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

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ASEA RALDA Frequency Bandwidth

Filtering Attenuates DC, Fund. and 3rd Harm.
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.

Amperes

Seconds

DC to 0.6 MHz

3 kHz–0.6 MHz
High-frequency transients contain precise information about the fault.
Learning From Fault Locating Experience

**BG Fault at 18.02 km From Drummond**

![Graph showing Goshen and Drummond fault locations with time and distance measurements.](image)

Data from 411L TW Record
Event Playback to Learn From Field Events

UHS Relay

1.2 Second Events

1 MHz Voltages

1 MHz Currents

Protection

Local and Remote Voltages and Currents
Faults Launch Waves
That Travel Close to The Speed of Light
Wave Arrives First to The Terminal Closest to The Fault

Line length: 300 km
TW line propagation time (TWLPT): 1 ms

\[ t_A = 0.25 \text{ ms} \]

\[ t_B = 0.75 \text{ ms} \]
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

![Graph showing operating time versus line length](image-url)

\[ \text{Operating Time (ms)} \approx 3 \cdot \text{TWLPT} \]
TW87 Operating Quantity

\[ i_{OP(t)} = \left| i_S(t) + i_R(t\pm\Delta t) \right| \quad \Delta t < TWLPT \]
$i_{RTI}(t) = \left| i_S(t - TWLPT) - i_R(t) \right|$
TW87 Restraining Quantity 2

\[ i_{RT2(t)} = \left| i_R(t-TWLPT) - i_S(t) \right| \]
TW87 Maximum Restraining Quantity

\[ \text{i}_{\text{RT}(t)} = \max \left( \text{i}_{\text{RT1}(t)}, \text{i}_{\text{RT2}(t)} \right) \]
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
TW87 Operates in 2 ms for an AG Fault

2 ms
TW87 Operates in 2 ms for an AG Fault

Graph showing electrical response over time with annotations for different voltages and currents.
16 ms Faster!
Faster Fault Clearing Times
Reduce Power Angle Oscillations
Faster Fault Clearing Times
Reduce Power Angle Oscillations
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?