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

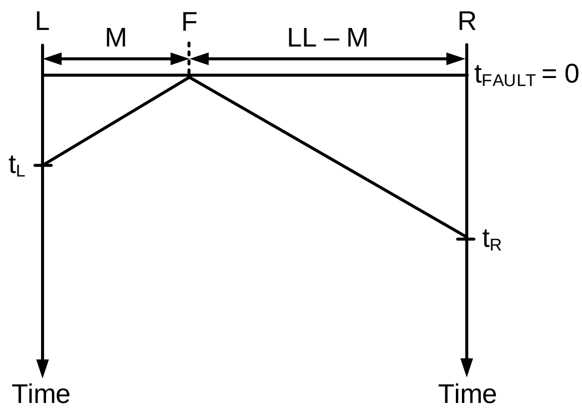
- 400 kV hybrid lines, 9.33 km overhead + 31.3 km submarine + 22.21 km overhead
- Accurate fault locating + adaptive autoreclosing cancel logic

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

$$M = \frac{LL}{2} \bullet \left(1 + \frac{t_L - t_R}{TWLPT}\right)$$

CT cable delay compensation

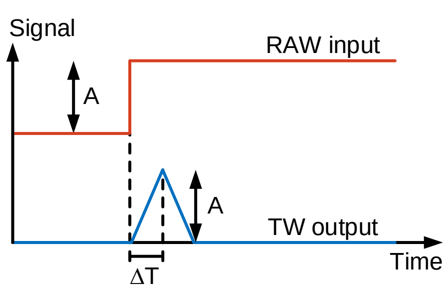
$$M = \frac{LL}{2}\left[1 + \frac{(t_L - TWCPT_L) - (t_R - TWCPT_R)}{TWLPT}\right]$$

Current TWs: mode and phase reference

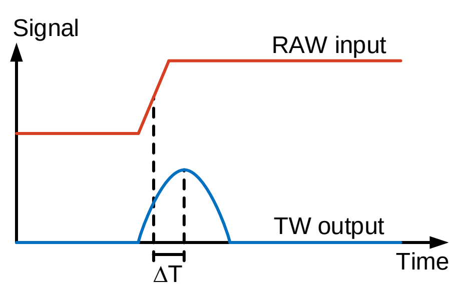
- Alpha mode for single-line-to-ground faults
- Beta mode for line-to-line faults

Time-stamping TW arrival time

Differentiator-smoother filter



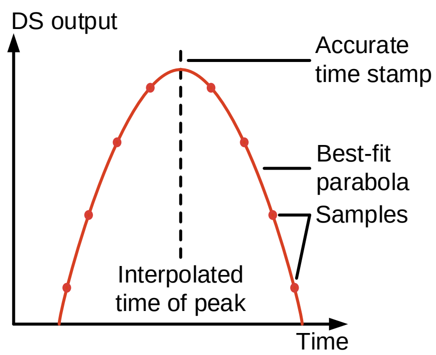
Response to a step



Response to a ramp

Time-stamping TW arrival time

Interpolation method



Extracting TW time stamps

Method 1: IEEE COMTRADE header files

Terminal L

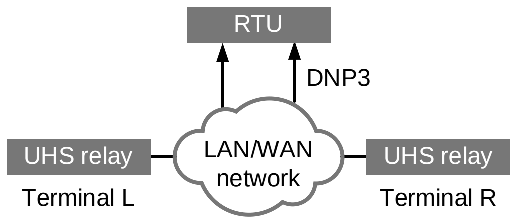
```
[Fault_Location]
SE_TW_Location1
SE_TW_Location2
SE_TW_Location3
SE_TW_Location4
DE_TW_Location
SE_Z-Based_Location
DE_Z-Based_Location
First_TW_Time_Local
First_TW_Time_Remote
```

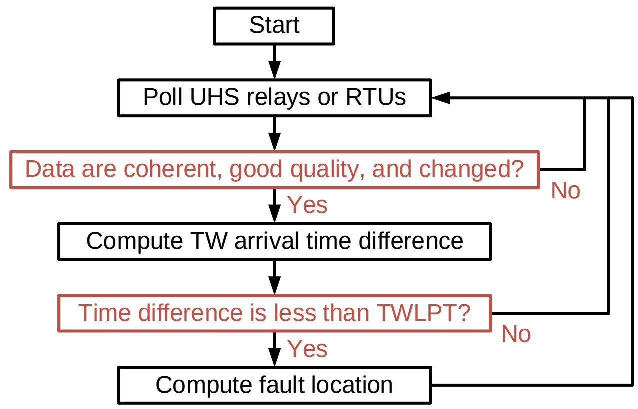
Terminal R

```
[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

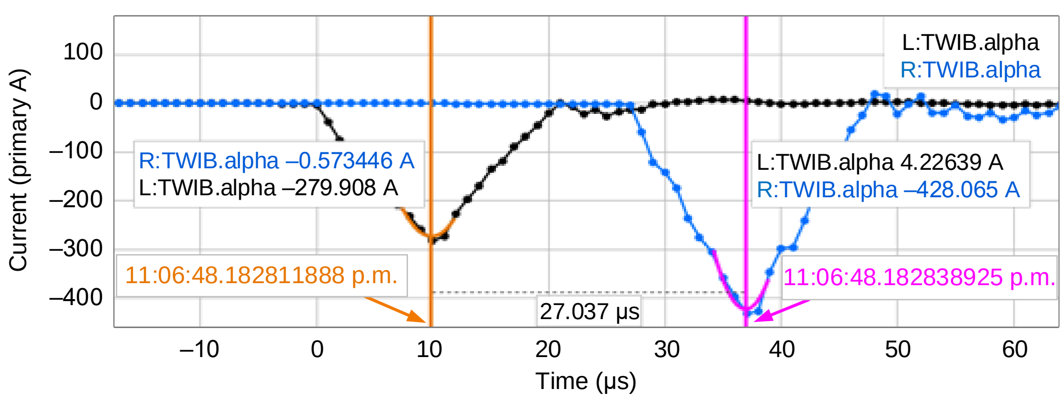
Method 2: DNP3 LAN/WAN over Ethernet





Extracting TW time stamps

Method 3: transient records with 1 MHz sampling



Arrival times must be compensated for by CT cable delay

Offline methodology

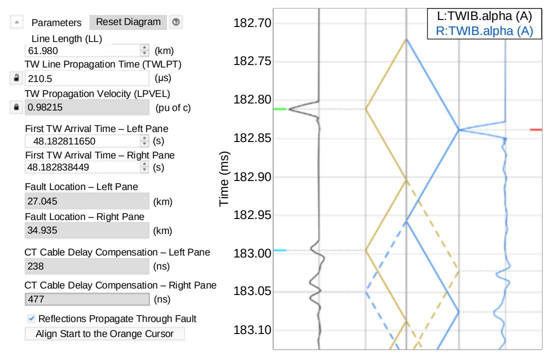
Manual calculations

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

$$M = \frac{LL}{2} \bullet \left(1 + \frac{t_L - t_R}{TWLPT}\right)$$

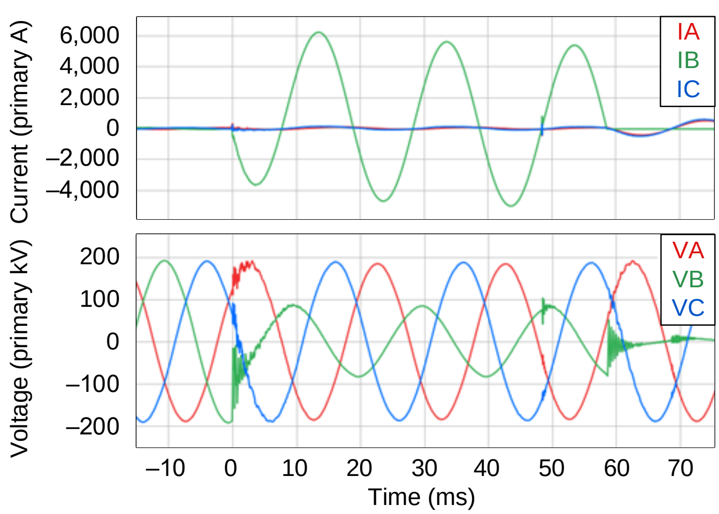
Software tools: Bewley diagram

- 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

```
[Fault_Location]
SE_TW_Location1,"26.728(km)"
SE_TW_Location2,"33.168(km)"
SE_TW_Location3,"$$$$$$$(km)"
SE_TW_Location4,"$$$$$$$(km)"
DE_TW_Location,"$$$$$$$(km)"
SE_Z-Based_Location,"24.220(km)"
DE_Z-Based_Location,"$$$$$$$(km)"
First_TW_Time_Local,"2019/12/08,05:06:48.182811650"
First_TW_Time_Remote,"$$$$$$$$"
```

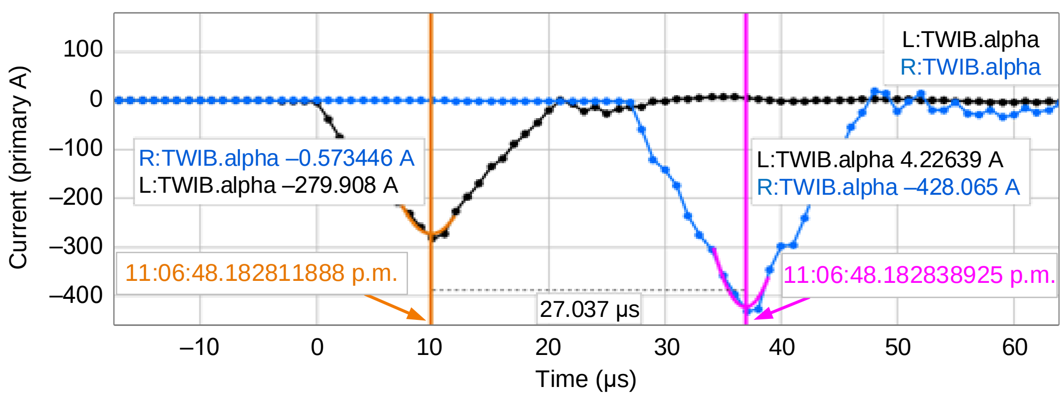
Terminal R

```
[Fault_Location]
SE_TW_Location1,"3.158(km)"
SE_TW_Location2,"27.738(km)"
SE_TW_Location3,"34.755(km)"
SE_TW_Location4,"38.668(km)"
DE_TW_Location,"$$$$$$$(km)"
SE_Z-Based_Location,"32.081(km)"
DE_Z-Based_Location,"$$$$$$$(km)"
First_TW_Time_Local,"2019/12/08,05:06:48.182838448"
First_TW_Time_Remote,"$$$$$$$$"
```

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

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

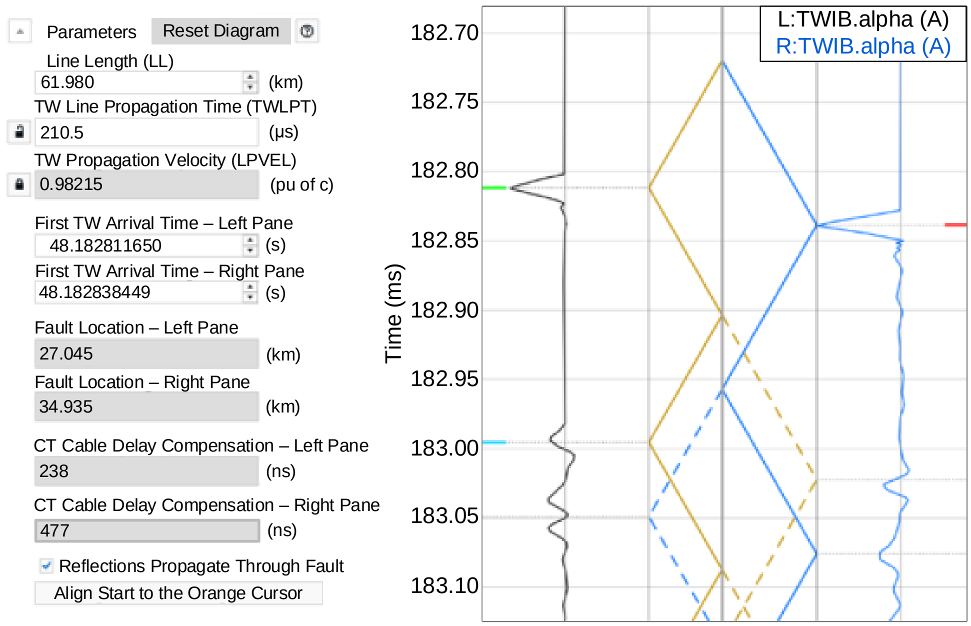
Transient records with 1 MHz sampling



$$\Delta t = \left(t_{L\_uncomp} - TWCPT_L\right) - \left(t_{R\_uncomp} - TWCPT_R\right)$$

$$\Delta t = (-27.037) - \left(TWCPT_L - TWCPT_R\right) = -26.798\ \mu s$$

Bewley diagram



BG faults on Casaquemada-to-Onuba line

Event date	Terminal	SEZFL (km) Result	SEZFL (km) Error	SETWFL (km) Result	SETWFL (km) Error	DETWFL (km) Result	DETWFL (km) Error	Tower location (km)
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

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?