fast fault clearing times
  - Reduce power angle oscillations
  - Minimize power system stress
  - Improves power quality

Questions?