New Possibilities for Testing Traveling Wave Fault Location Functions in the Field
Phasor vs. Time Domain

Key technologies

> Accurate time
> Processing speed (FPGAs)
> High bandwidth communication

- Traveling Wave
- Incremental Quantities
Traveling Wave

> A fault on a line generates a traveling wave
  > (inception angle $\neq 0^\circ$)

> The wave propagates close to the speed of light
Wave Terminology

- Traveling Wave
- Dispersion
- Reflection
- Transmission
Bewely lattice diagram
Challenges for Traveling Wave Algorithm

> CVT & CCVT have a bad high frequency transmission
> Discriminating Reflections
Two-Ended Fault Location

> Only relying on first wave, thus immune to reflections. Robust!
> Successfully used in fault locators for many years
> Protection will require high bandwidth communication
> Requires highly accurate absolute time stamping

\[
m = \frac{1}{2} (l + (t_L - t_R) v)
\]
Single-Ended Fault Location

- No communication required
- Only relative timestamps
- Susceptible to reflections
- First principle that was used

\[
m = \frac{t_{L2} - t_{L1}}{2} v
\]
Laboratory vs. Field Environment

> EMTP simulation with 2MHz
  > Required for wave steepness
  > Several MB size
  > Minutes to calculate a few 100ms

> Real-time simulator
  > with high-speed FPGA

> Relays in one place

> Injection to the low-level Inputs
  > bypassing internal CTs
  > Opening the housing

> Test set with max. 10kHz

> End-To-End setup

> Injecting in 5A inputs

> Driving inductive burden
Signal-Generation & Injection

> Driven by single application
> Simultaneous testing with fault current & TW pulses
  > Required by relay logic
> Test set is in a phase lock loop (PLL)
> TW pulses timed exactly point on wave
Commissioning

> Single ended execution possible

> Highly accurate synchronization
Time Accuracy

Time Accuracy is vital

- 1µs Jitter = 300m/900ft error

Achieved Accuracy in experiment over End-To-End!

- Jitter of +/- 40ns achieved
- Relay fault locator compared to simulated fault location
  10-30m / 30-90ft
Future Outlook

> Experiments only done with two ended Fault Locator

> Time Domain Protection a new challenge:
  > Multiple TW elements and incremental quantity elements combined
  > Elements logic working together to achieve security
  > Voltage and current waves
  > Discriminates polarity

> Challenging Test Cases
Conclusion

> TW Fault locator was successfully tested!
  > Without test modes, masking, disabling or any other manipulation of the relay

> New Generation Protection requires new tools for commissioning

> For compliance an End-To-End test will be required

> Today test sets can be enabled for testing TW protection relay

> Test sets must have a high time accuracy (<100ns)

> The future stays exciting!