Experience in Application of Traveling Wave Fault Detection

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Introduction

- The need to detect and locate faults in transmission lines quickly and accurately has grown significantly in power systems globally
- Protection and fault location systems based on new techniques that are faster and more accurate than traditional phasor-based methods have attracted interest of electric utilities
- Use of traveling waves in fault detection both for fault location systems and protection functions has been studied for application in power transmission systems on a larger scale for more than 70 years (since the 1930s)

Introduction

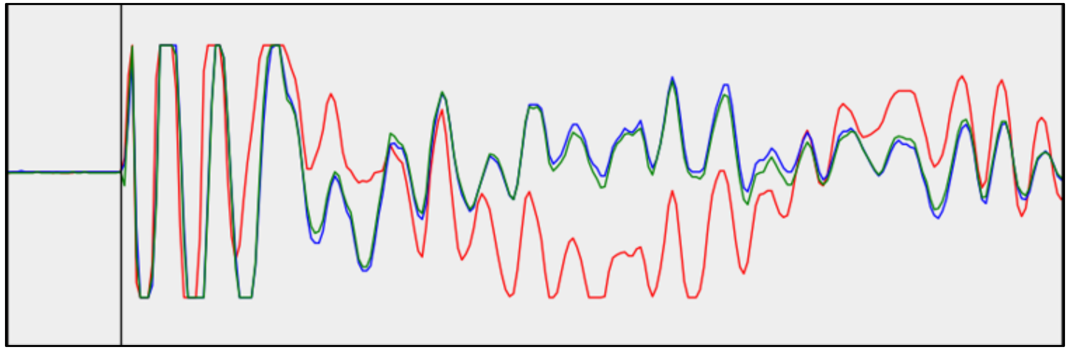
- With the evolution of protection and control technology, mainly in the 80s, the first equipment that used concepts of traveling waves for selectivity and protection began to appear in static relays with actuation times of up to 2 ms
- In the same decade, first traveling wave fault locators appeared presenting accuracies of hundreds of meters without significant influence of transmission line length or electrical parameters (such as reactive compensation)
- Growing interest of power system engineers in the application of systems that guarantee more accurate fault location
- This paper highlights valuable considerations in the use of traveling wave fault location and the results with the use of this technology over the past 13 years

Traveling Wave in Power Systems

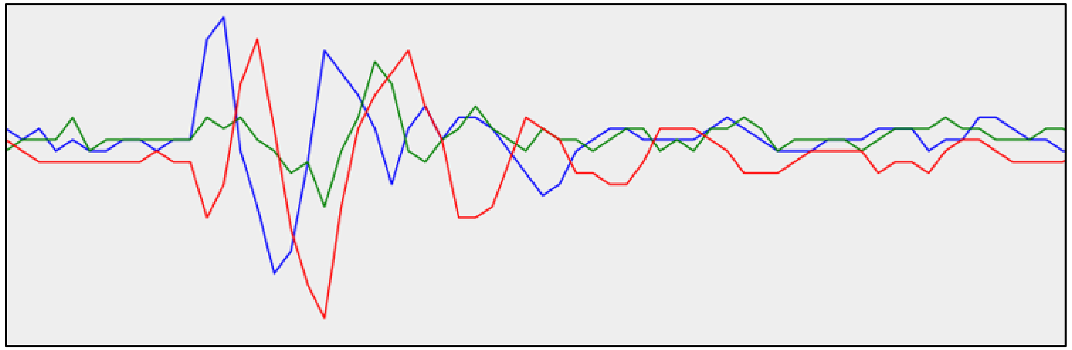
- **Traveling wave phenomena** (*TW – Traveling Waves*) on power transmission lines arises from several types of events, such as faults, switching operations and lightning strikes. Propagation speed of current and voltage traveling waves in overhead power lines is in general close to the speed of light
- These traveling waves are typically composed of a wavefront usually with a **short rising time and a long falling time**
- Although studies date back to the 30's, 40's and 50's, applications in protection systems based on traveling waves started only in the 1970s
- Practical applications of TW Fault Location gained strength mainly after the development of **synchronized clock technology via GPS became available** for civil use, as it allowed the TW system to have a unique time base used by equipment that is generally installed at both ends of transmission line
- For double-ended fault location method it is necessary to use GPS sync signal so traveling wave records at both ends of transmission line are synchronized

Traveling Wave in Power Systems

- Recent studies over the last decade compared single and double-ended impedance fault location methods with traveling wave fault location methods. The results pointed out that errors for a 200 km line can be on the order of kilometers for impedance-based methods and hundreds of meters for methods based on Traveling Wave (TW)
- The way to measure TW can be either using current or voltage, and the field experience shows that accuracy in both methods is similar, making the decision up to manufacturers on how the traveling wave signal is measured in their equipment



TW Voltage signal measured during a fault on a 500kV system



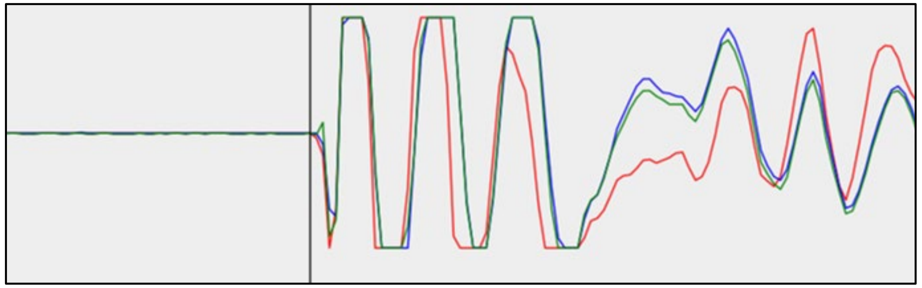
TW Current signal measured during a fault on a 500kV system

Considerations in the use of Traveling Wave in Power Systems Application

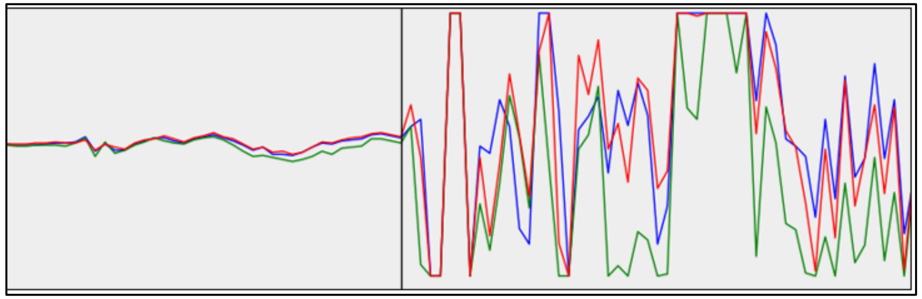
- **Traveling wave fault location has proved to be more accurate** when compared to other traditional methods. Very good results have been obtained over time for TW systems with different characteristics, such as short and long AC lines (with or without reactive compensation), mixed lines and HVDC lines
- Tests and practical experience have proven that **accuracy has little or no relationship** with the length of the transmission line, power flow, series compensation or usage of reactors in the busbar or transmission line
- The **complexity** of determining the fault location when there are elements of compensation, medium or high impedance faults, lightning strikes, is greater compared to low impedance faults or faults on uncompensated lines
- **A fault location system is perceived as accurate** when, in front of different fault scenarios, it remains accurate in the fault location within the **expected range by the technology**, of a few hundred meters, even in situations where the wavefront is low or barely perceptible against the captured noise
  - Situations of possible negative influence on fault location: High impedance faults, faults with slow wavefront rise, faults caused by lightning

Considerations in the use of Traveling Wave in Power Systems Application

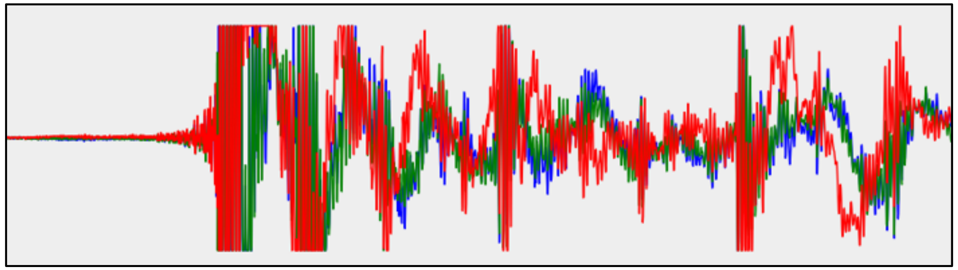
- Following figures show several TW records captured by traveling wave fault locator recorders for lines with voltages above 220 kV and whose signals are measured by secondary voltage of capacitive voltage transformers (CVT)



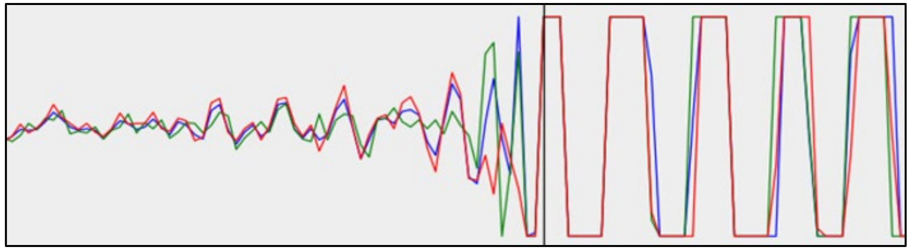
Example of TW signal measured by a CVT for low impedance fault



Example of TW signal measured by a CVT for low impedance fault on a compensated line



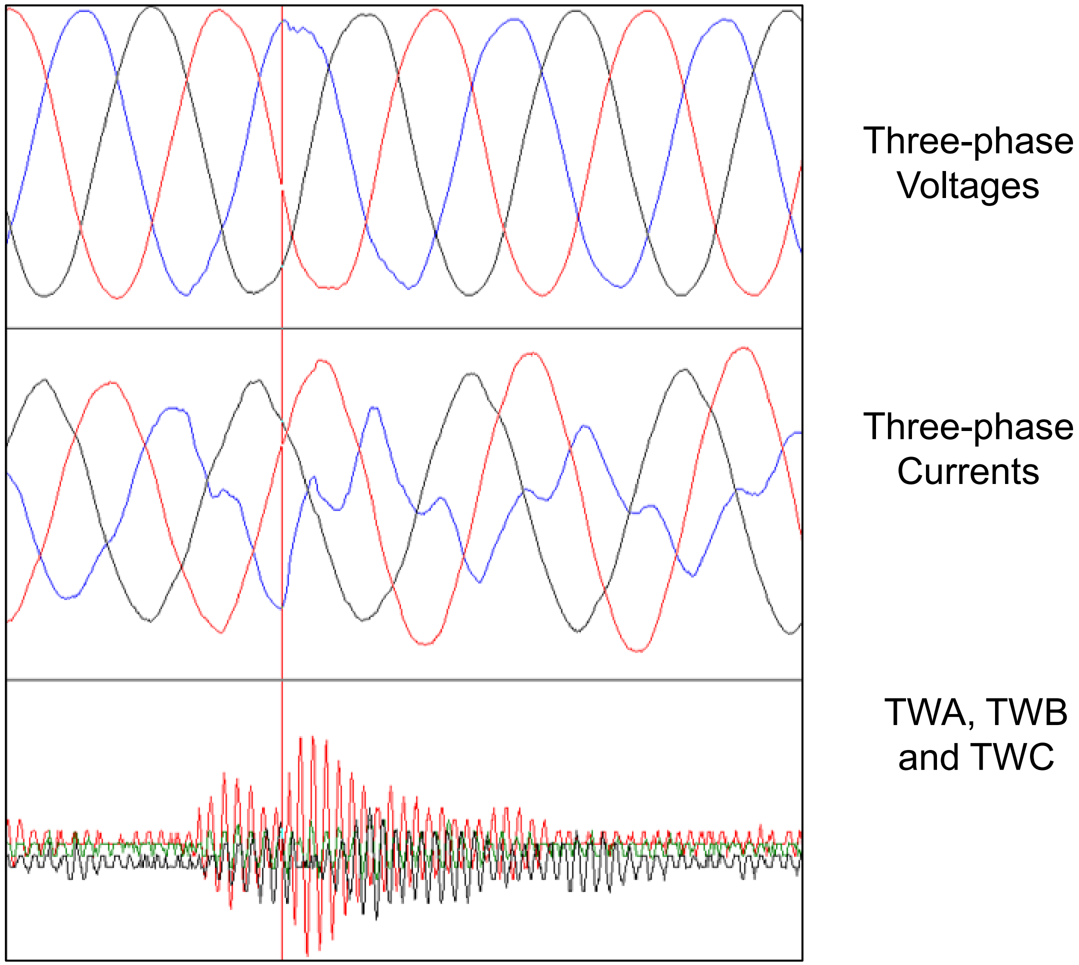
Example of TW signal measured by a CVT for a lightning strike on a line with reactors



Wavefront detail

Considerations in the use of Traveling Wave in Power Systems Application

- For **faults with high or very high impedance**, as in cases involving faults with trees, the level of the signal to be captured from the wavefront is superimposed by noise related to the fault but the noise is not interesting to the fault locator
- This characteristic adds difficulty to automatic fault location algorithms since the magnitude, the duration and the behavior of the traveling waves are not easily modeled in these situations
- One way to overcome this is to use records triggered by a Fault Recorder (FR) synchronized in same time base as the fault locator
  - Where FR oscillography record is used as an additional tool to evaluate the time instant when the fault occurs, then traveling wave record is used with same time base



Traveling Wave Fault Location Examples with Confirmed Fault Location

- Most of the TW applications are related to fault location and its use is seen as more consolidated in countries and systems with long transmission lines
- Some results of TWFL applications are shown here, in different regions, with low and high impedance faults, different operating voltage levels and line lengths, as well as compensated lines up to 765 kV

System Voltage	Country	Date (mm/yy)	L (km)	Confirmed Location (km)	Calculated Location (km)	Error (m)	Relative Error Based on Line Length (%)
765 kV	India	04/20	231.40	32.436	32.390	46	0.020
765 kV	India	06/20	231.40	40.365	40.240	125	0.054
765 kV	India	07/20	240.00	239.100	239.010	90	0.038
765 kV	India	07/20	240.00	239.100	239.140	40	0.017
765 kV	India	08/19	361.00	0.000	0.000	0	0.000
765 kV	India	07/19	342.00	270.000	270.068	68	0.020
765 kV	India	08/20	240.00	238.700	238.760	60	0.025
765 kV	India	04/21	334.46	0.300	0.300	0	0.000
500 kV	Brazil	05/08	248.28	206.000	206.220	220	0.089
500 kV	Brazil	04/08	248.28	206.000	206.150	150	0.060
400 kV	India	04/21	216.00	47.750	47.180	570	0.264
400 kV	India	05/17	262.41	1.902	1.920	18	0.000
230 kV	Brazil	02/09	325.73	122.430	122.560	130	0.040
230 kV	Brazil	07/09	325.73	325.680	325.690	10	0.003
230 kV	Brazil	10/09	325.73	99.510	99.550	40	0.012
230 kV	Brazil	02/09	325.73	194.620	194.650	30	0.009
230 kV	Brazil	09/09	325.73	156.960	156.990	30	0.009
230 kV	Brazil	09/18	64.72	48.000	46.260	1740	2.689
230 kV	Brazil	06/21	140.59	40.000	39.920	80	0.057
220 kV	Spain	08/15	16.40	14.960	14.959	1	0.000
220 kV	Spain	08/15	16.40	13.098	13.160	62	0.378

Traveling Wave Fault Location Examples with Confirmed Fault Location

- Most results are single-phase-to-ground and low impedance faults
- The TW fault location is performed with the records of the first TW event, which is the Trip event
- The fault location results have an **accuracy with errors below 0.5% for most cases**. This precision is achieved with the calibration of the traveling waves parameters, such as the line length (L) and the wave propagation speed (k) that indicates a percentage of speed of light at which the wave travels on the line
- The **error is greater than 1% for the high impedance event** where the wavefronts do not have a discontinuity as clear as a low impedance fault, thus being more difficult to determine the time instant of the wavefront accurately
- It is always important to have **confirmation of the real fault location by field personnel** to feed back the system and ensure better accuracy of the TW fault location method for future events

Traveling Wave Fault Location Examples with Confirmed Fault Location

- **Faults with low impedance characteristic -** the current waveform quickly goes high, and the voltage waveform suffers an abrupt drop. The intensity of the TW wavefronts for low impedance faults is clear enough to identify the timestamps to be used to locate faults

2nd fault in previous table

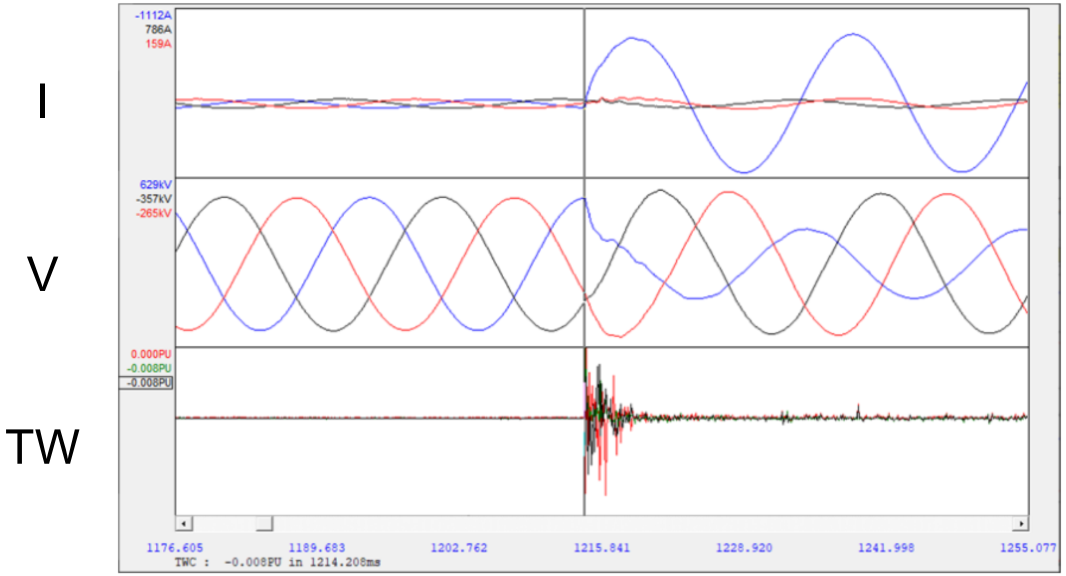


Figure 13 – Waveform record and TW record for terminal A.

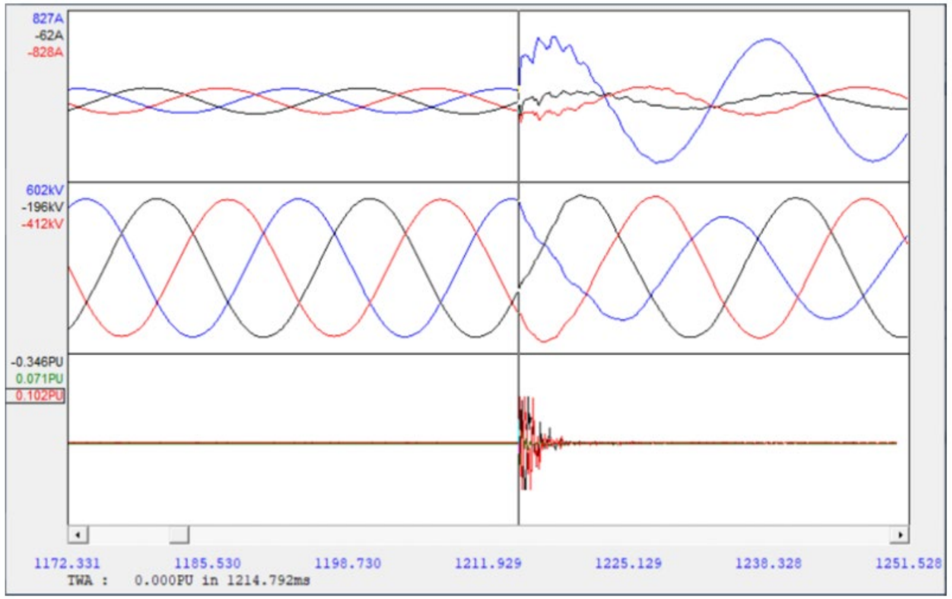


Figure 14 – Waveform record and TW record for terminal B.

Traveling Wave Fault Location Examples with Confirmed Fault Location

- When **real fault location confirmation results are not available** from field/maintenance team, the results provided by single or double ended impedance methods can be used as reference to compare the fault location but not to calibrate the TWFL system
- There are tools that perform **TWFL automatically** based on fault records of the fundamental frequency (50/60 Hz) and high frequency components (TW records). These tools use a pair of TW records and a pair of Waveform records at each end of the transmission line to perform the automatic fault location

Conclusions

- **Experience and practical examples** accumulated in the last 13 years have been presented using Traveling Wave Fault Location techniques, having applications in several transmission companies in Brazil and several countries around the world such as Latin America, Europe and Asia
- The application of the TWFL over the years has **made it possible to have a relevant history of the behavior of traveling waves** for different types of faults, electrical systems and at different voltage levels
- Examples of the traveling wave technology in operation show that, for different types of faults, high or low impedance, line lengths of hundreds of kilometers, with or without reactive compensation, etc., **the accuracy of the fault locations can range from tens to hundreds of meters**

Questions