Dependability of Transient-Based Line Protection Elements and Schemes

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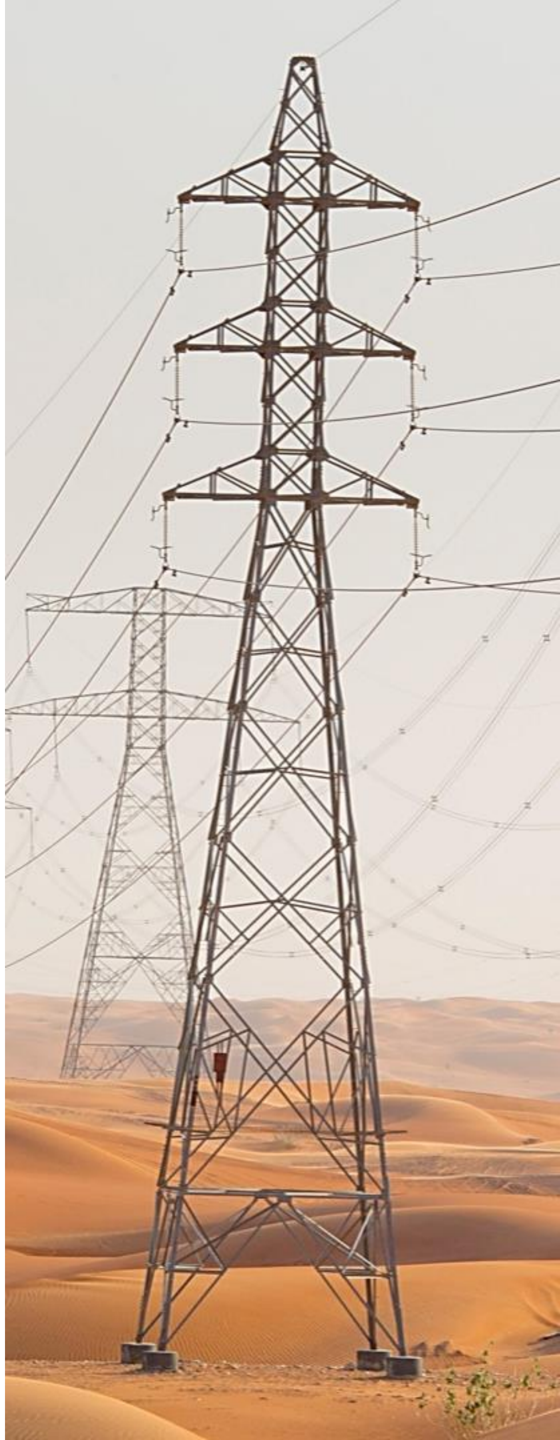
Transient-Based Line Protection

- Operates on signals driven by the energy stored in power lines before the fault, not driven by sources during the fault
- Introduced in 2017 with outstanding track record in the field
  - TW differential (TW87) scheme
  - TW directional (TW32) and incremental-quantity directional (TD32) elements in a POTT scheme
  - Incremental-quantity distance (TD21) element



Example

BG fault on a
345 kV, 109 mi line

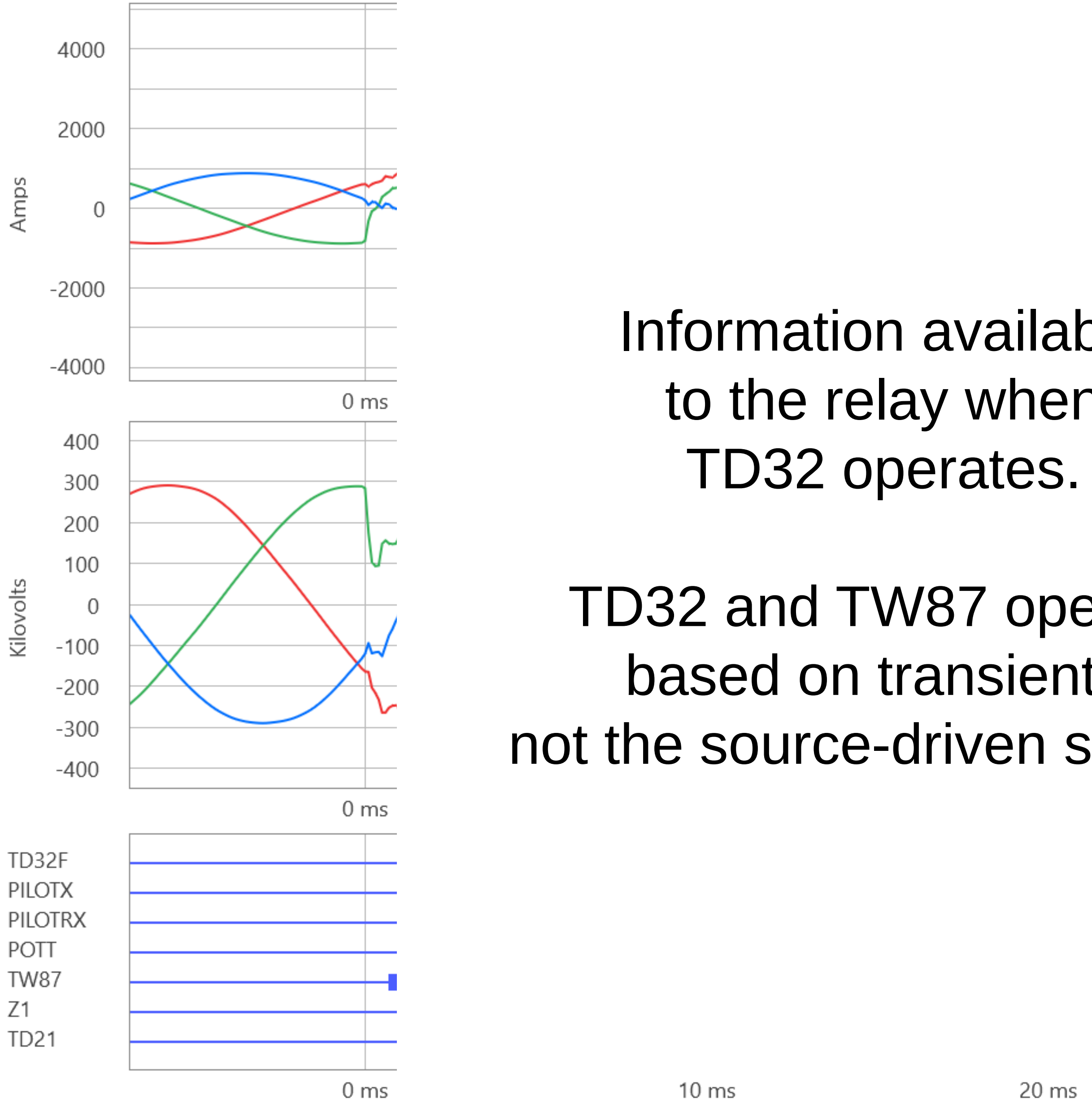
TD32 asserted in 1 ms
(PILOTX sent)

PILOTRX received in 2.6 ms

POTT tripped in 2.6 ms

TW87 tripped in 1 ms

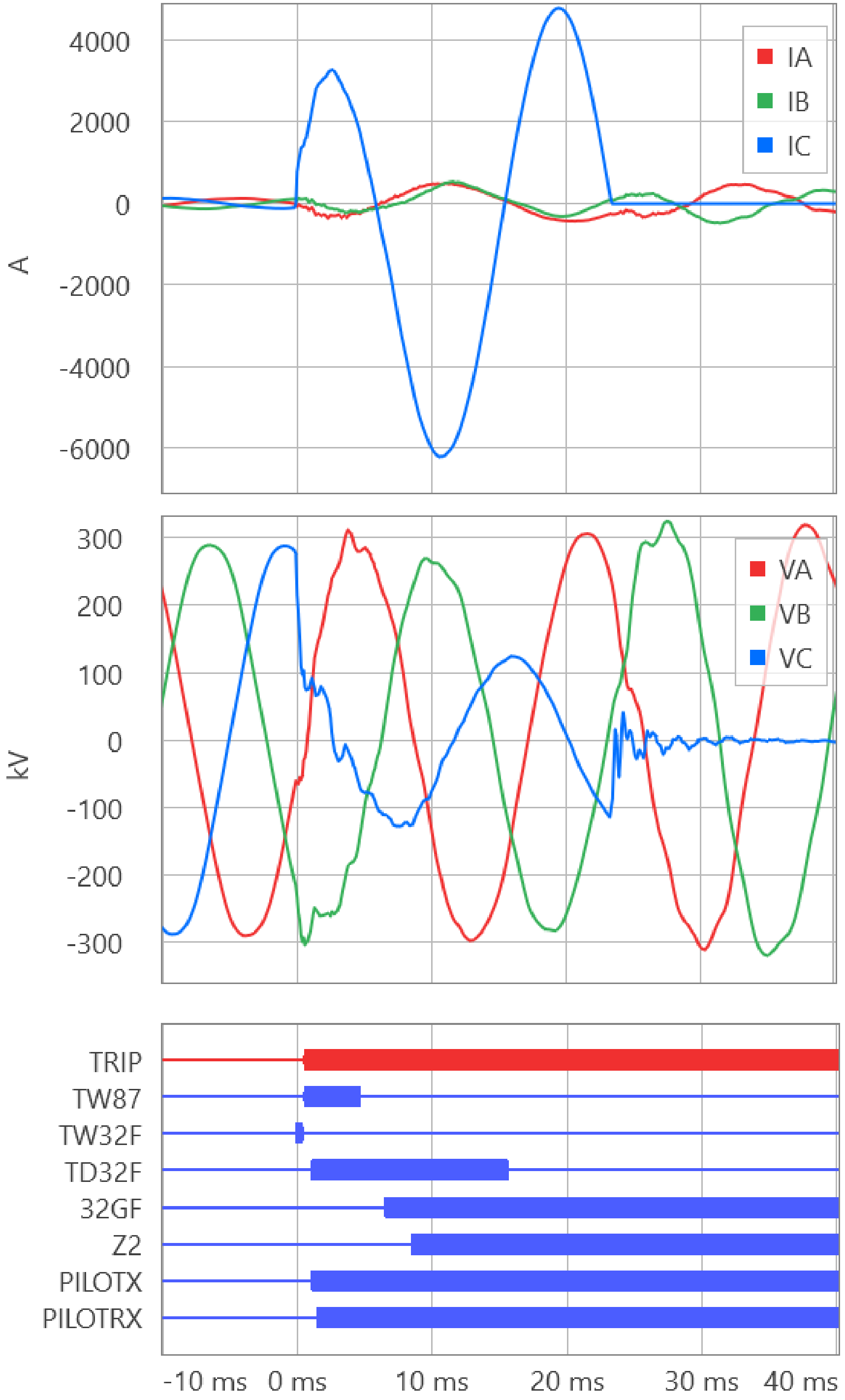
Fault cleared in 25 ms

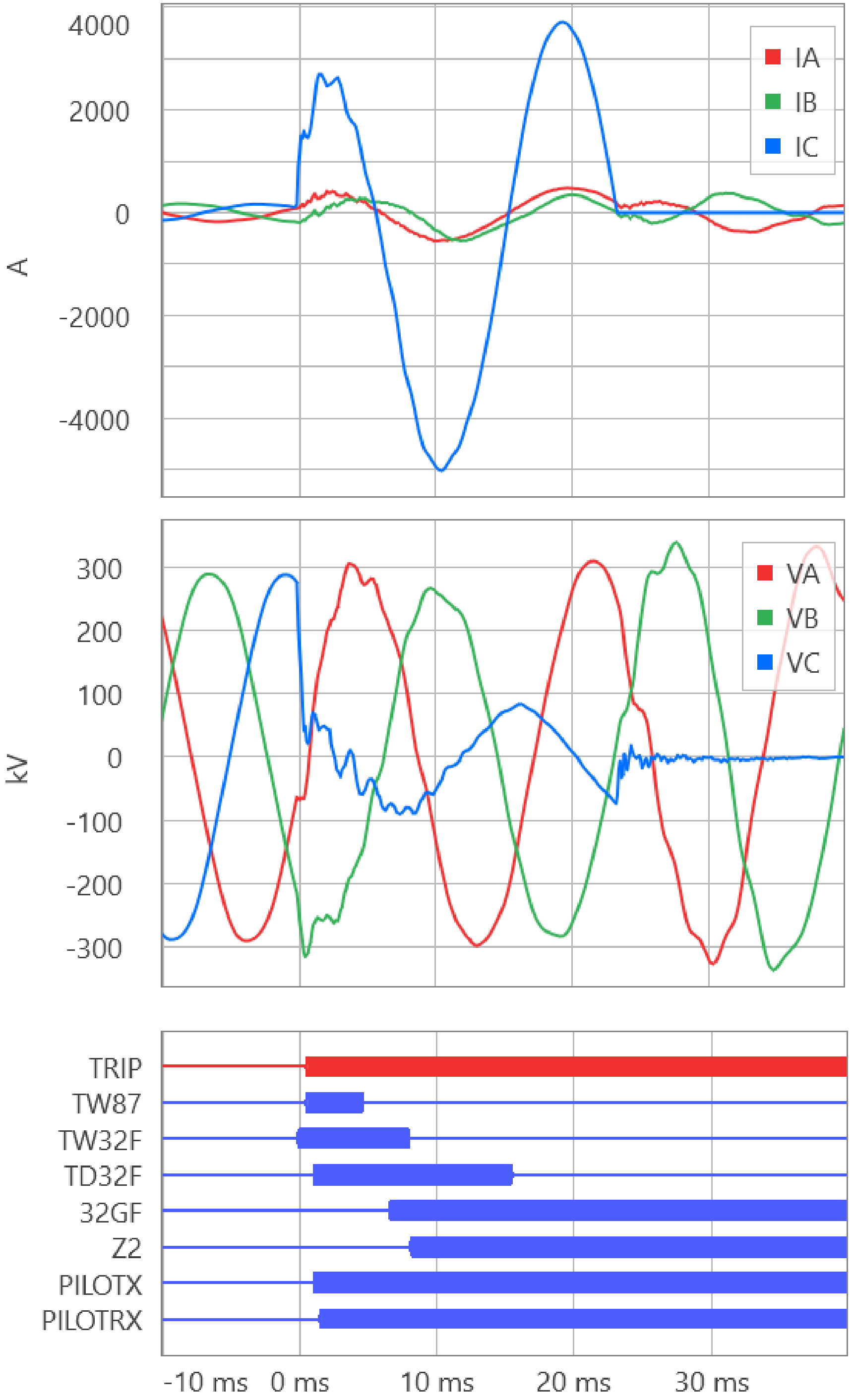


Information available
to the relay when
TD32 operates.

TD32 and TW87 operate
based on transients,
not the source-driven signals.

More Examples





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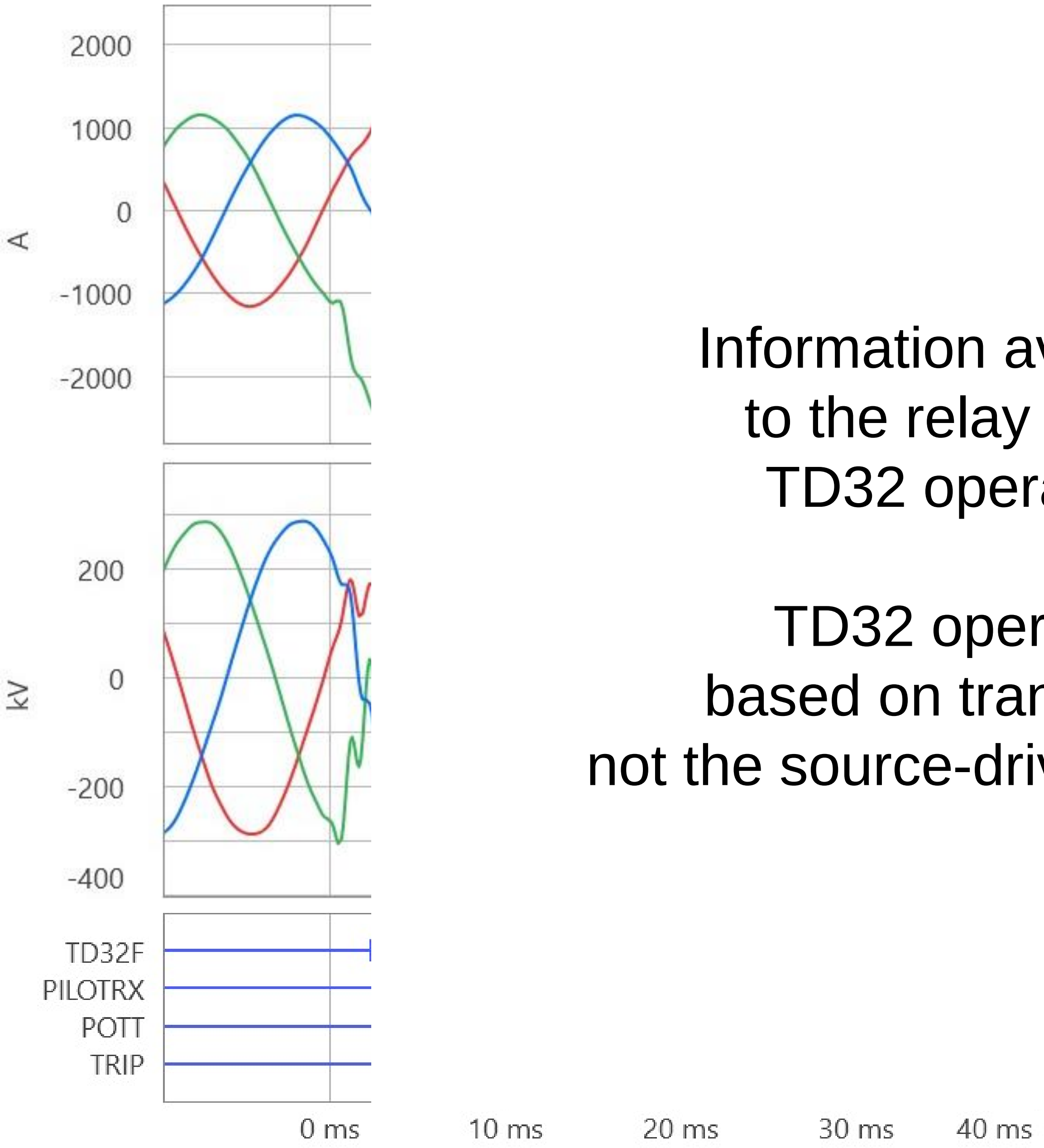

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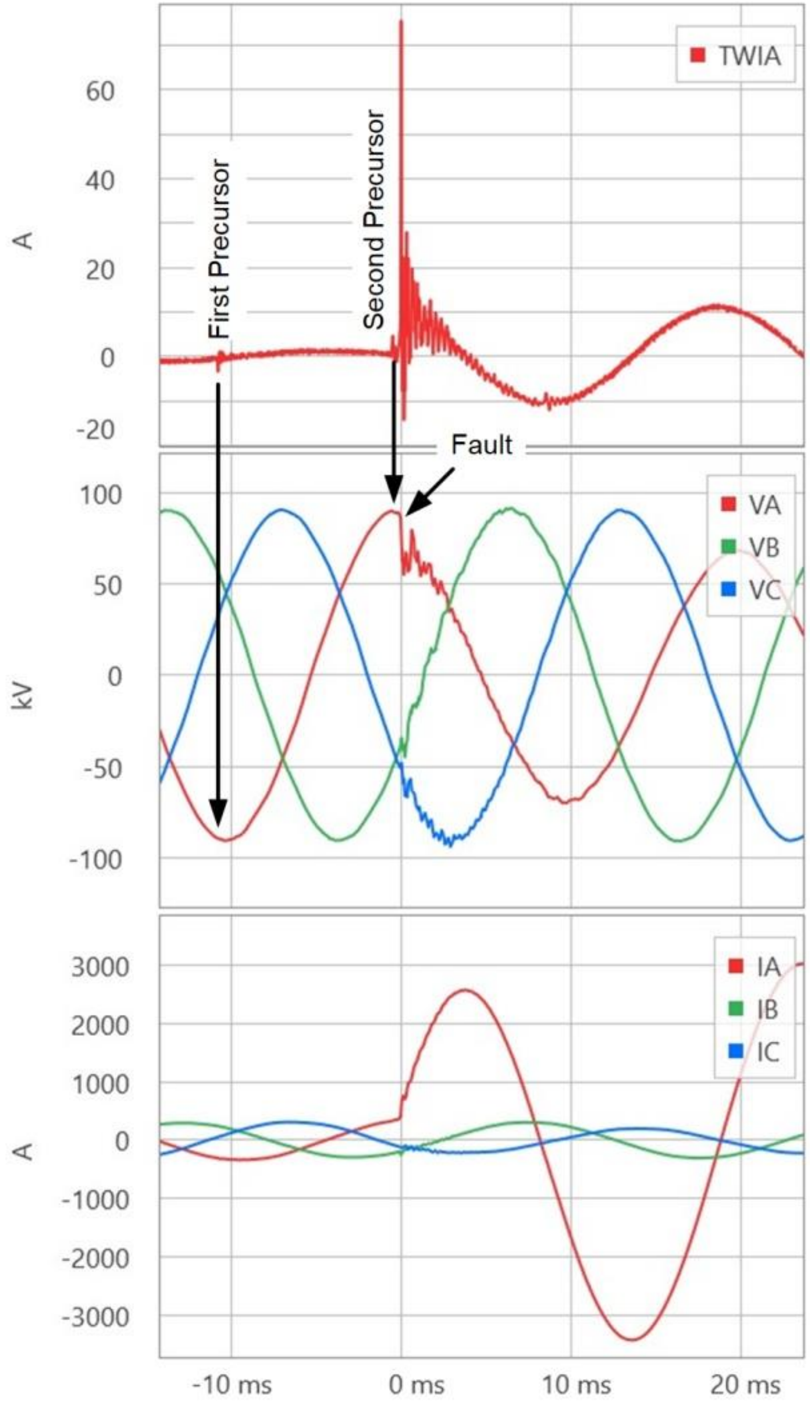
Voltage Point-on-Wave Dependability Considerations

- Faults that occur when the instantaneous voltage is small launch small TWs
- No measurable TWs when the fault happens at voltage zero crossing
- Insulation breakdown root causes
  - Electrical
  - Mechanical

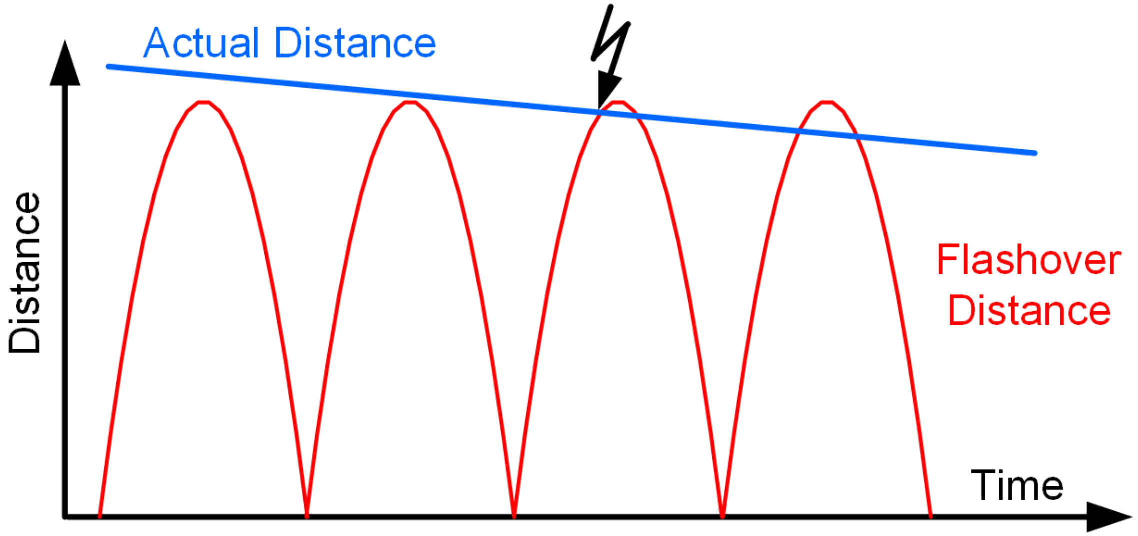
Electrical Breakdown

- Insulation is unlikely to break down when the voltage is small
  - It takes stress to break down insulation
  - The insulation withstood the full voltage just a quarter cycle earlier
- A fault may occur at a small point-on-wave *angle*, but the point-on-wave *voltage* is still large



Mechanical Breakdown

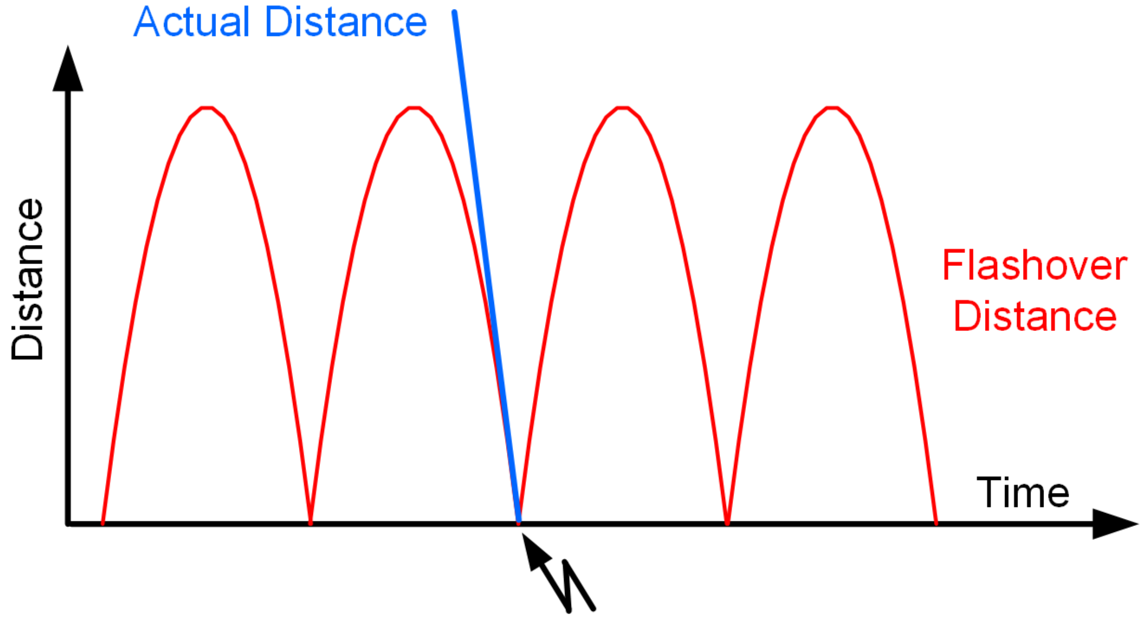
Flashover distance $$d_{MIN(t)} = \frac{|v_{F(t)}|}{E_{MIN}}$$ (E_{MIN} = 3 kV/mm)



Slowly moving objects cause faults near voltage peak:

- Falling trees
- Kites and balloons
- Flying debris
- Animals

Fast-Moving Objects

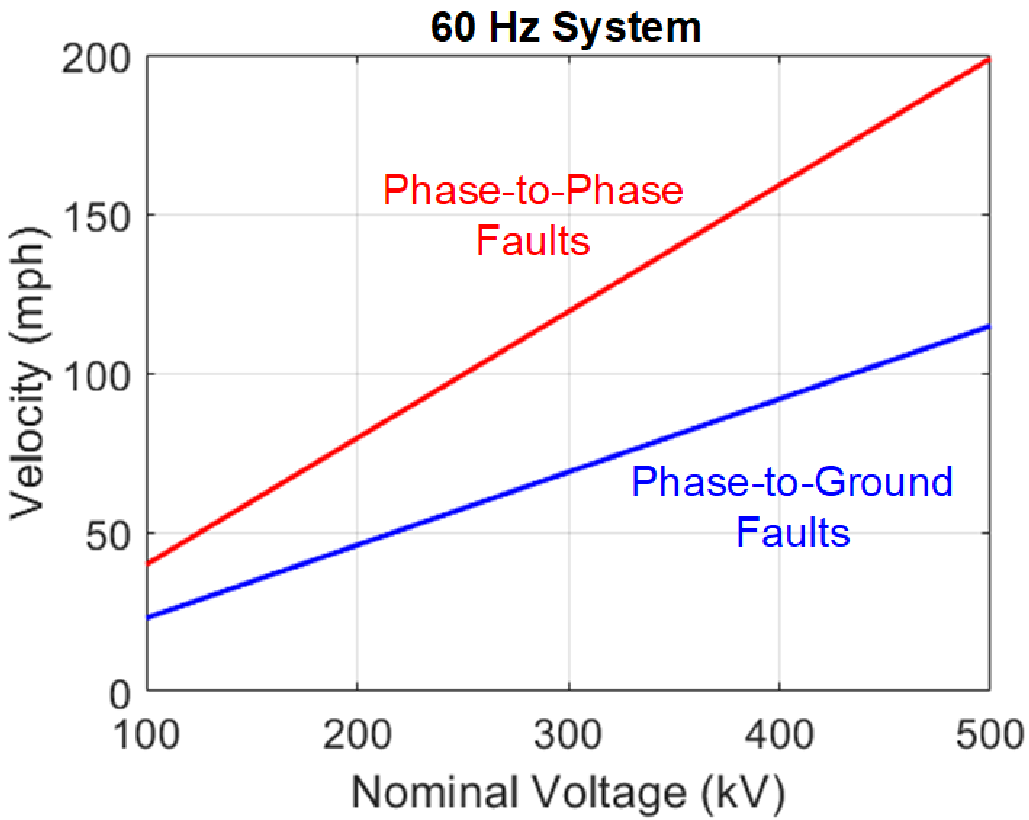


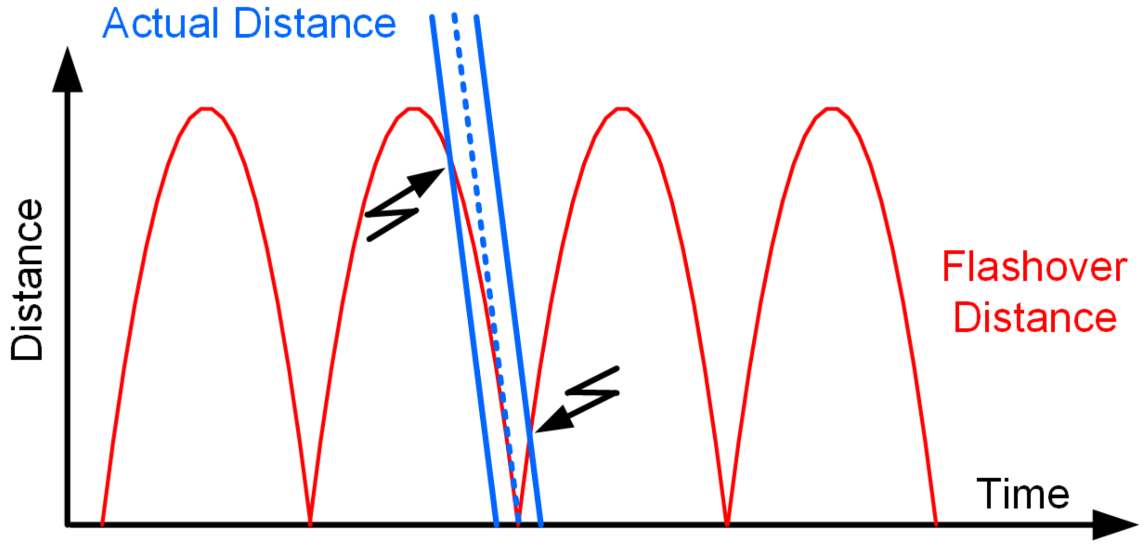
Minimum velocity

$$VEL = \frac{d}{dt}\left[\frac{\sqrt{2} \cdot V_{NOM}}{k \cdot E_{MIN}} \cdot \sin(2 \cdot \pi \cdot t \cdot f)\right]_{t=0}$$

$$VEL = 2 \cdot \sqrt{2} \cdot \pi \cdot \frac{V_{NOM} \cdot f}{k \cdot E_{MIN}}$$

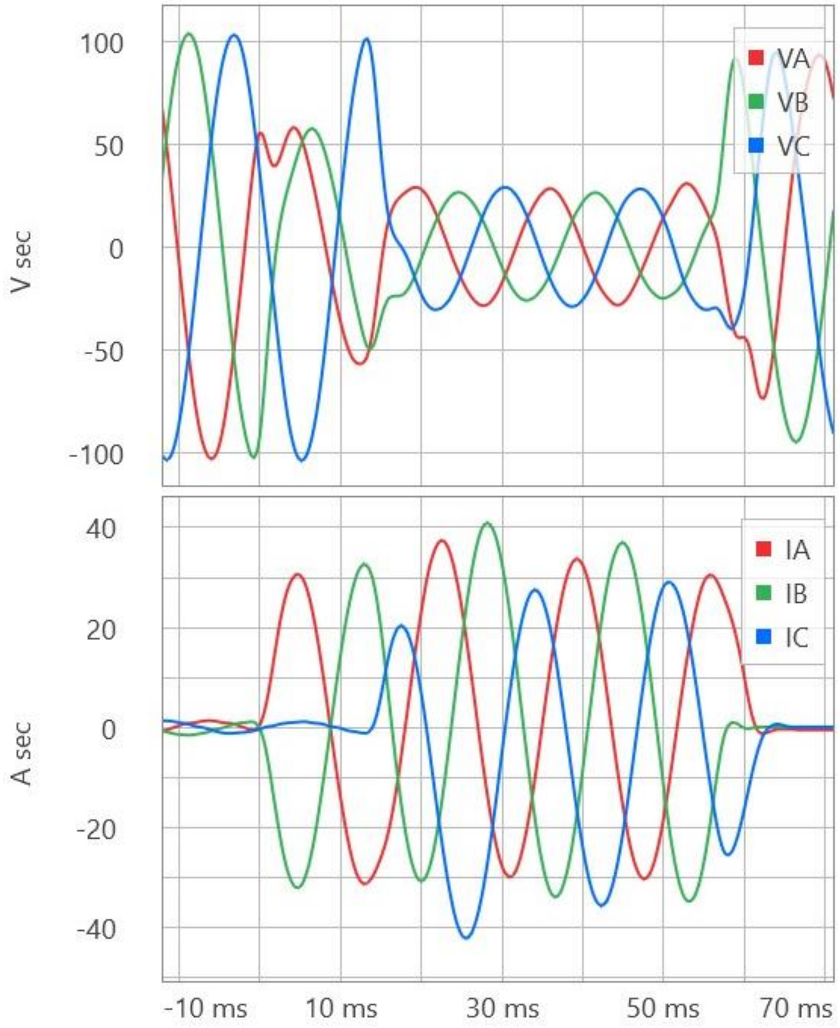
Minimum Velocity to “Fly Into Zero Crossing”



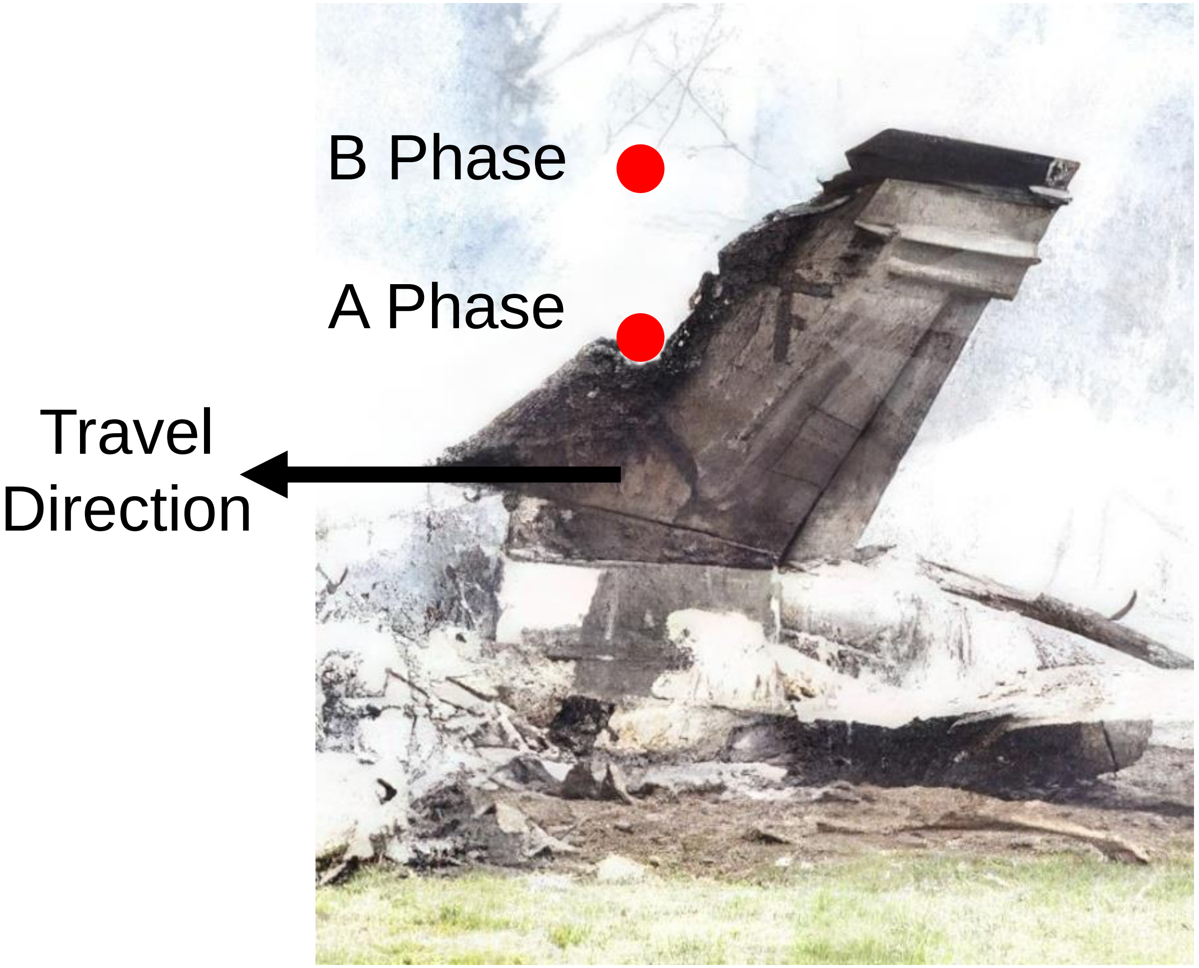


Field Example

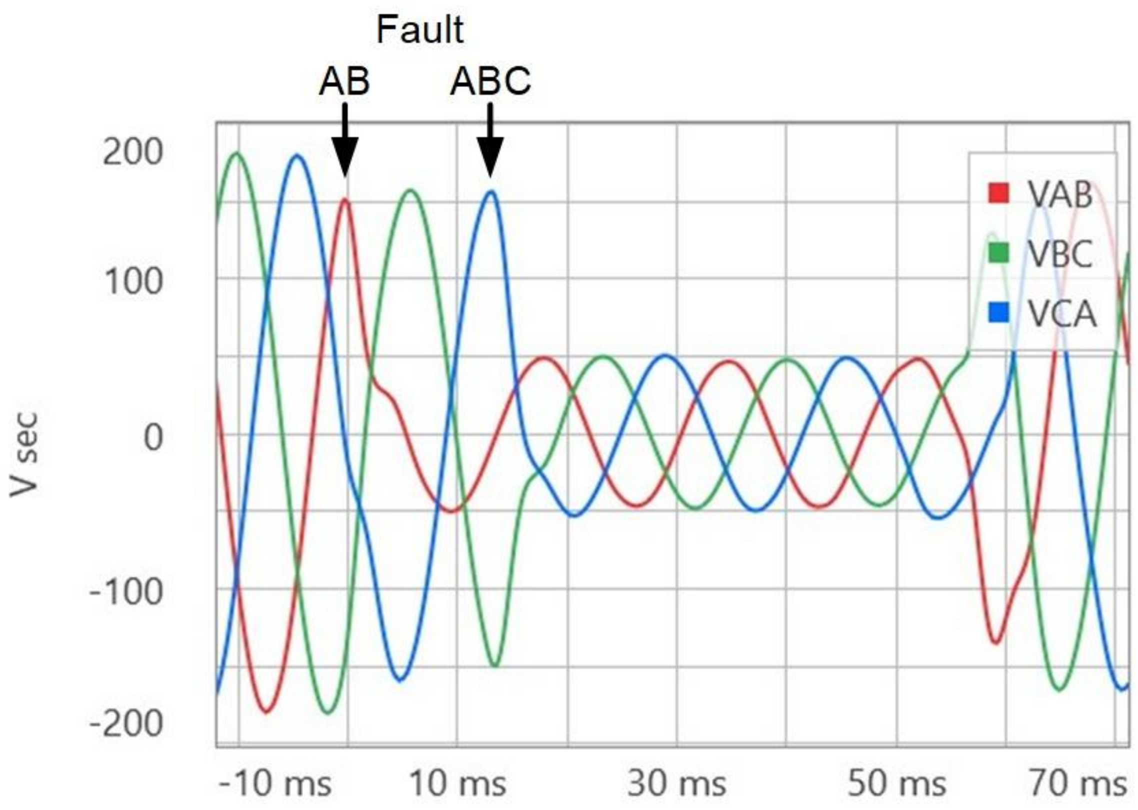
Suspected contact
with conductors

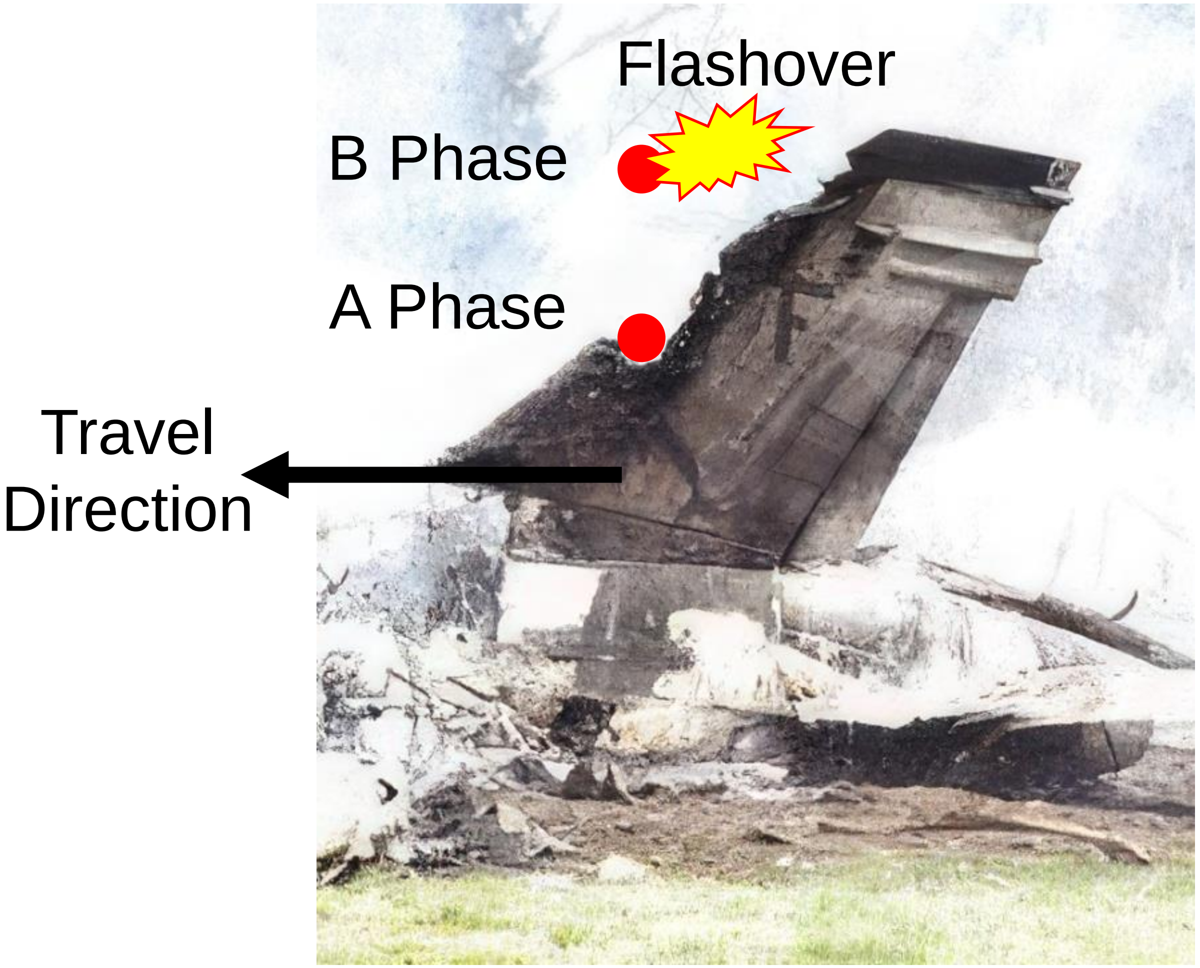


Field Example



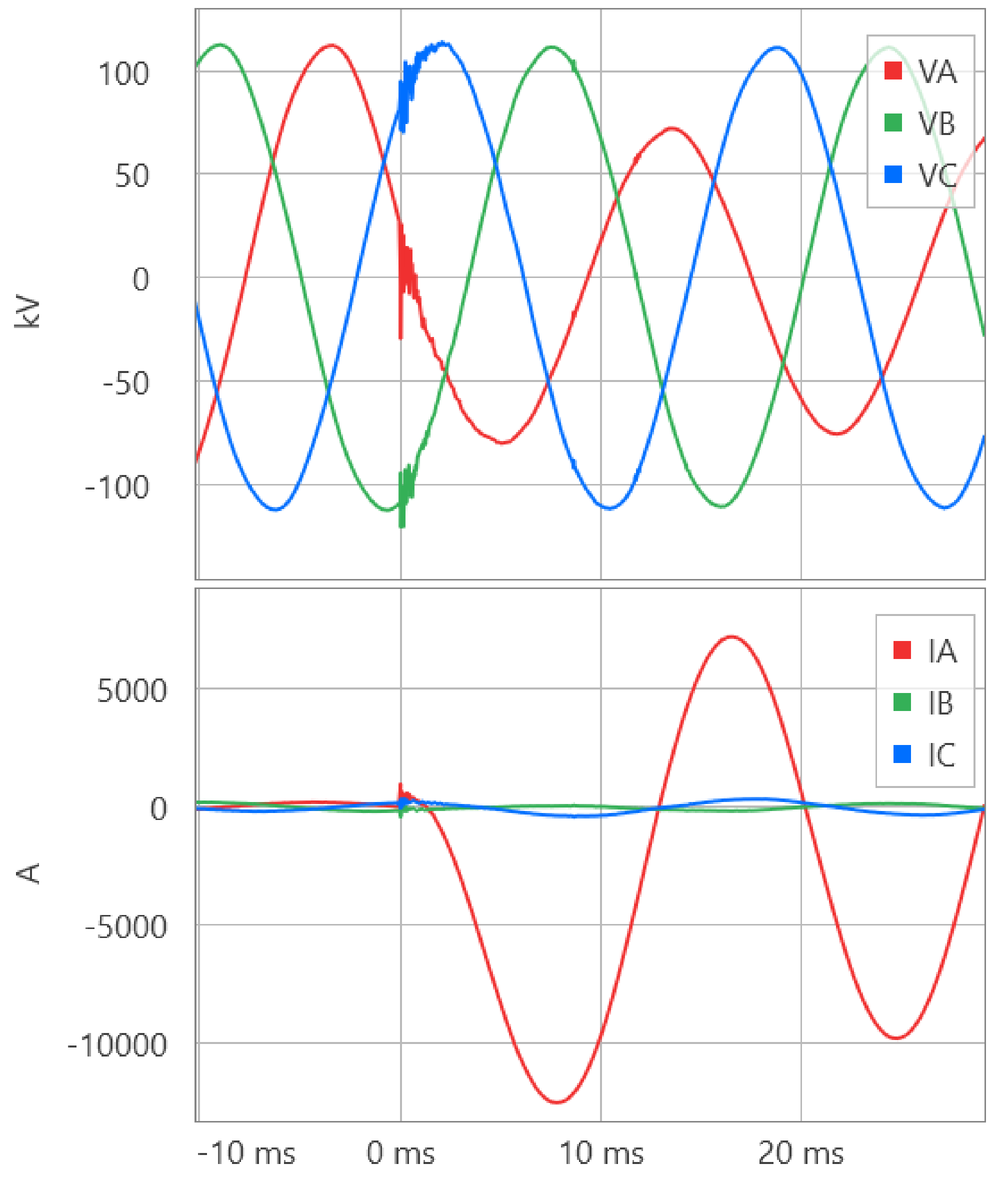
Field Example



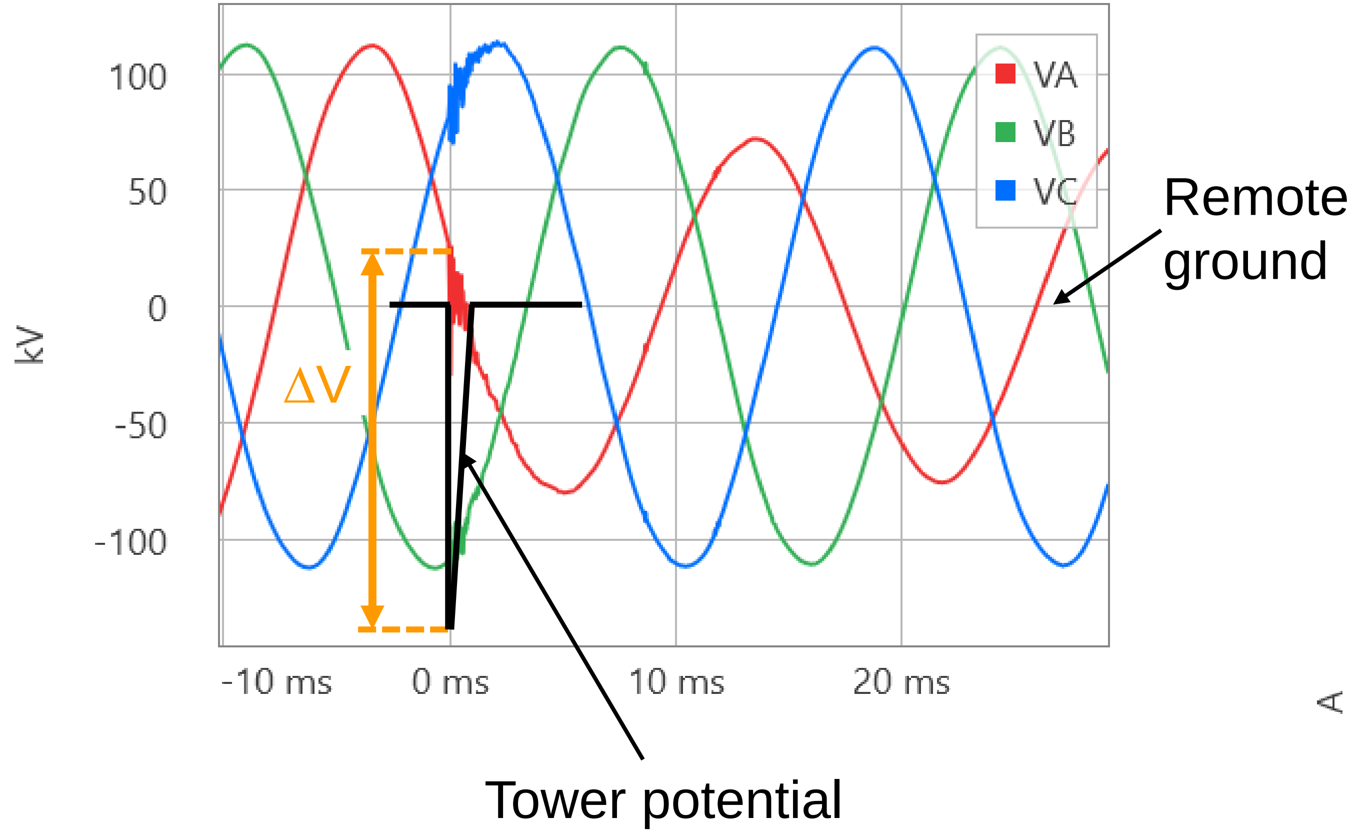


Back Flashover

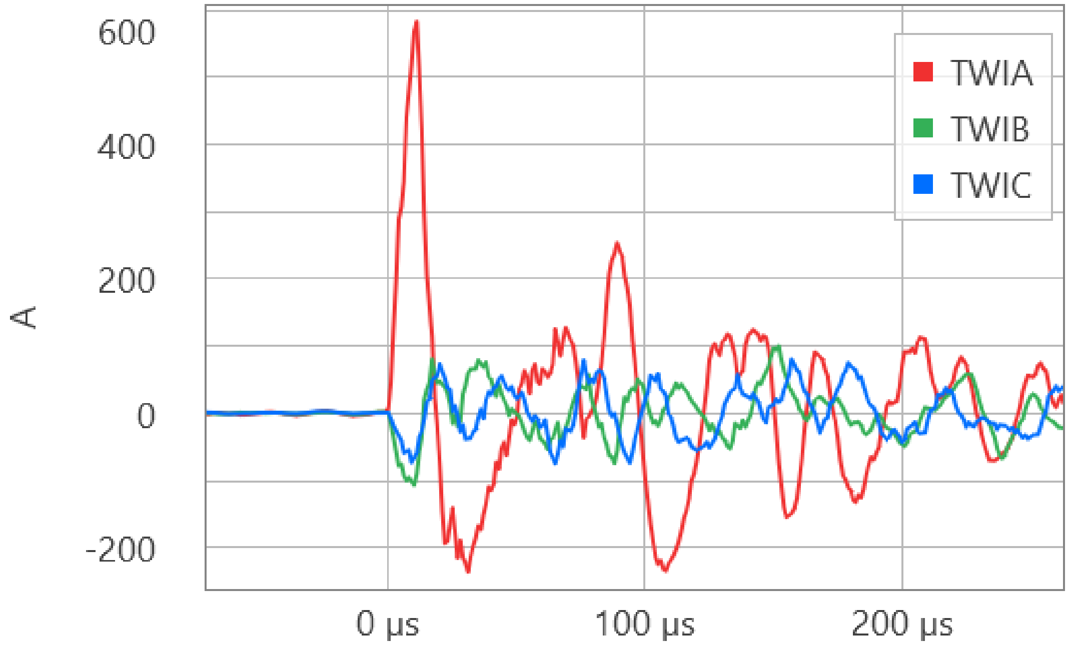
- A lightning strike hits the ground wire or a tower
- Tower potential increases relative to remote earth
- Insulation breaks down even if the phase-to-remote-ground voltage is small



Back Flashover Field Example



Current TW is significantly higher than the point-on-wave voltage would allow



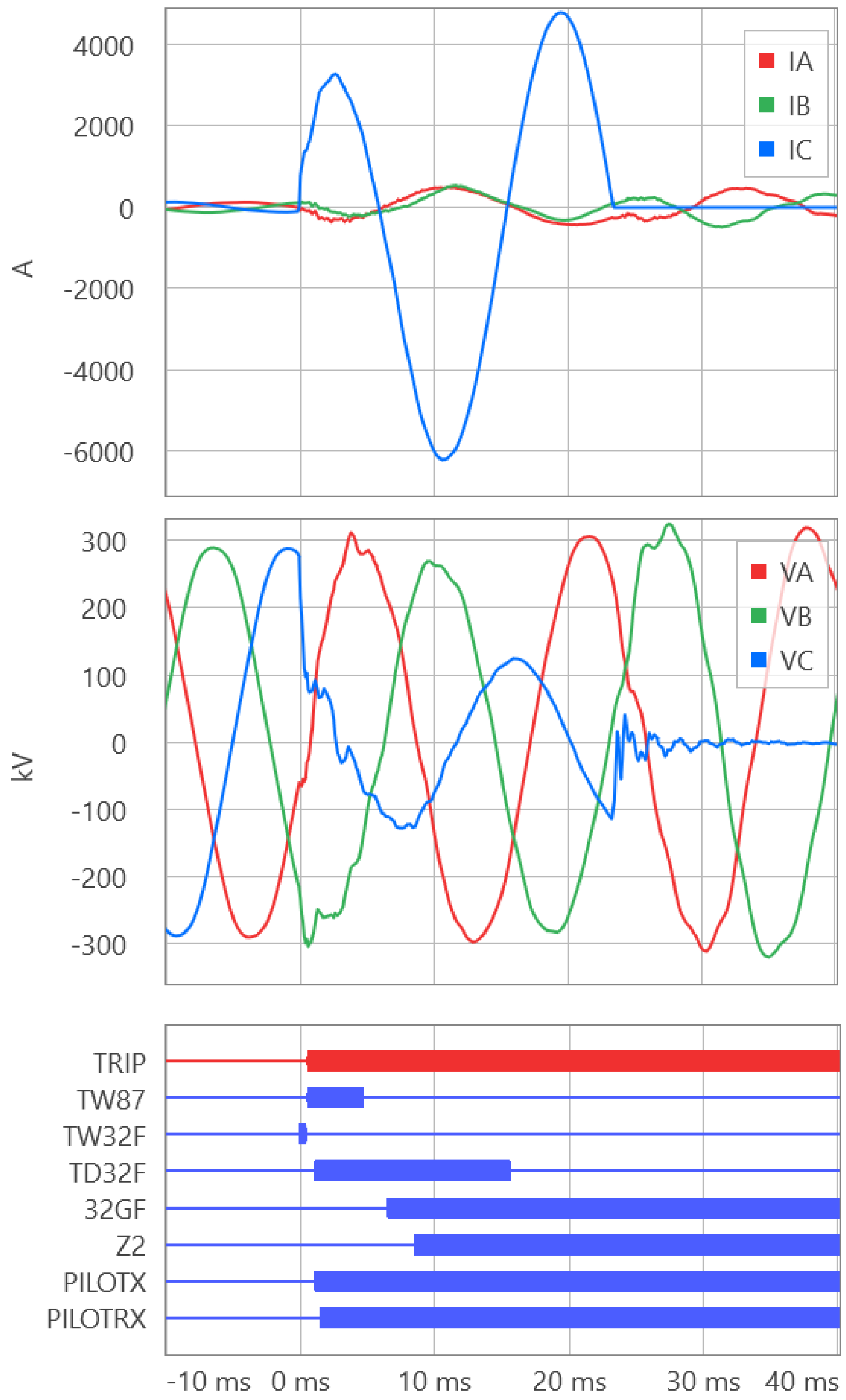
Fault Point on Wave Is NOT a Dependability-Limiting Factor

- Incremental-quantity-based protection inherently unaffected
- Traveling-wave-based protection unaffected because practically, faults do not happen when the voltage is zero

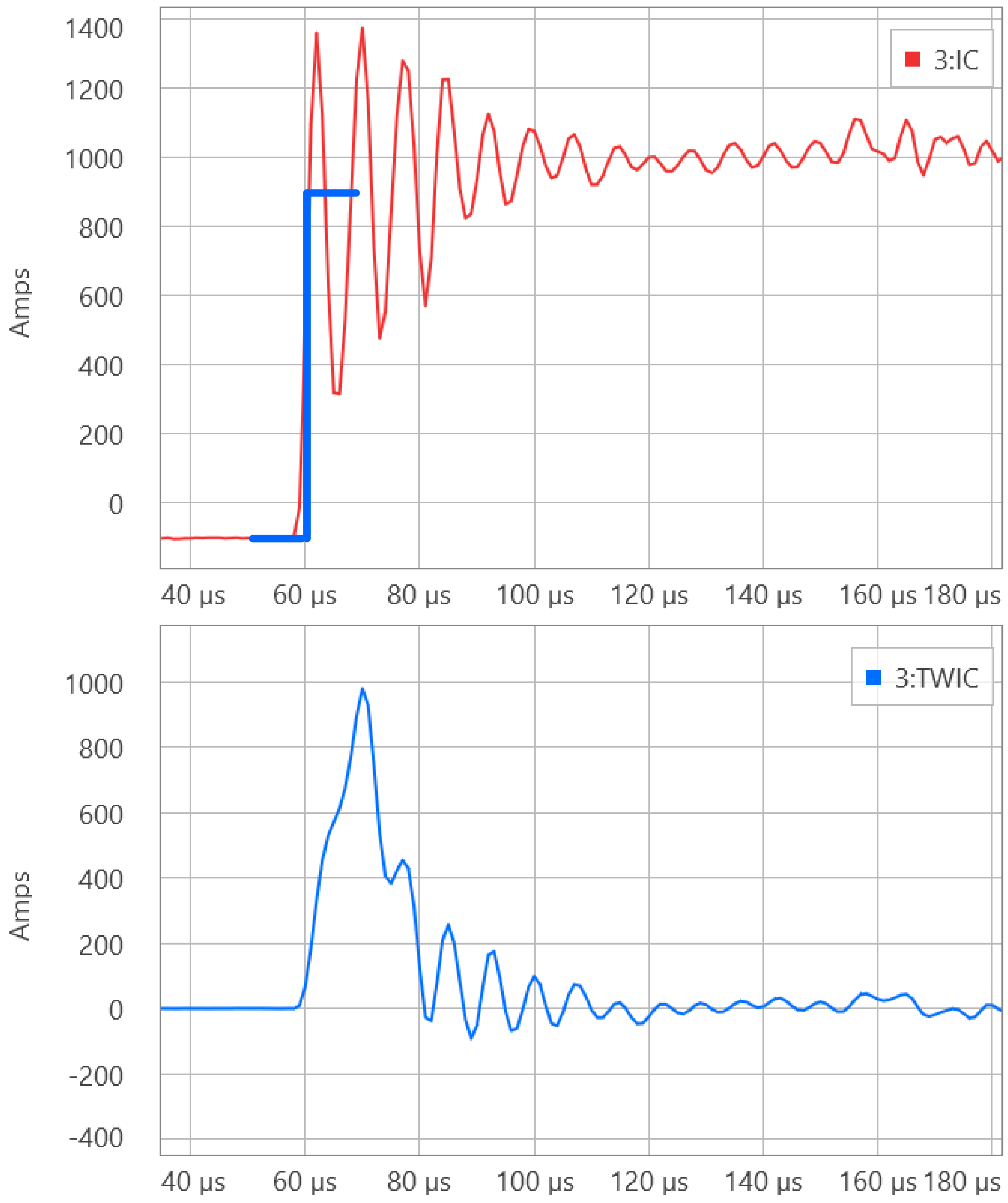
Defensive Design for Security

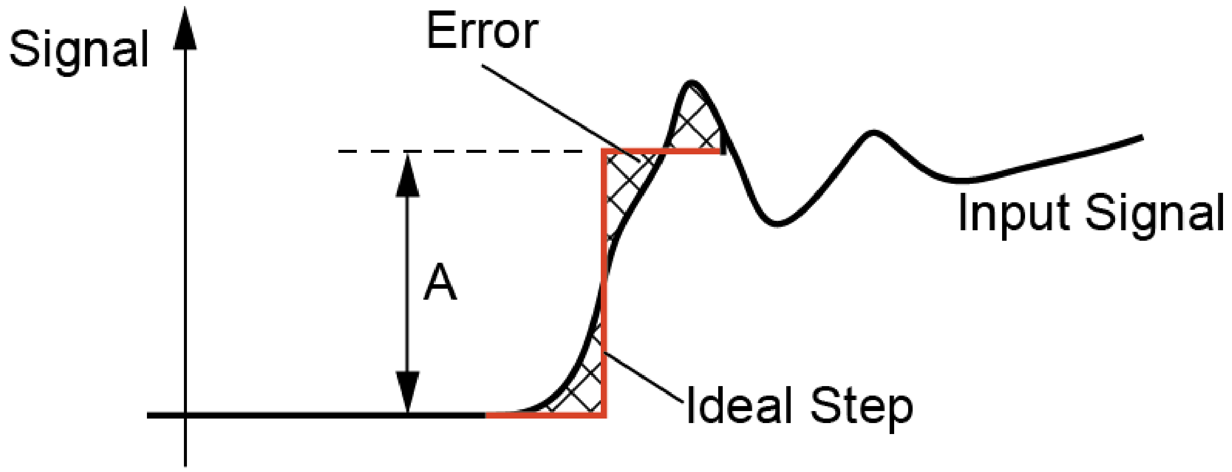
Security

- Arming logic
- TW level validation
- TW shape validation
- TW mode validation



TW Shape Validation



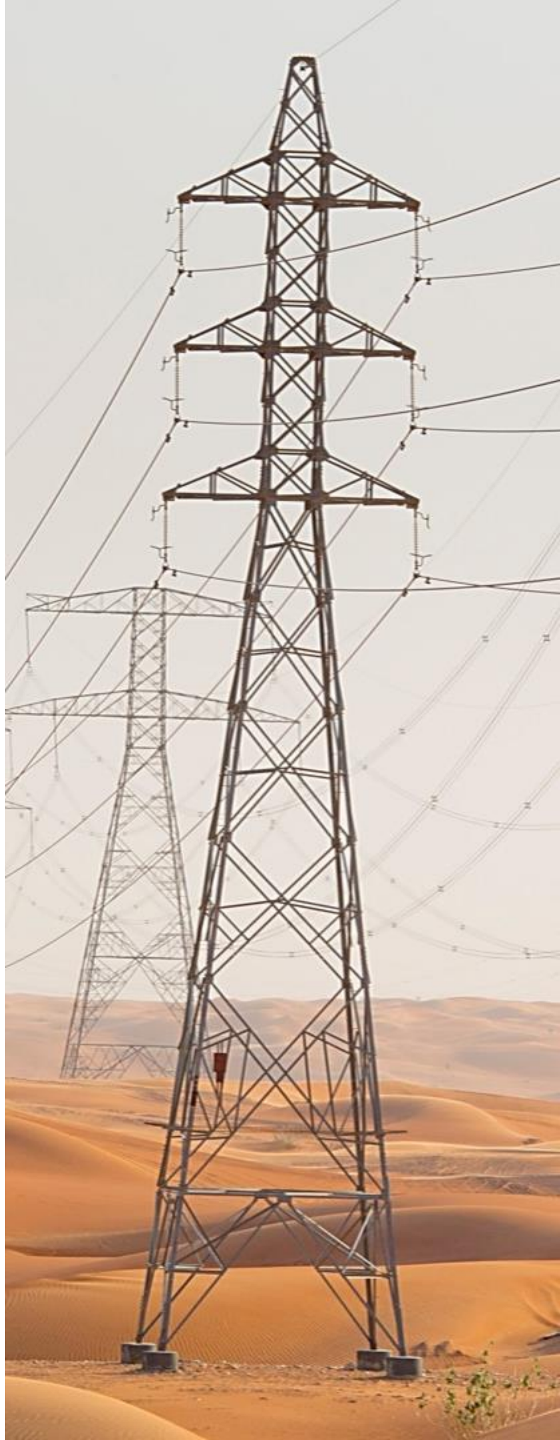


Restrain if

Error > k · (TW Amplitude)

Factors That Impact TW Protection Dependability

- Ringing in CT secondaries
- High termination impedance (no current TWs)
- Very high fault resistance
- Faults very close to terminals (TW87 only)
- CCVTs that are “too good” (TW32 only)



Conclusions

- Transient-based line protection
  - Secure
  - Fast
  - Highly (but not perfectly) dependable
  - Valuable near unconventional sources
- POTT with TD32 is extremely dependable
- Fault point on wave is not a problem
- TW87 scheme impacted mostly by ringing in CT secondaries (a rare situation)