Solving Line Protection Challenges in Systems with Inverter-Based Sources Using Protection Principles Based on Fault-Induced Signals

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Desired Line Protection Characteristics for Systems with Renewables

- Sensitivity for resistive faults

- Very fast operation

  - Preserve dynamic system stability
  - Operate before fault signals subside

- Operation based on fault-induced signals; less reliance on sources

- Dependability with all line terminals fed from renewables
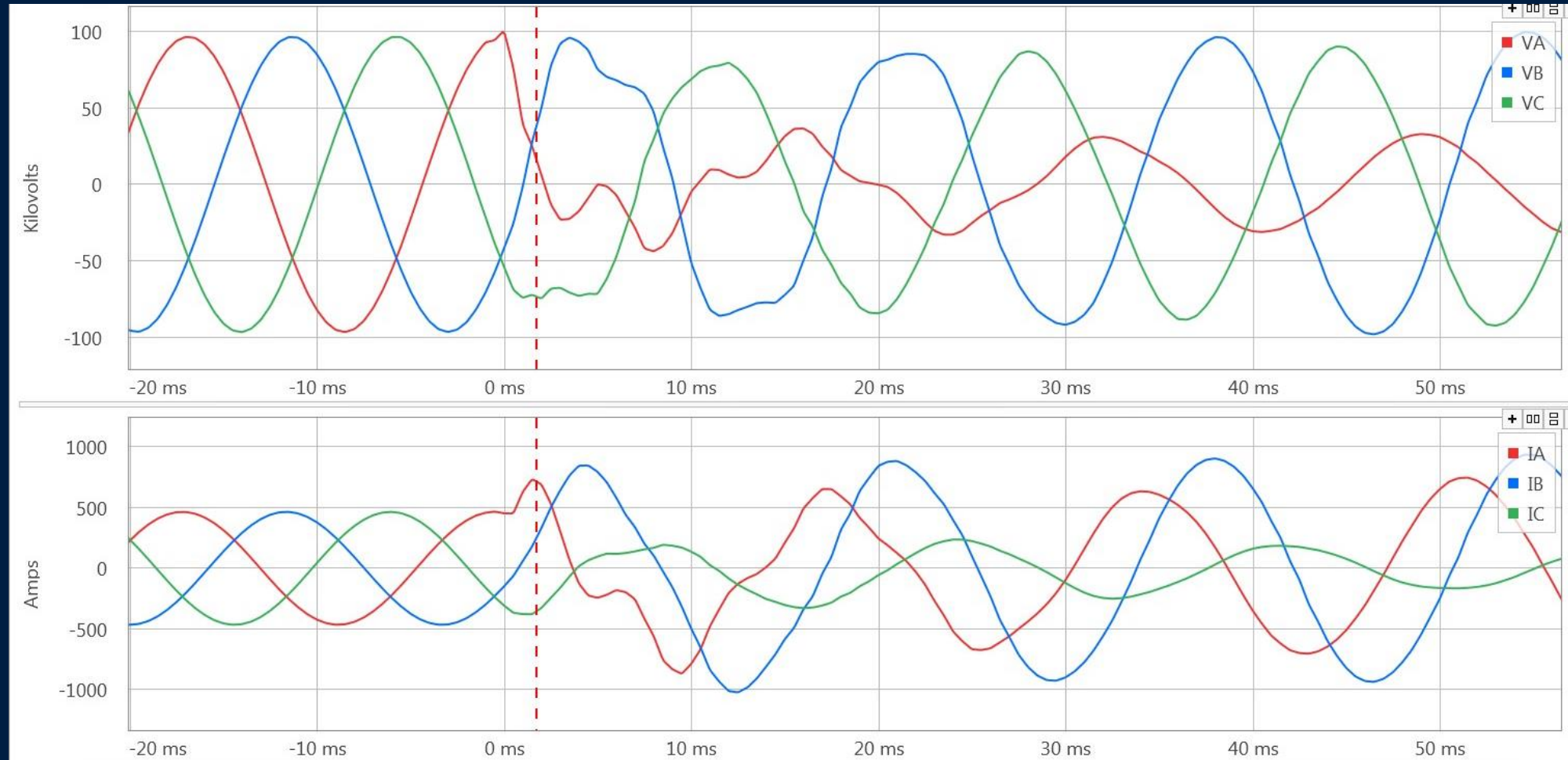
Example
AG Fault on a Line Interconnecting a Type 3 Wind Farm
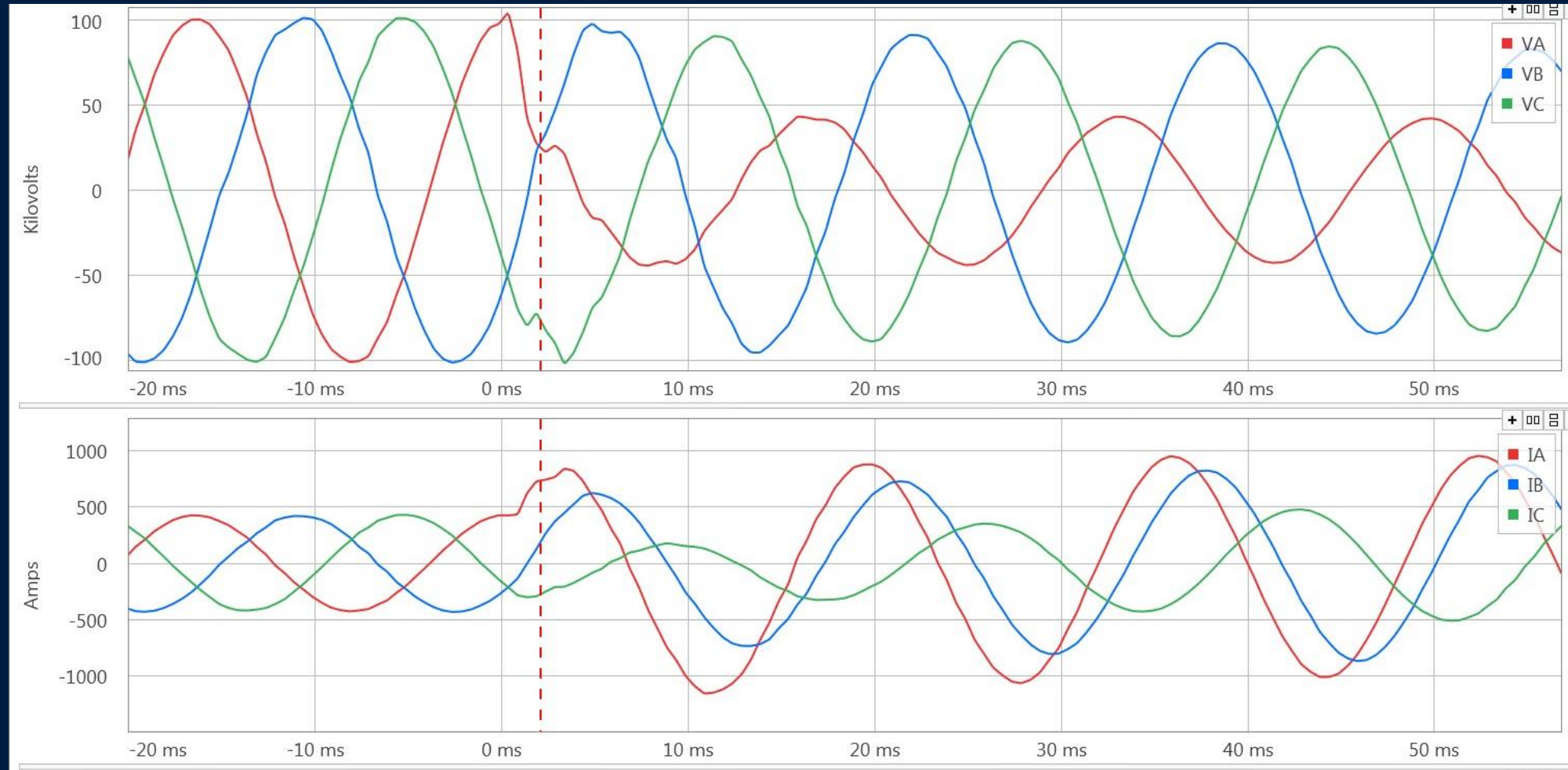
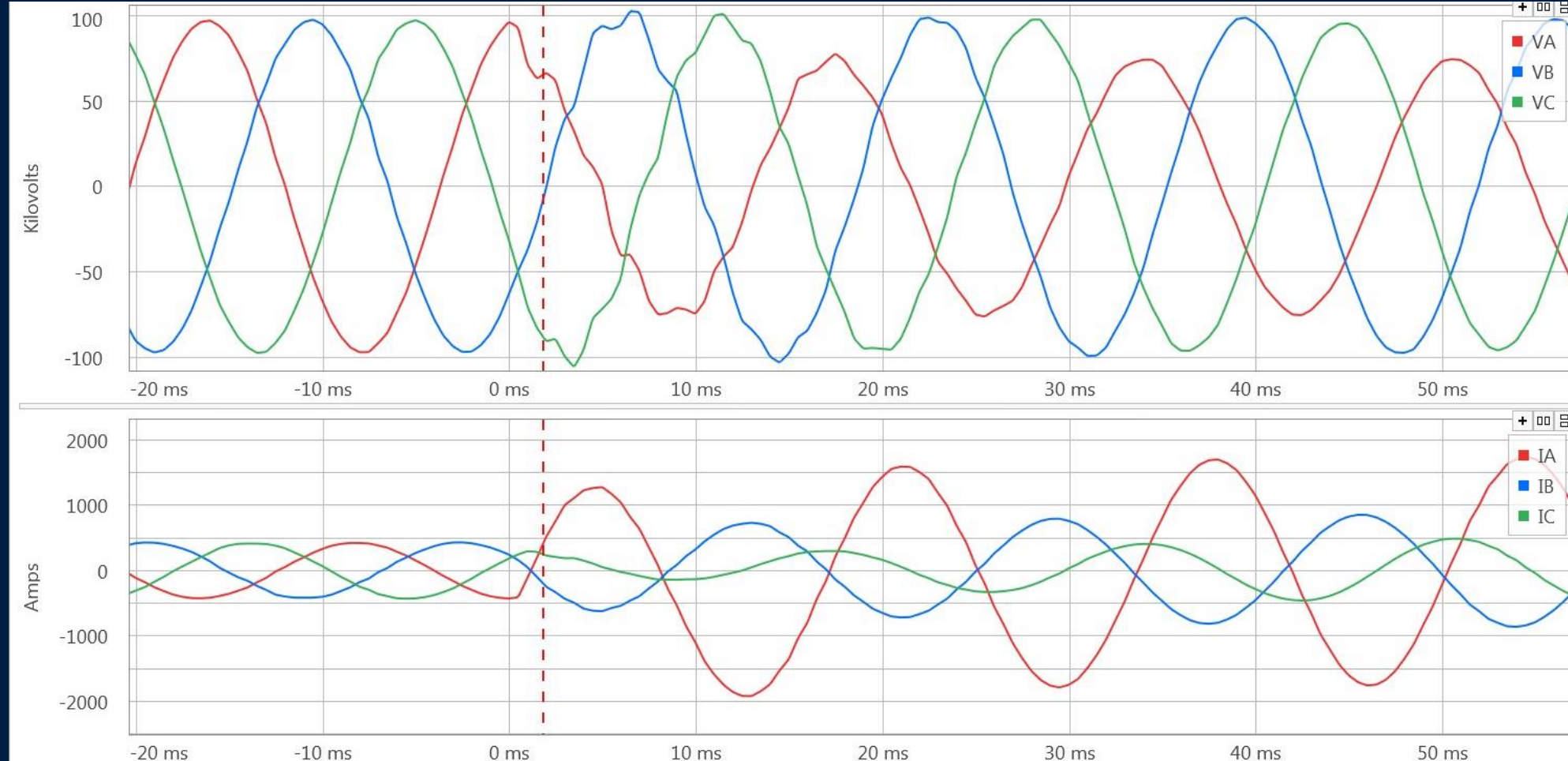100 km, 120 kV line carrying 60 MW of wind-generated power

Example
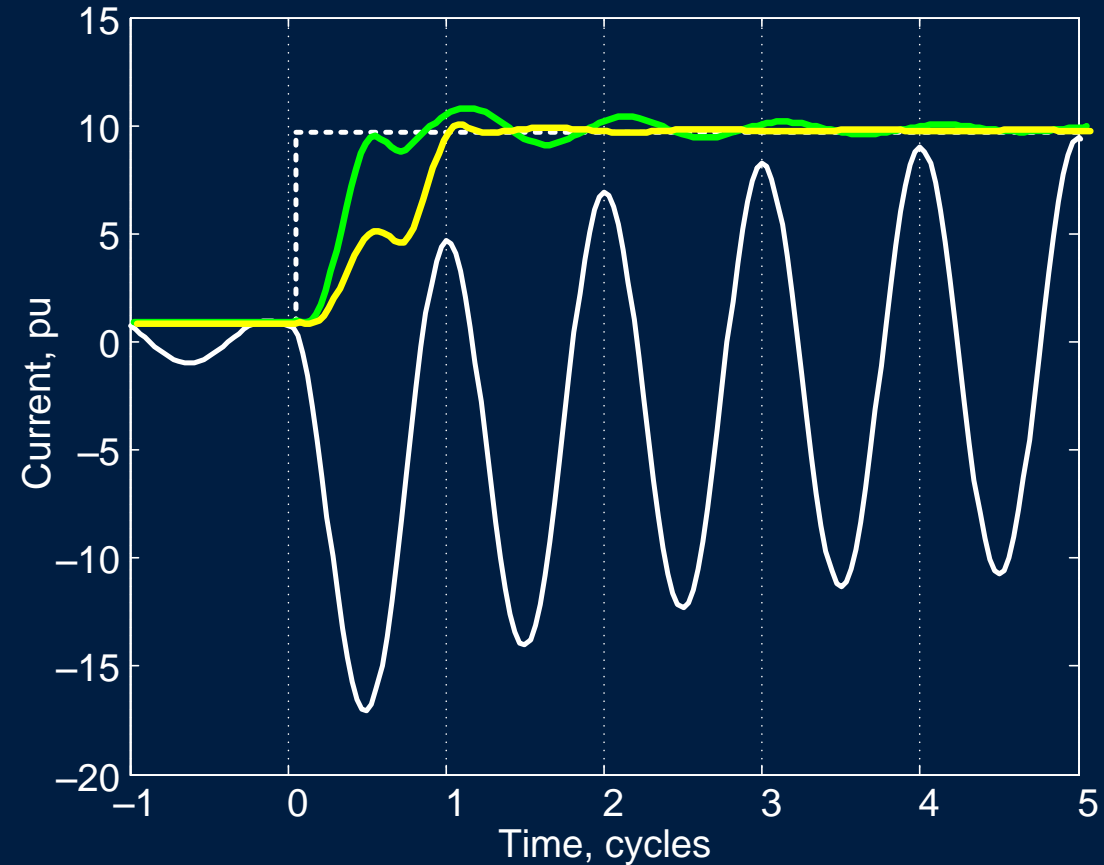## AG Fault on a Line Interconnecting Type 4 Wind / PV Farm

Example
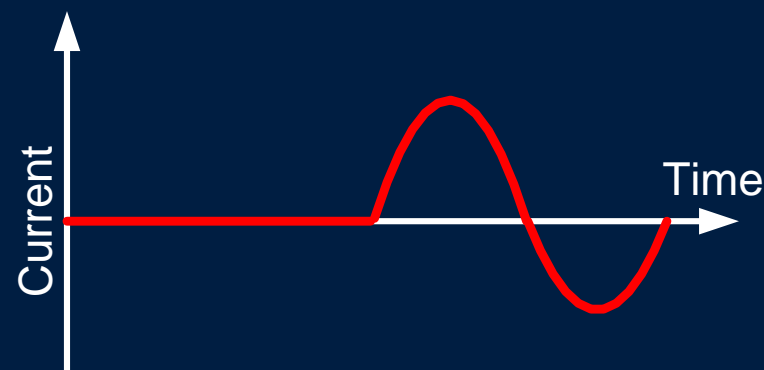## Same AG Fault From the System Terminal

Present-Day Relays

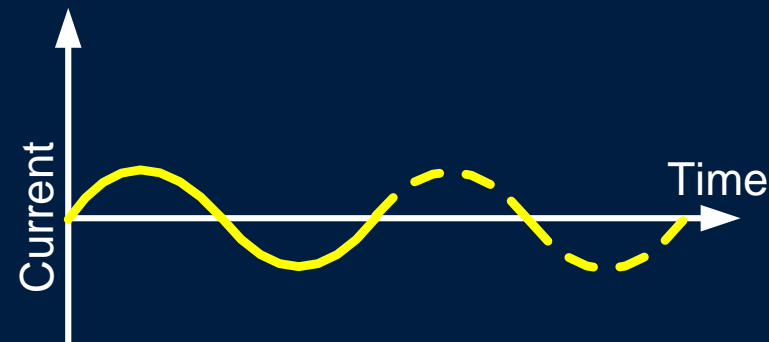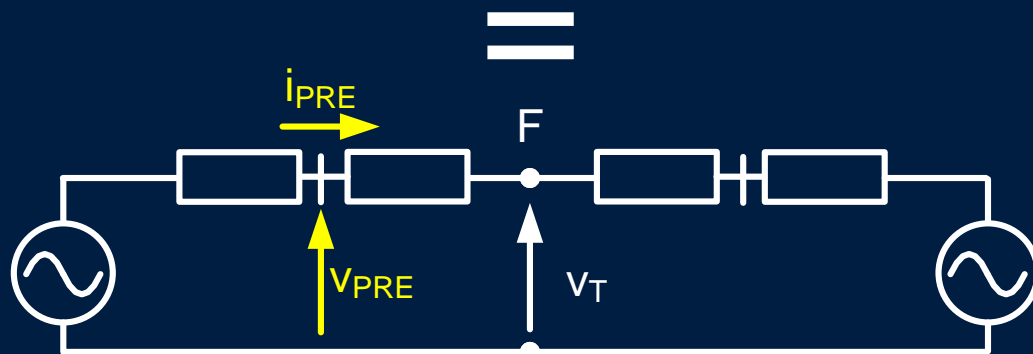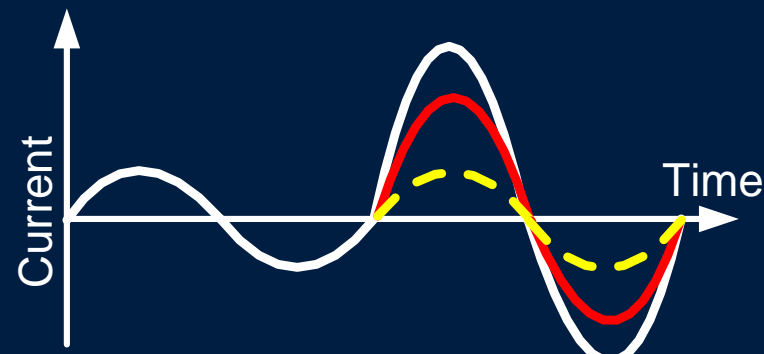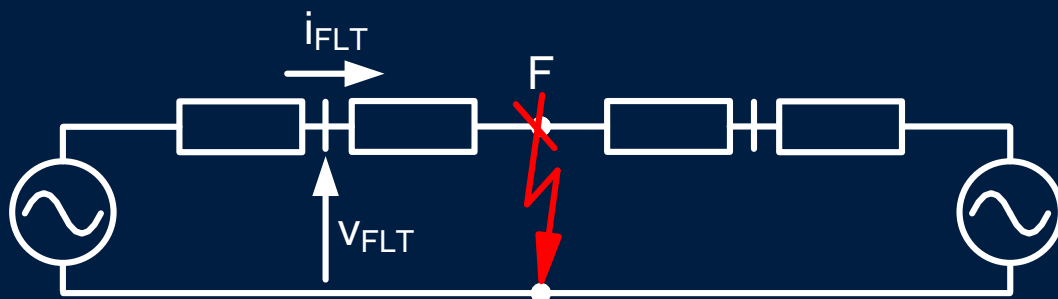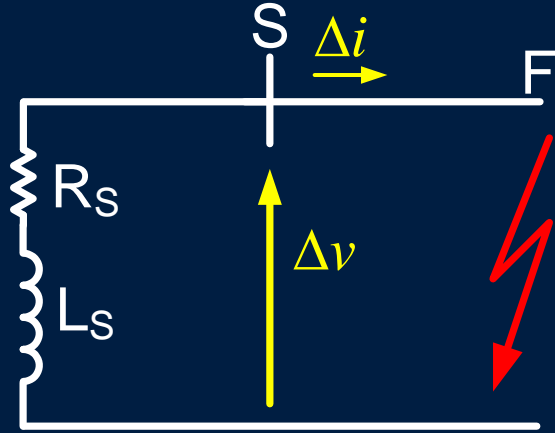- Relays work on phasors

- Phasors represent steady state

- Determining steady state takes time
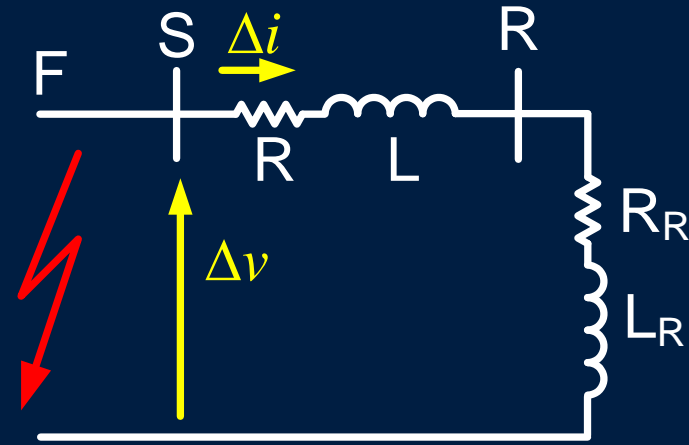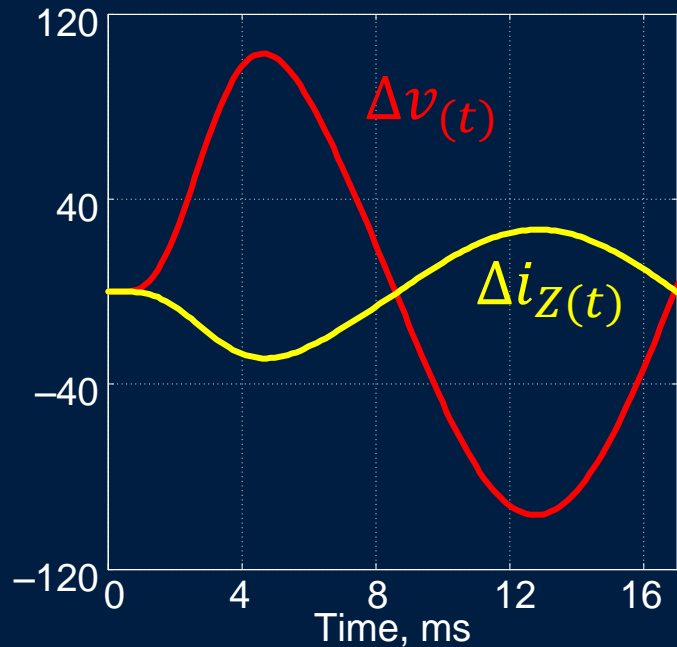
- Shorter windows are faster but less accurate
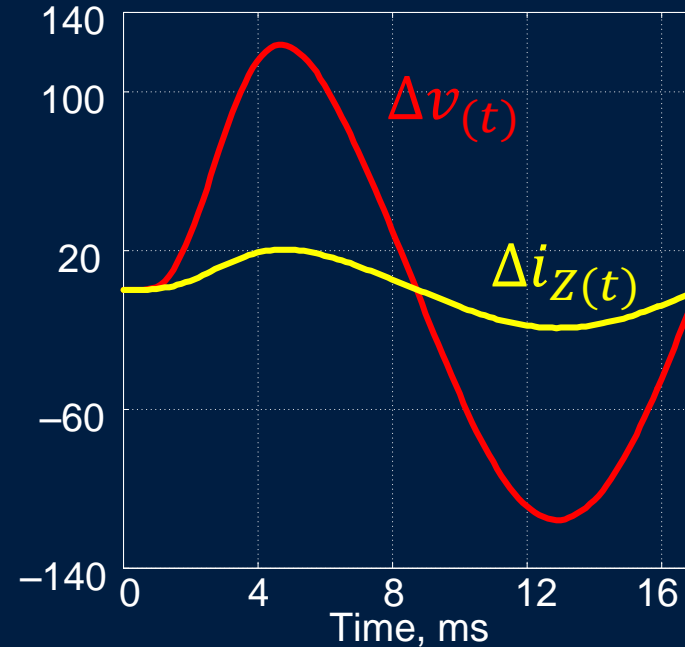
Superimposed Components
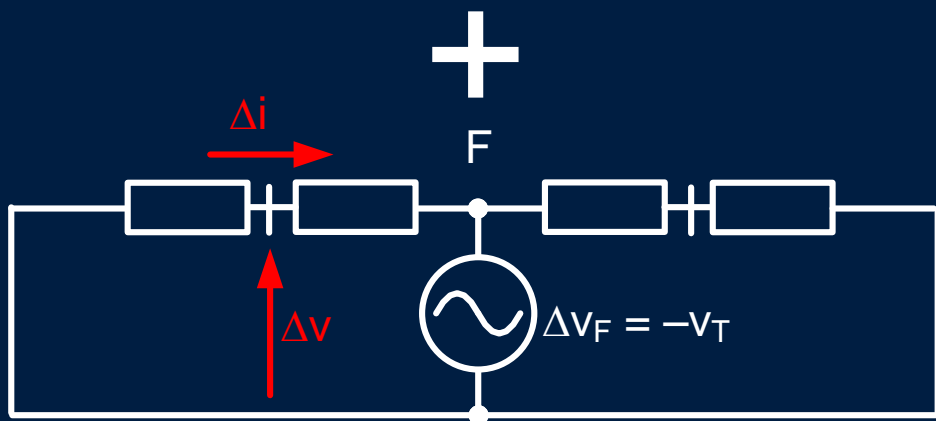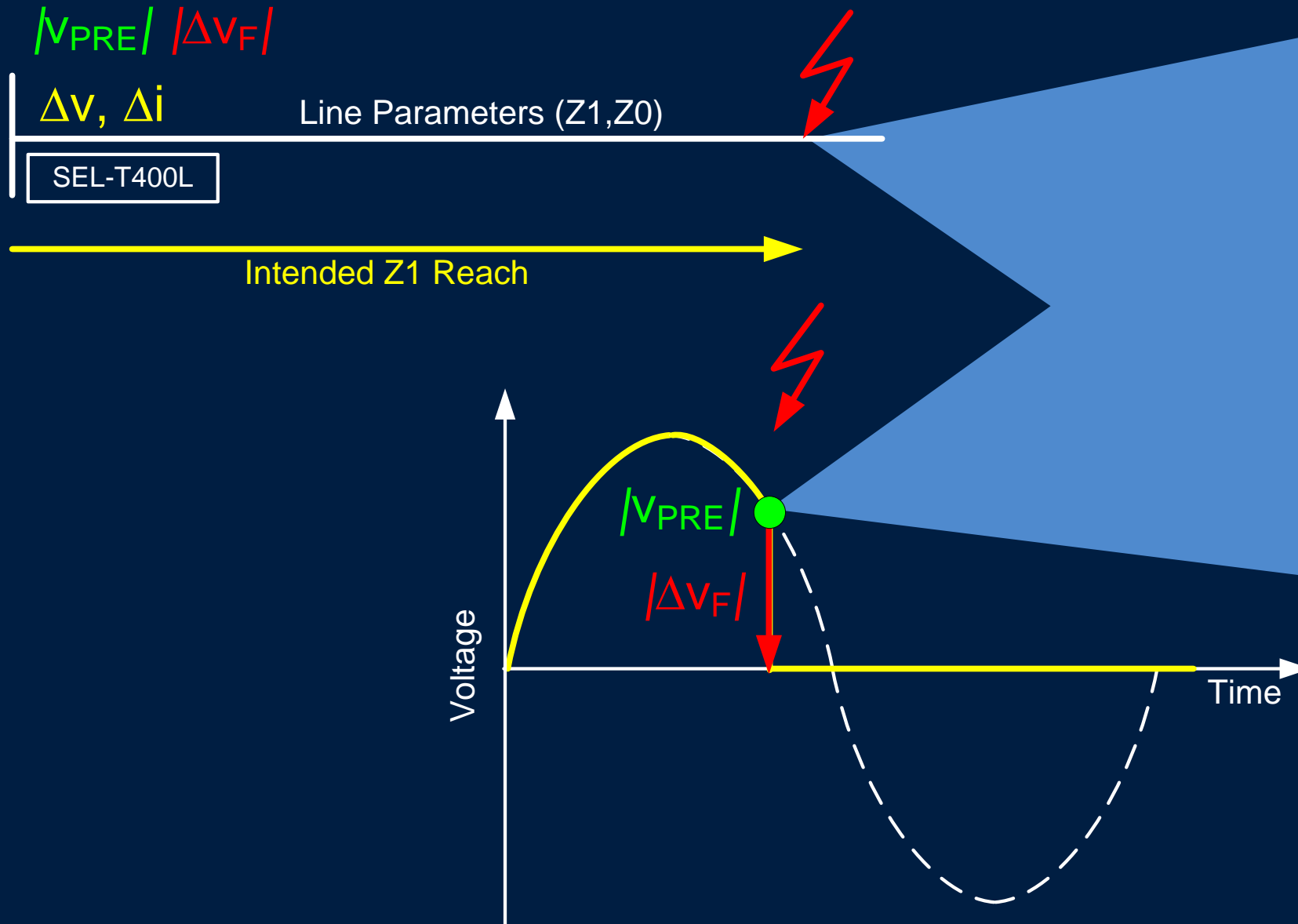
Incremental Quantity Directional (TD32)

Forward fault: $\Delta v = -|Z_S|\Delta i_Z$

Reverse fault: $\Delta v = |Z + Z_R|\Delta i_Z$

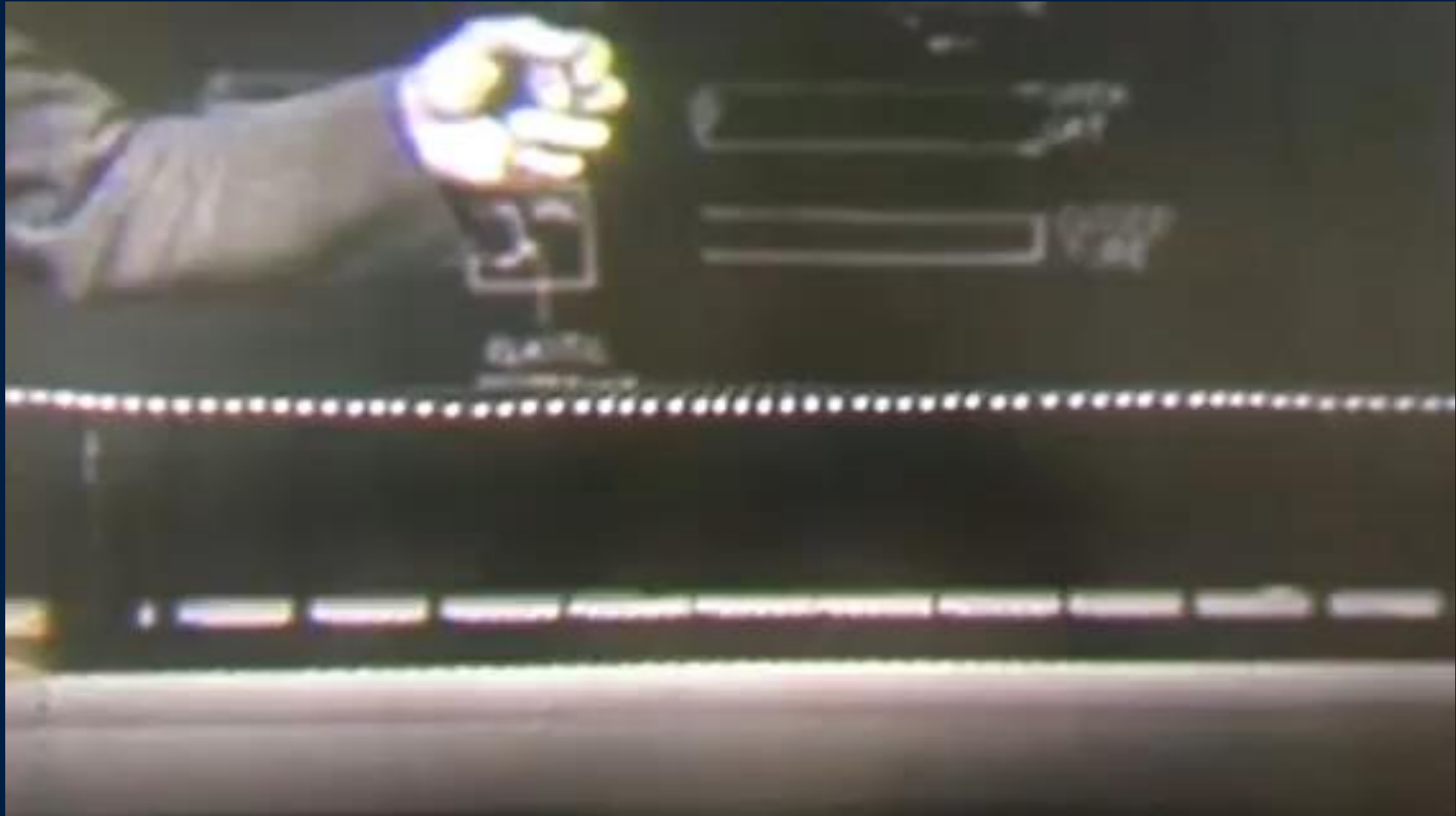# Time-Domain Distance Element Principle

$|V_{PRE}|$ $|\Delta v_F|$

$\Delta v, \Delta i$ Line Parameters (Z1,Z0)

SEL-T400L

Intended Z1 Reach

$|V_{PRE}|$

$|\Delta v_F|$

Voltage

Time

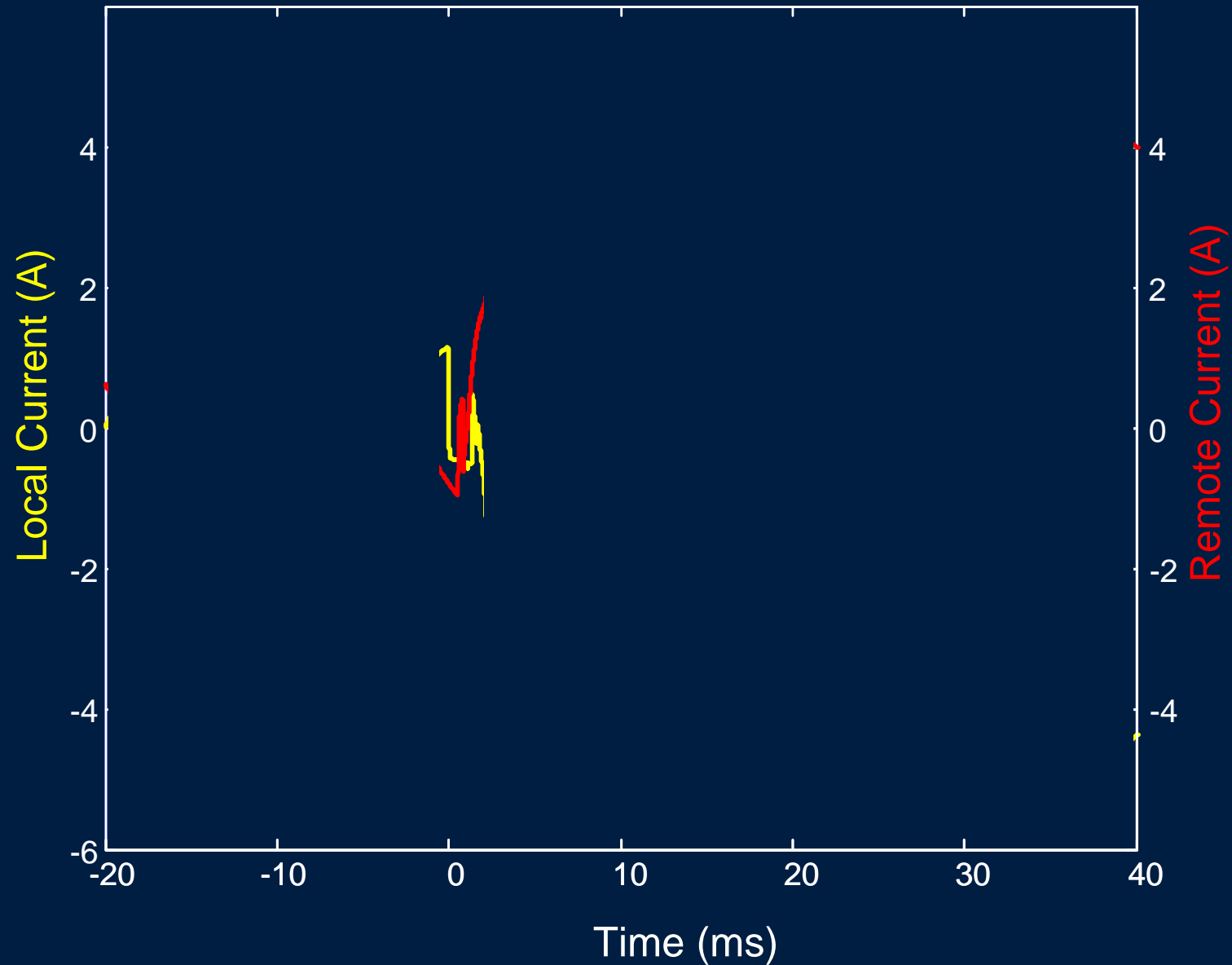# Zone 1 Distance Element (TD21)
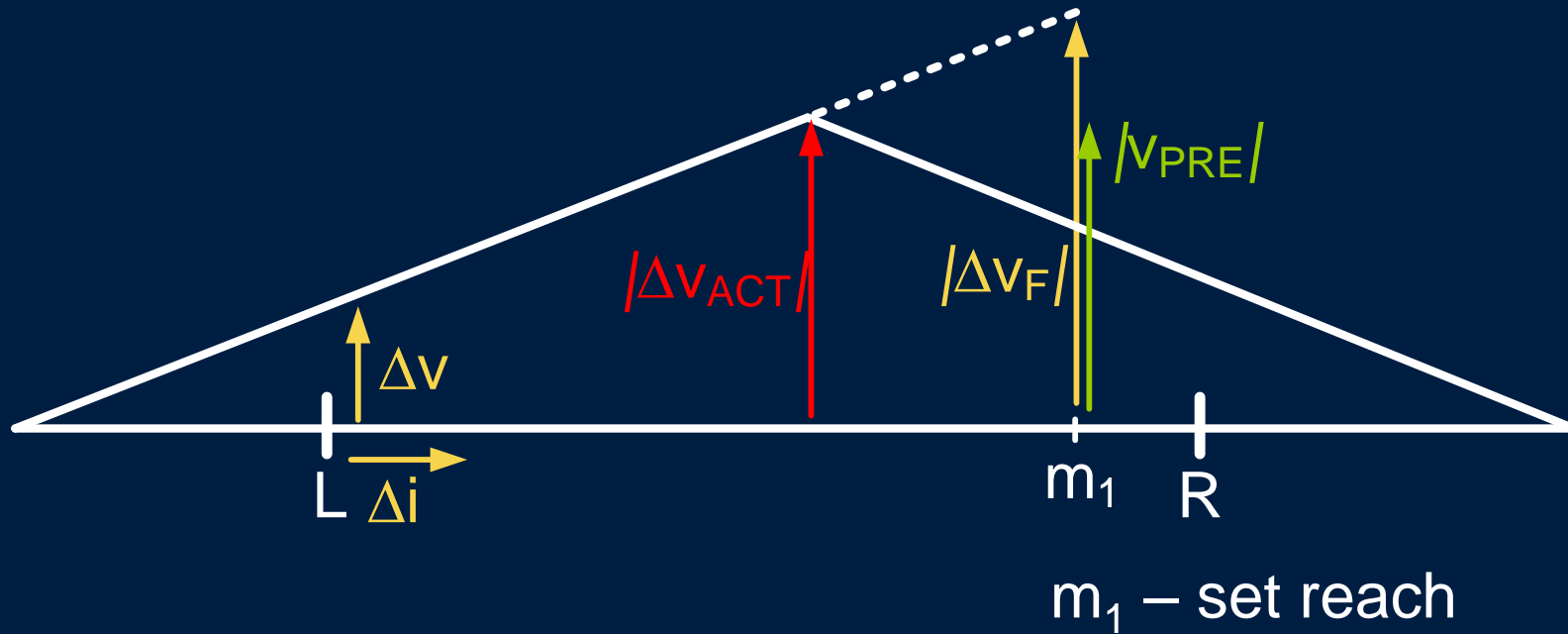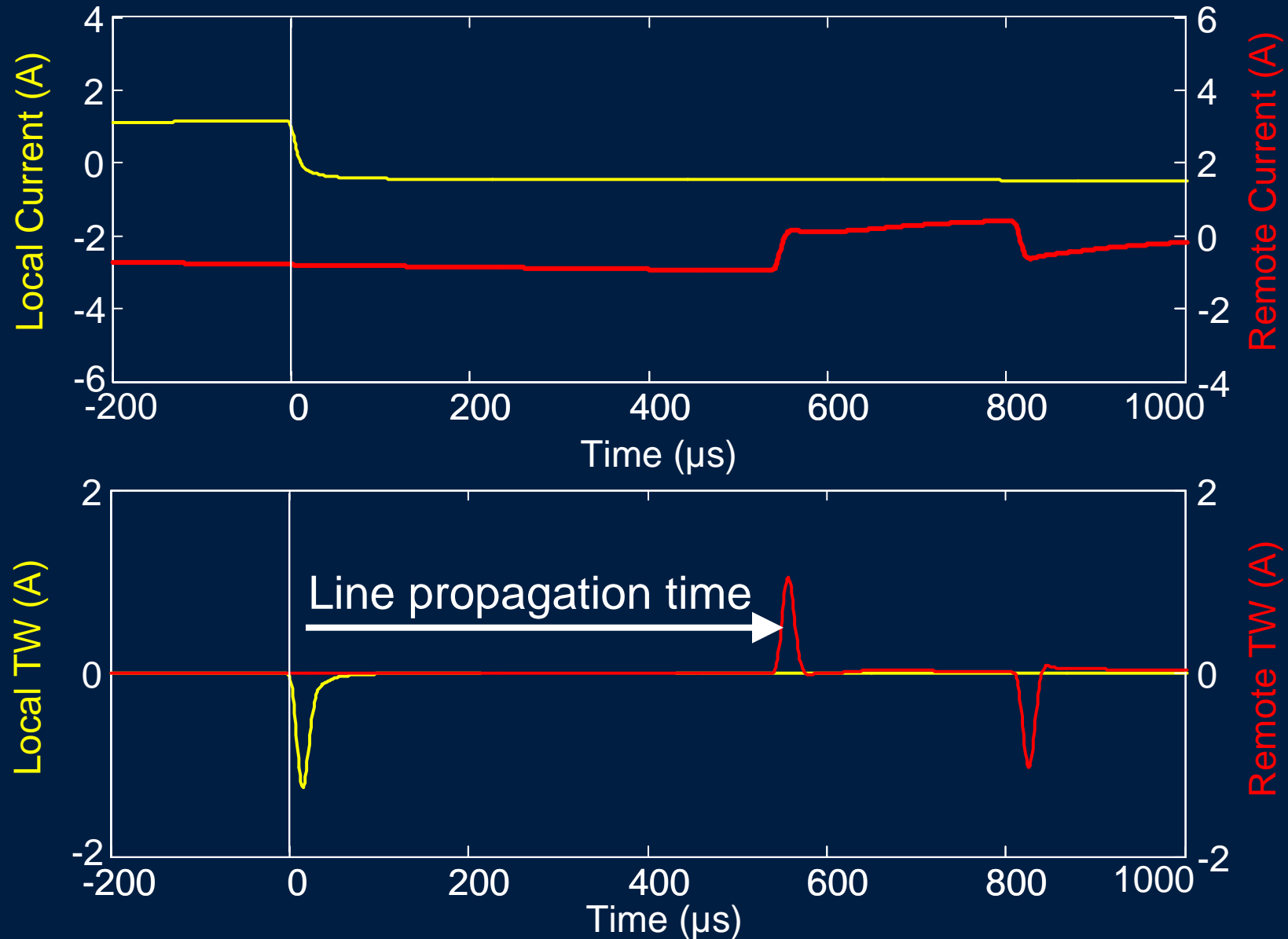
Traveling Waves in Transmission Lines
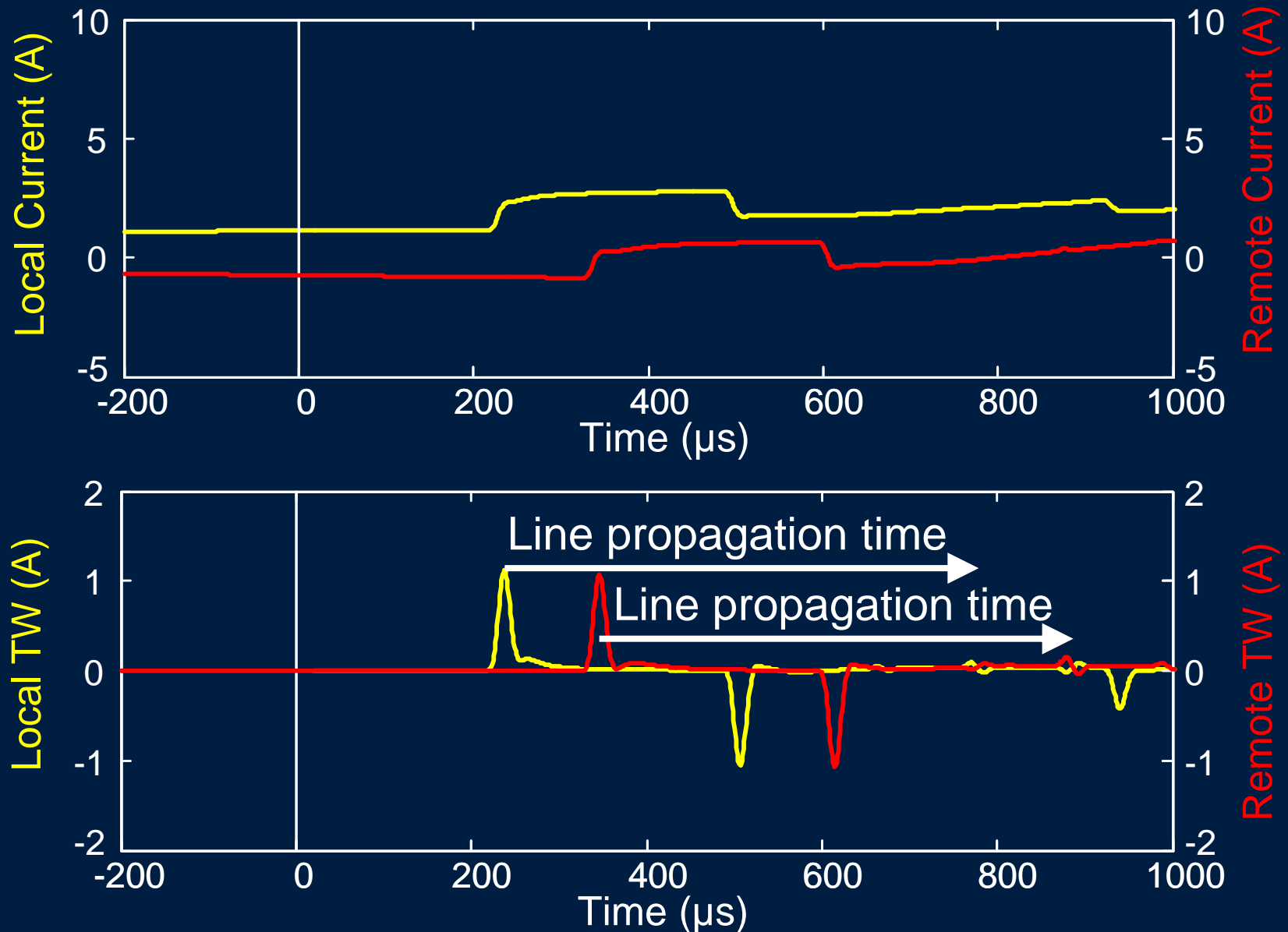

From AT&T Archives

Line Protection with Traveling Waves
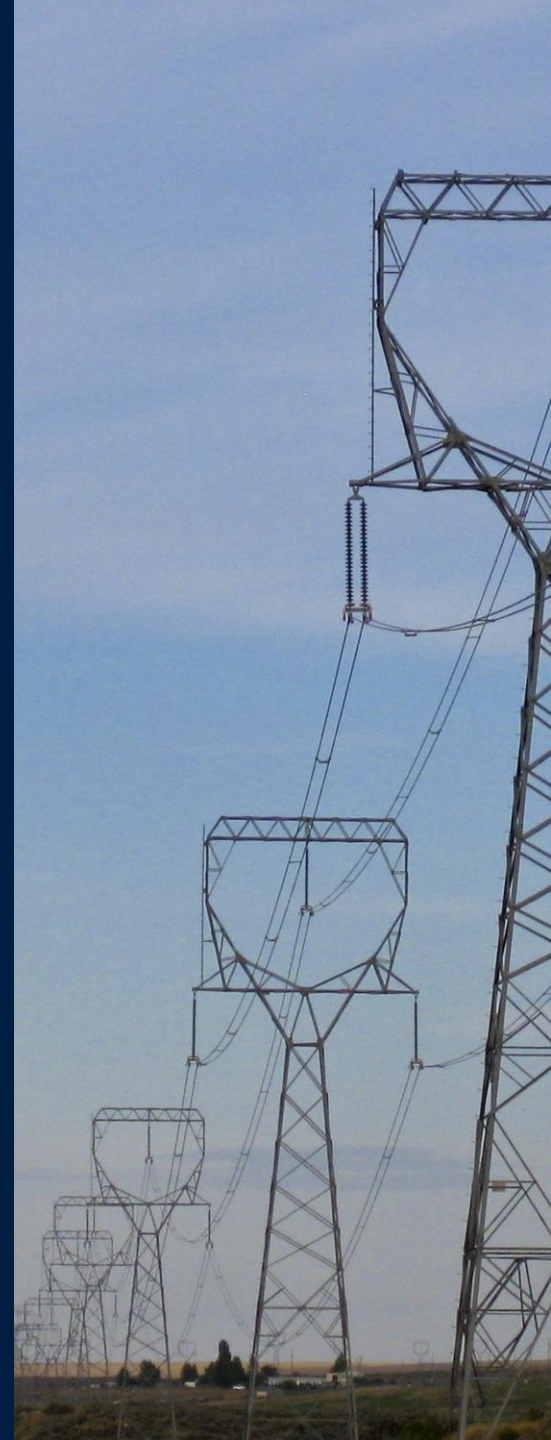
TW87 Operating Principle – External Fault

# TW87 Operating Principle – Internal Fault

TW87 Principle of Operation

- Kirchhoff's current law factoring-in line travel time
"TW in = TW out after end-to-end travel time"

- External faults
TWs of opposite polarities, spaced by travel time
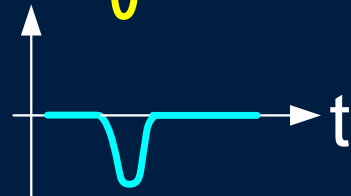
- Internal faults
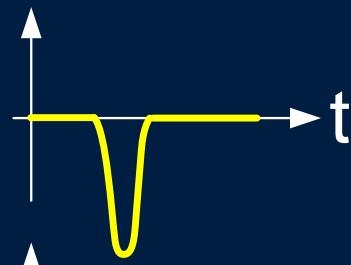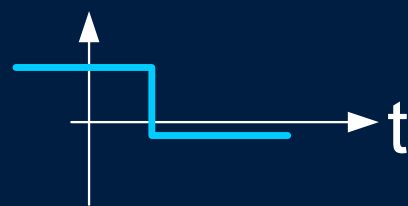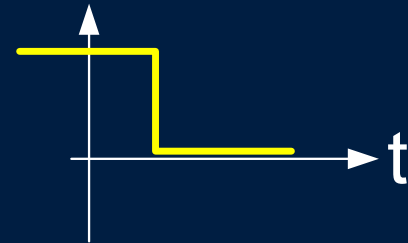TWs of same polarities, spaced less than travel time

Traveling-Wave Directional (TW32)

Forward Event

Reverse Event

Voltage

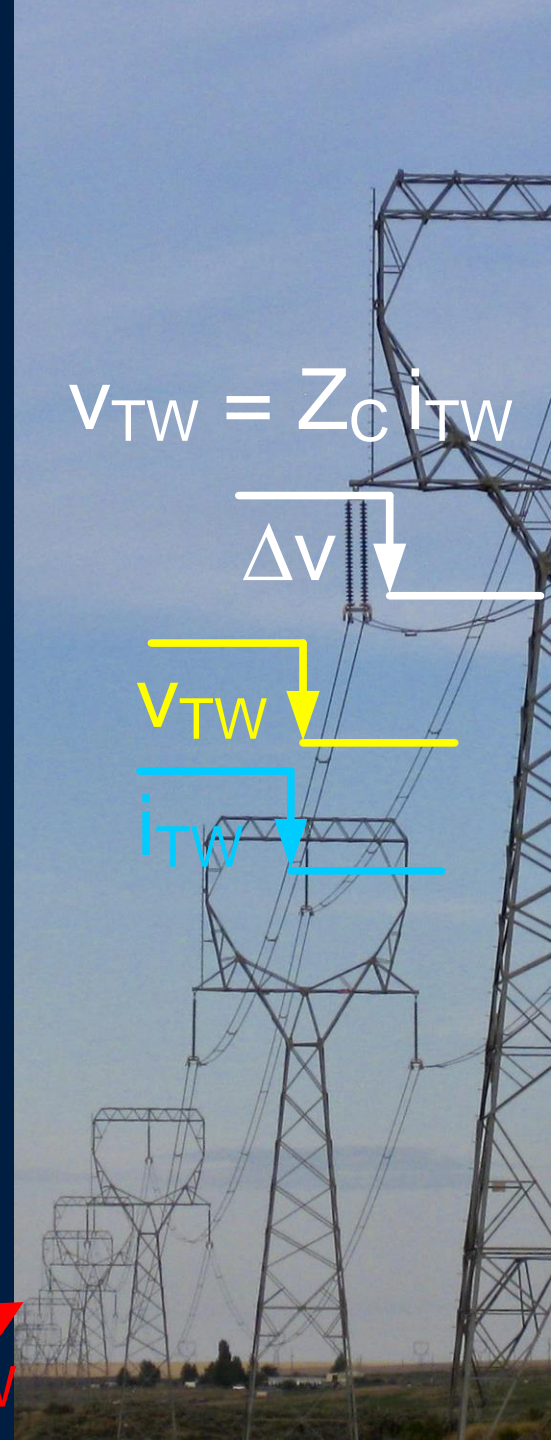Current

Voltage TW

Current TW
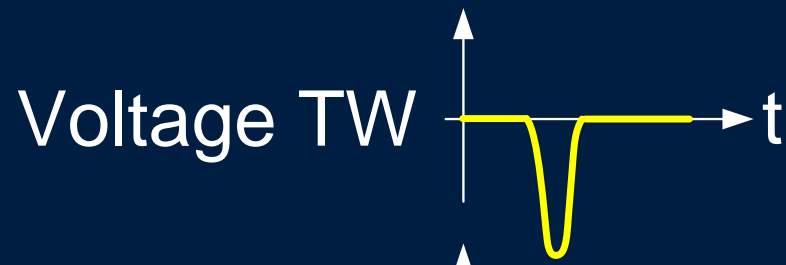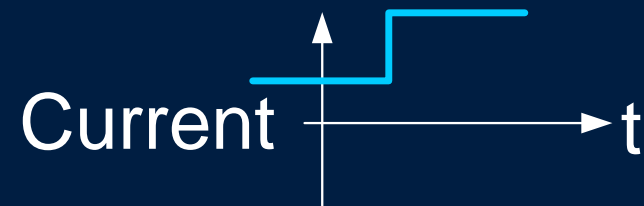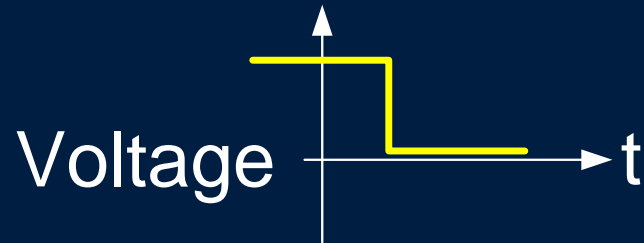
$$v_{TW} = Z_C \, i_{TW}$$
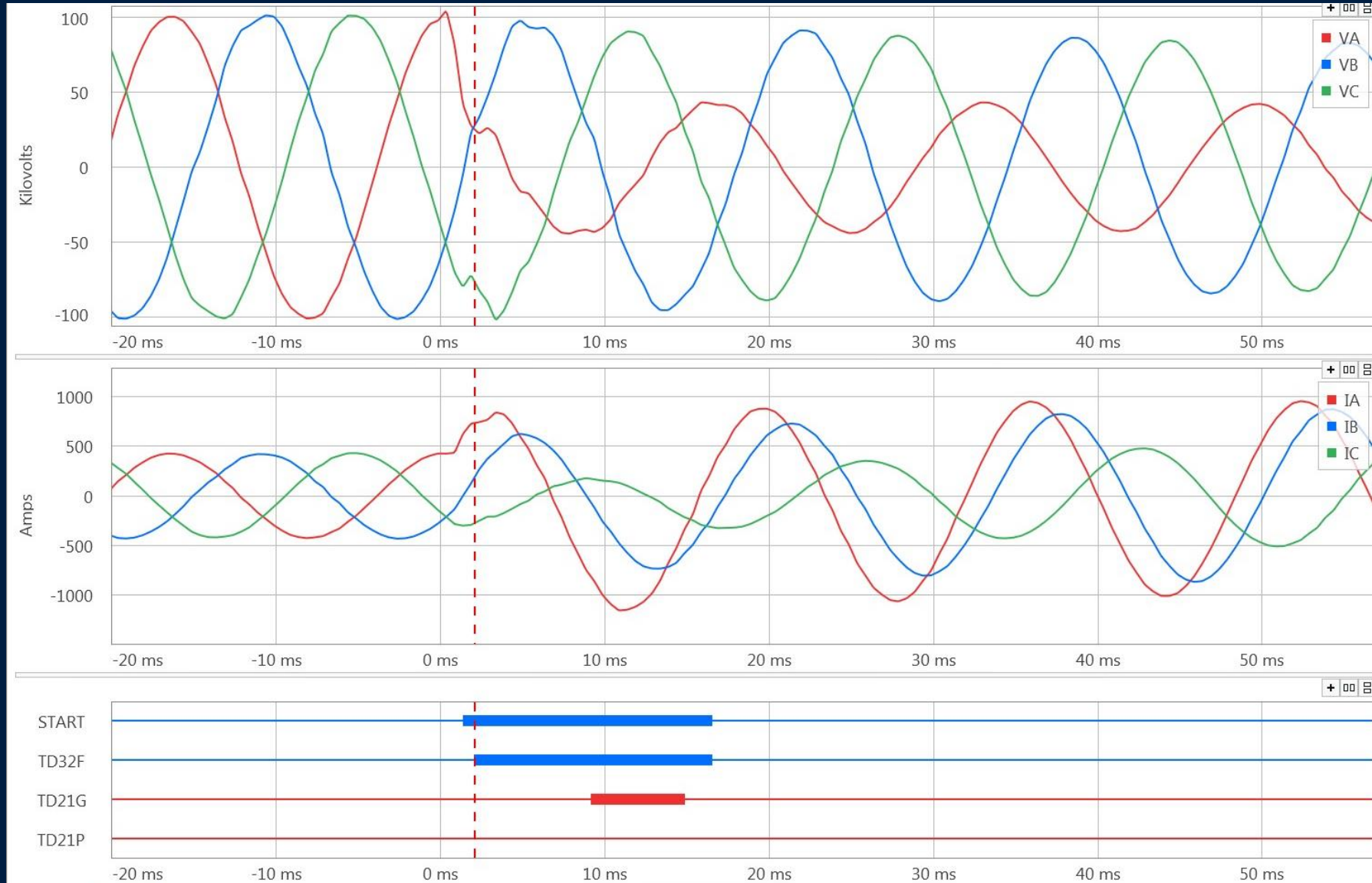
Δv
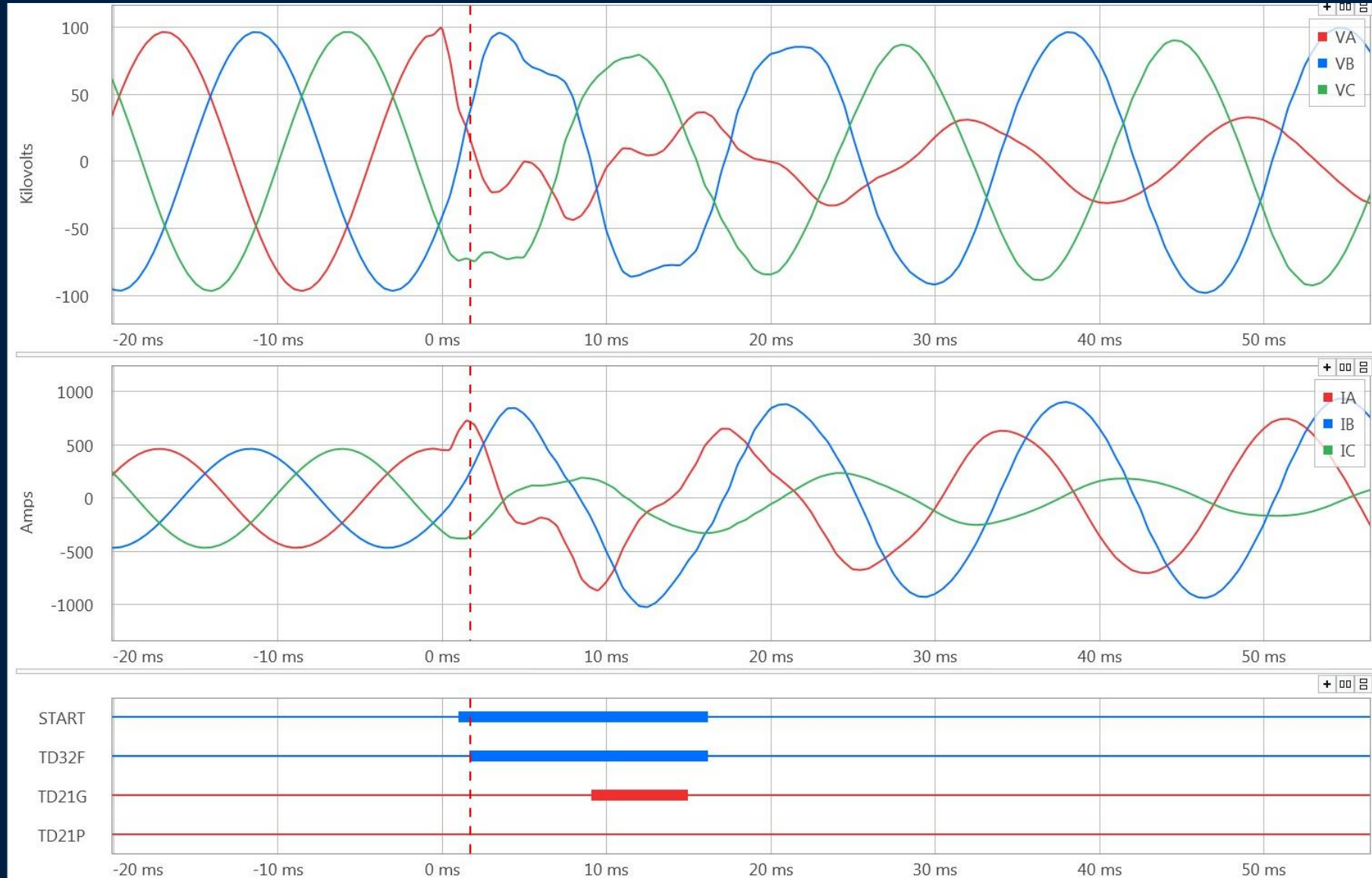
v_{TW}

i_{TW}

$i_{RELAY} = - i_{TW}$

Example
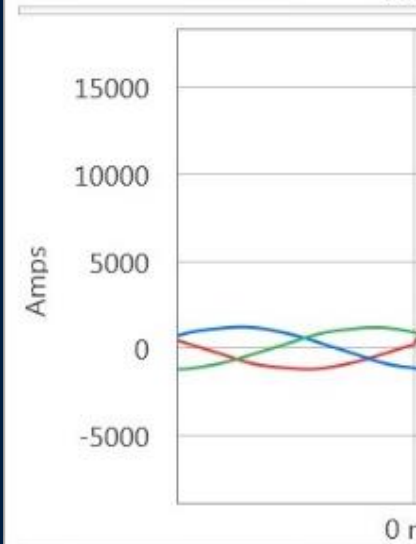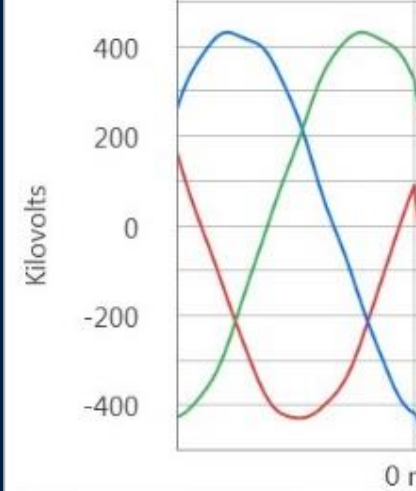## AG Fault on a Line Interconnecting a Type 3 Wind Farm

Example
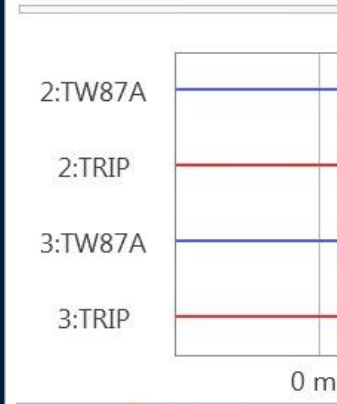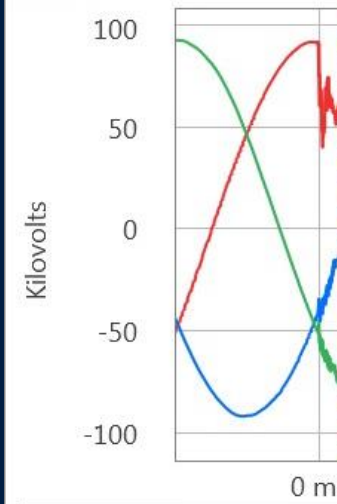## AG Fault on a Line Interconnecting Type 4 Wind / PV Farm

TW32 Field Case

Data Window Required for Traveling Wave Directional Element Operation

TW87 Field Case

Data Window Required for Traveling-Wave Line Differential Scheme Operation

Summary

- Traveling-waves and fast incremental quantities are fault induced and do not depend on sources

- Line relays using traveling waves and incremental quantities are a good fit for inverter-based sources

- True traveling-wave protection protective relays are already here