Double-Ended Traveling-Wave Fault Locating Without Relay-to-Relay Communications

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Red Eléctrica Group
Established 1985

- First company in the world dedicated exclusively to electricity transmission and Spanish electricity system operation
- Established itself as a global operator of essential infrastructure, managing electricity transmission grids in Spain, Peru, Chile, telecommunications networks (fiber optics and satellites), and important elements of innovation and technological development
**Project drivers**

**Accurate fault locating**
- Present limitations: accuracy
- Outage times

**Adaptive autoreclosing**
- Mandatory autoreclosing in overhead lines, not allowed in cables
- Large security margins present in algorithms

**New possibilities**
- Line monitoring
- High-voltage equipment analysis
- Protection for systems with high penetration of power electronics

**Pilot installations**

**N. Valladolid-to-Mudarra**
- 220 kV hybrid line, 21.85 km overhead + 2.42 km underground
- Adaptive autoreclosing cancel logic

**Spain-to-Morocco 1 and 2**
- 400 kV hybrid lines, 9.33 km overhead + 31.3 km submarine + 22.21 km overhead
- Accurate fault locating + adaptive autoreclosing cancel logic

**Casaquemada-to-Onuba**
- 220 kV overhead line, 61.98 km
- Accurate fault locating
- Initially installed with no relay-to-relay communications
Double-ended TW-based fault locating

Principle of operation

General equation
\[ M = \frac{LL}{2} \left( 1 + \frac{t_L - t_R}{TWLPT} \right) \]

CT cable delay compensation
\[ M = \frac{LL}{2} \left[ 1 + \frac{(t_L - TWCP_TL) - (t_R - TWCP_TR)}{TWLPT} \right] \]

Current TWs: mode and phase reference
- Alpha mode for single-line-to-ground faults
- Beta mode for line-to-line faults

Time-stamping TW arrival time

Differentiator-smoother filter

Response to a step

Response to a ramp
Time-stamping TW arrival time
Interpolation method

Extracting TW time stamps
Method 1: IEEE COMTRADE header files

**Terminal L**

[Fault_Location]
SE_TW_Location1
SE_TW_Location2
SE_TW_Location3
SE_TW_Location4
DE_TW_Location
SE_Z-Based_Location
DE_Z-Based_Location
**First_TW_Time_Local**
First_TW_Time_Remote

**Terminal R**

[Fault_Location]
SE_TW_Location1
SE_TW_Location2
SE_TW_Location3
SE_TW_Location4
DE_TW_Location
SE_Z-Based_Location
DE_Z-Based_Location
**First_TW_Time_Local**
First_TW_Time_Remote
Extracting TW time stamps
Method 2: DNP3 LAN/WAN over Ethernet

- Poll UHS relays or RTUs
- Compute TW arrival time difference
- Compute fault location
- Time difference is less than TWLPT?
  - Yes
  - Data are coherent, good quality, and changed?
    - Yes
    - Start
    - No
    - Compute fault location
  - No

Extracting TW time stamps
Method 3: transient records with 1 MHz sampling

Arrival times must be compensated for by CT cable delay
Offline methodology

Manual calculations

Apply TW arrival times obtained from the methods previously described in equation

\[ M = \frac{LL}{2} \cdot \left(1 + \frac{t_L - t_R}{TWLPT}\right) \]

Software tools: Bewley diagram

- Plot MHR recordings from both ends of line
- Align time cursors to initial TW peaks

Field experience for internal BG fault

220 kV, 61.98 km Casaquemada-to-Onuba line
IEEE COMTRADE header files

Terminal L

\[ \Delta t = t_{L\_comp} - t_{R\_comp} = -26.798 \mu s \]

\[ M = \frac{61.98}{2} \left( 1 + \frac{-26.798}{210.50} \right) = 27.045 \text{ km} \]

Terminal R

\[ \Delta t = t_{L\_comp} - t_{R\_comp} = -26.798 \mu s \]

\[ M = \frac{61.98}{2} \left( 1 + \frac{-26.798}{210.50} \right) = 27.045 \text{ km} \]

Transient records with 1 MHz sampling

\[ \Delta t = (t_{L\_uncomp} - \text{TWCP}_L) - (t_{R\_uncomp} - \text{TWCP}_R) \]

\[ \Delta t = (-27.037) - (\text{TWCP}_L - \text{TWCP}_R) = -26.798 \mu s \]
Bewley diagram

11/29/19 Casaquemada 30.573 3.294 33.449 0.418 33.872 0.005 33.867
Onuba 25.332 2.753 28.212 0.127 28.108 0.023 28.085
12/8/19 Casaquemada 24.220 2.723 26.728 0.215 27.045 0.102 26.943
Onuba 32.081 2.928 34.755 0.254 34.935 0.074 35.009
12/17/19 Casaquemada 25.922 3.115 28.758 0.279 29.138 0.101 29.036
Onuba 29.825 3.091 32.714 0.202 32.842 0.074 32.916
12/26/19 Casaquemada 55.398 4.033 33.153 26.278 59.210 0.221 59.431
Onuba 2.154 0.367 2.505 0.016 2.770 0.249 2.521
1/1/20 Casaquemada 30.447 3.420 33.343 0.524 33.908 0.041 33.867
Onuba 25.162 2.923 27.918 0.167 28.072 0.013 28.085

BG faults on Casaquemada-to-Onuba line
Conclusions

- DETWFL results can be obtained offline by using
  - Manual calculations (may be automated using DNP3 protocol over Ethernet)
  - Software tools (Bewley diagram)
- REE is gaining experience with UHS relays for TWFL
  - Five faults occurred while relay-to-relay communications were unavailable
  - DETWFL results obtained offline were accurate to within one tower span
  - Confident to move forward with project
- Offline DETWFL results can confirm SETWFL result(s), help select alternative result, or provide TW-based results when results from other methods are not available

Questions?