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COUNTRY : BR
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GROUP REF. : B5
PREF. SUBJECT : PS2
QUESTION N° : 2.03

Q2.03: What are the experiences to fault identification and location and how to design the scheme to meet the practical application requirement?

Although traveling waves is a topic studied since the 30's for different reasons it hasn't yet been widely adopted in practical applications, however, the comments and conclusions herein stated are based in experiences of a company with a installed base of over 15 years and installation on more than 300 lines around the globe.

Challenges of theoretical models

For years the literature exclusively based in theory brings the discussion that Traveling Waves technology has flaws in two scenarios weren't observed in practical applications:

- **Faults with 0° inception:** Although in theoretical models this type of fault would not generate traveling waves, this situation has never been reported
- **VTs with low bandwidth:** Simple modeling of certain types of VTs considers that they behave as a low-pass filter which should remove TW components from the network, however real products are installed worldwide proving that Traveling Waves can be used in such kind of VTs for accurate fault location.

One of the hypotheses is that the literature uses the same philosophy of modelling circuits for power flow purposes to model the interaction for TW applications, which proves not to be representing cases from real experiences. There are possibly phenomena, as multiple parasitic impedances and interaction in between phases, that are being neglected in the current theoretical approach that might be leading to these wrong results.

Other important phenomena that have been seen in practice but is not widely discussed in the literature is the dynamics of a fault. Models considers that a fault occurs instantaneously, however there is a variety of cases where the impedance of the fault evolves which generates multiple behaviors in the waveform of the Traveling Wave, consequently impacting automatic fault location algorithms, these are situations that can be seen in cases of fire or lightning strikes when the air is ionized before the actual strike. As example the Figure 1 show a record of a real traveling wave where it is hard to identify the starting point of the fault, not because of the amplitude of the TW, but because of the dynamics during beginning of the event.

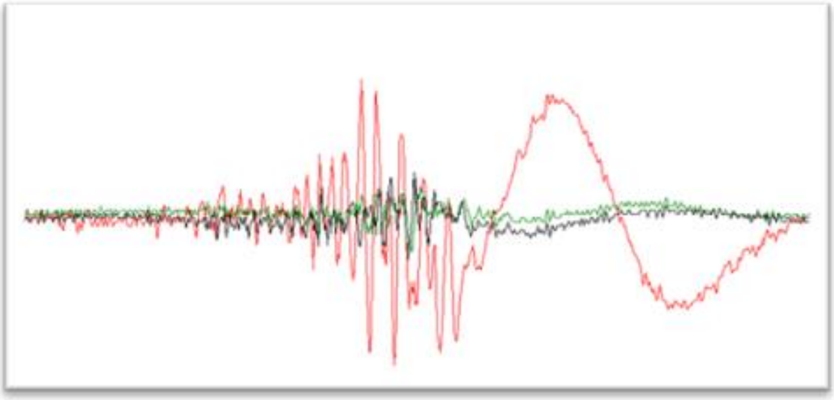

Figure 1 - TW Record of a real fault in a 765kV line

Having more accurate models is crucial to evolve TW technologies and to build trust in their users, especially when expanding to more critical applications. Accurate models are also important to be used in combination with new testing tools that are achieving the capability to perform hardware simulation replicating TW phenomena.

Leveraging lower frequency measurement to increase accuracy and simplify algorithms

As commented before, Traveling Wave phenomena has been studied for many years, but it is still a technology less explored than conventional measurements at frequencies below 15kHz. In practical experience the usage of both concepts simultaneously is a powerful tool to simplify the analysis, algorithms and increase accuracy.

One technique is to use the low frequency signal to determine a Region of Interest around when the fault happened, which allows to simplify the algorithms applied to the high frequency signal and consequently increase reduce the possibility of errors, as exemplified in Figure 2.

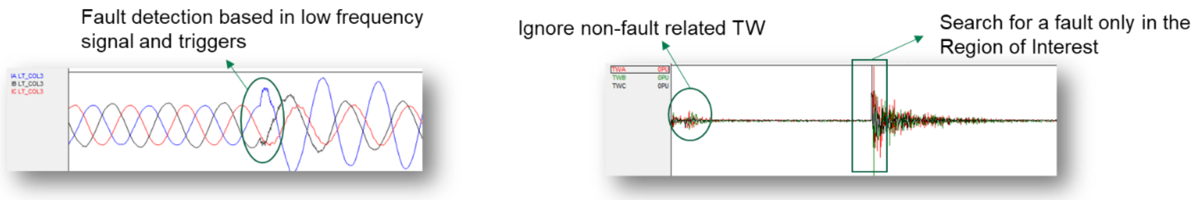

Figure 2 - Exemple of TW analysis based on a Region of Interest

Double Ended TWFL covering all use cases

With regards Fault location Double Ended architecture has proven to be the method capable to support the most diverse types of lines and systems in terms of fault, especially because this architecture doesn't require to identity the TW reflection which may not be possible in non-linear systems or when the TW has low energy.
Among the different use cases for Double Ended TWFL it can be highlighted:

- Hybrid lines;
- High impedance faults;
- T-lines;
- Railways;
- HVDC;
- Switch-on to Fault;
- Short Lines

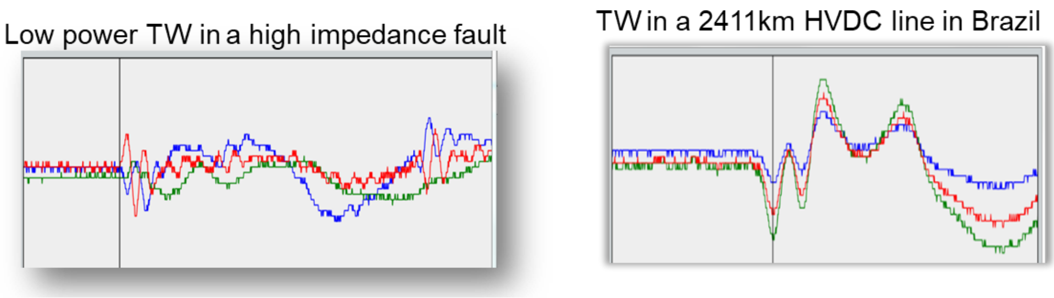

Figure 3 - Examples of real records of Traveling faults for High Impedance and HVDC

Return of the Investment

A recent paper from a Brazilian company analyzed the payback of the investment on Traveling Wave technology based in five lines where they have both TWFL and impedance fault location solutions.
According to the practical experience of this utility, Impedance fault location achieve an average fault location error of 5.5% of the line length, meanwhile TWFL has an average error of 0.19% as show in Figure 4.

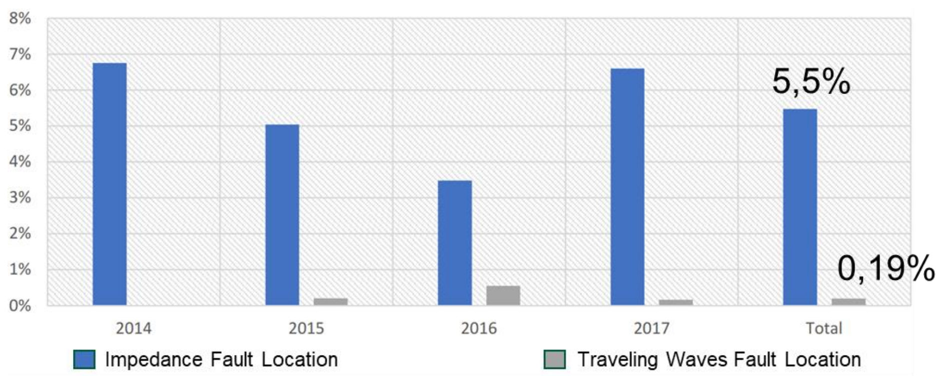

Figure 4 - Study of accuracy comparing Impedance Fault Location and TW Fault Location

Considering the cost of their crew to investigate the cause of the fault and inspect the area, for the five lines the payback was calculated as presented in Table 1.
Considering an average of all lines the Return of Investment of the TWFL technology was estimated in 3,3 years for non-permanent faults. In case of permanent faults it is estimated that the return of the investment can happen in first occurrence.

Line	Length (km)	Payback time
CO-MC	174,0	3,3 years
SM-SB3	248,6	2,5 years
GU-MC	254,9	5,8 years
SM-GU	257,3	3,5 years
IZ-CO	343,5	2,8 years
Average	-	**3,3 years**

Table 1 - Return of investment of the TWFL technology for each line