Implementation of Double Ended Travelling Wave Fault Location When One End is a Transformer Feeder

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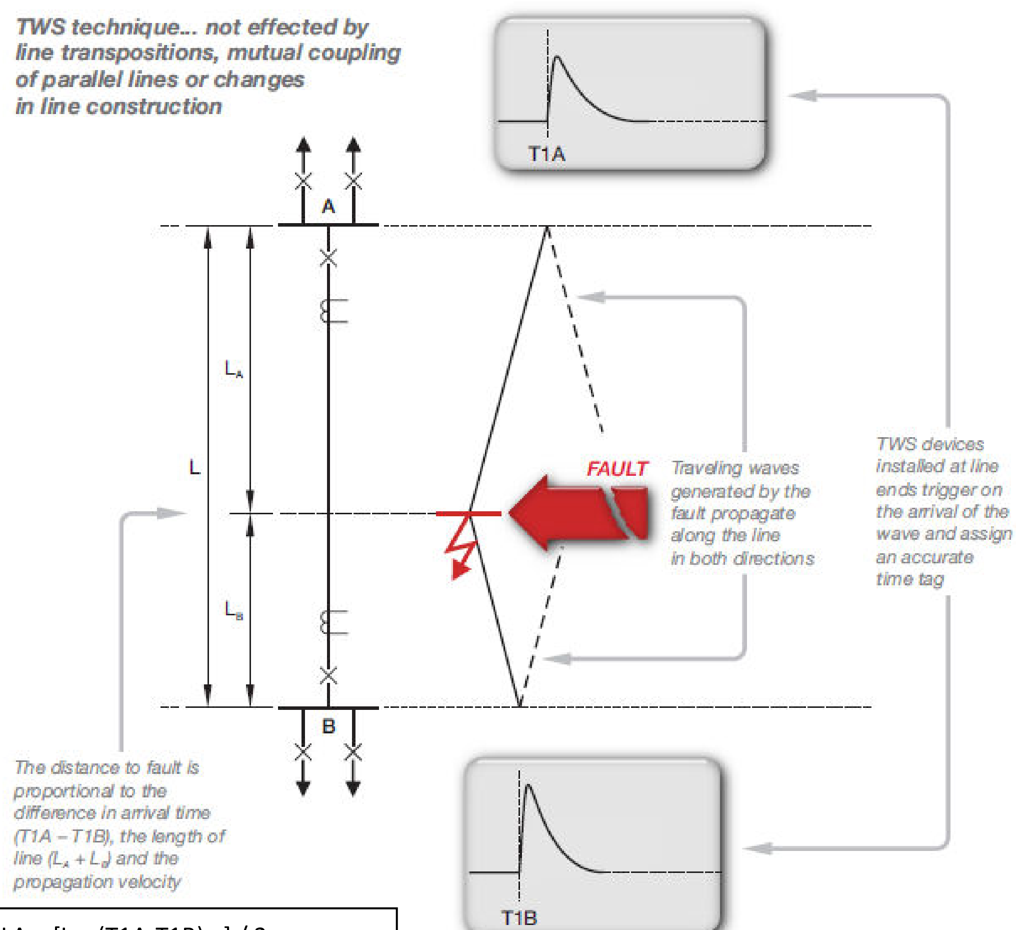
Double Ended Travelling Wave Fault Location

Travelling wave fault location has been used on transmission lines for the last decade for accurate and consistent location of permanent and intermittent line faults typically to the nearest tower or span. Modern travelling wave systems (TWS) use a double ended (Type D) method for fault location that does not rely on operator intervention to determine distance to fault. Results are automatically calculated and immediately available for use. The power arc at the fault site and the resulting step change in voltage generates a travelling wave that propagates along the line in both directions to the line ends. TWS fault locators positioned at the line ends accurately tag the arrival time of the waves using GPS as a reference. These time tags are sent to a central location where they are used to calculate distance to fault using the line length and the velocity of propagation. Further details are given in Fig 1.



LA = [L + (T1A-T1B).v] / 2

LB = [L + (T1B -T1A).v] / 2

V = propagation velocity

Fig 1 Type D Travelling Wave Technique

Monitoring the Travelling Waves

The fault generated travelling wave has a voltage and current component. The relationship between the two is shown in the equation below:

Iwave = Vwave / Zo (Zo is the characteristic impedance of the line, typically 200 to 300ohms)

In deciding whether to monitor the **voltage** or **current** component for fault location it is necessary to consider the terminating impedance at the line end. A change in impedance will result in part of the wave being reflected back into the line and part being transmitted onwards into other connected lines (if they exist).

The reflection factor for the voltage and current components due to the impedance discontinuity at a line end is equal in magnitude but opposite in polarity. Reflection factor is defined as follows:

Voltage reflection factor = $\frac{Zs-Zo}{Zs+Zo}$

Current reflection factor = $\frac{Zo-Zs}{Zs+Zo}$ (Zs is the surge impedance of the terminating busbar)

The dominant impedance contributing to Zs are other connected lines. If the busbar has a total of n similar lines connected to it then Zs will be:

Zs = Zo/(n-1)

The reflection factors now become:

Voltage reflection factor = (2-n)/n
Current reflection factor = (n-2)/n

The voltage and current transients measured at the substation busbar are the sum of incident and reflected waves which in per unit terms based on the number of lines n is:

Voltage = 2/n **Current** = (2n-2)/n

From this it can be seen that as the number of lines increases the voltage transient tends to zero while the current transient tends to double.
When two lines are connected the reflection factor is unity and either voltage or current transients can be monitored.
When one line is connected to a busbar the voltage transient tends to double while the current transient tends to zero.

TWS Deployment

Many TWS systems are retrofitted to existing substations so it is essential that TWS installation is easy and non-intrusive where possible.

At substations where more than one line is connected to the busbar and the terminating impedance is low compared to the line surge impedance then, from the above analyses, it is best to monitor the current component of the travelling wave. See figure 2.

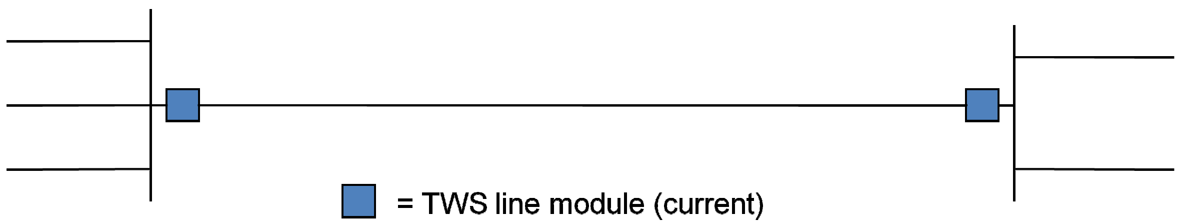


Fig 2 Monitor Current Transients for Low Zs

Fortunately the protection CT has sufficient bandwidth to pass enough of the current transient for fault location. High frequency couplers can be fitted to the CT secondary wiring without the need for line outages. Most TWS devices in transmission substations are connected this way.

However, at substations where a single line connects to a busbar with local transformer(s) and the terminating impedance is high compared to the line surge impedance then, from the above analyses, it is best to monitor the voltage component of the travelling wave. See figure 3.

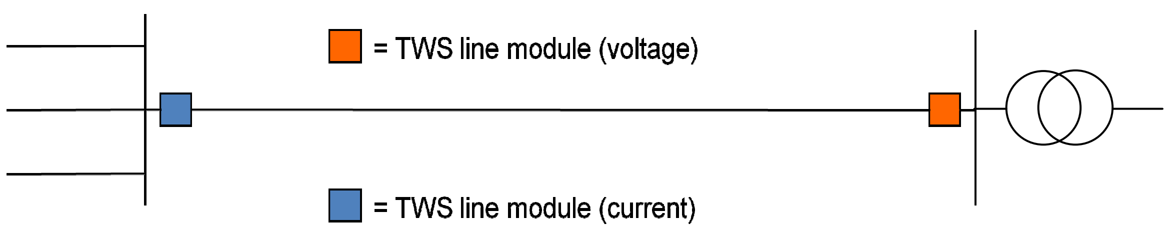


Fig 3 Monitor Voltage Transients for High Zs

Such transformer feeders are rare at transmission but more common at sub transmission where TWS systems are now being deployed. A similar situation can arise when a double circuit line connects to a transformer station and one line is switched out. To maintain fault location capability it will be necessary to monitor voltage transients on both lines.

Accurate travelling wave based fault location on teed or branched sub transmission networks with transformer feeders has real added value. Conventional impedance techniques are less effective, there is less redundancy so the impact of faults on security of supply is greater and line construction is less robust making the system more prone to weather related and environmental effects.

Monitoring Voltage Transients

The standard output of a capacitive or inductive PT is bandwidth limited and not suitable for travelling wave location. The ideal solution is to measure the current through an existing capacitive path to ground. The easiest way to accomplish this is to use the line capacitive PT, when one is available, as shown in Fig 4.

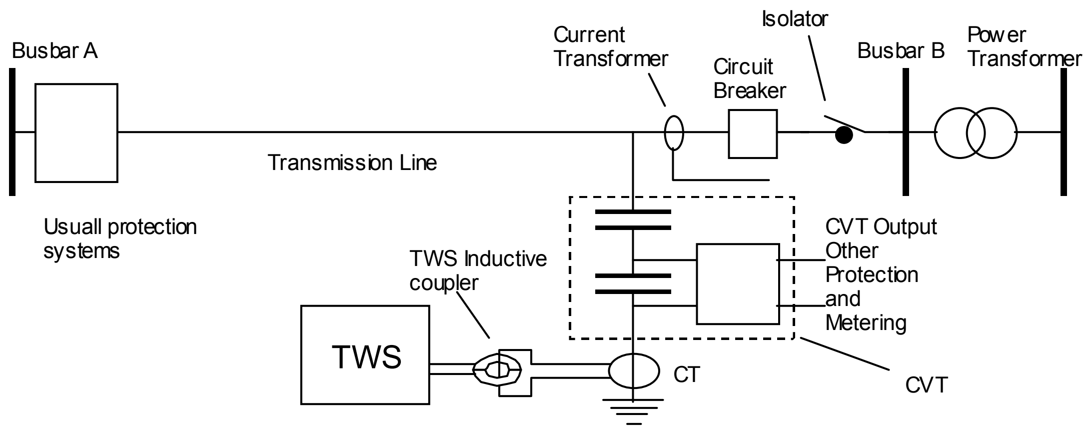


Fig 4 Using a Capacitive PT to Collect Voltage Transients

A toroidal CT is connected into the earth connection of the CVT capacitor stack to monitor the current from the HV line voltage. High frequency components are effectively amplified. The signal is taken to the relay room via a twisted pair screened armoured cable and shorted. A standard high frequency coupler as used in the 'current' method is then placed around the shorted turn and connected to the TWS. This technique provides good high frequency coupling but it requires a line outage to fit the toroidal CT and the installation of a new length of cable to the relay room.

An example of the use of this technique from Russia on a 110KV network is given below in Fig 5. The line L-107 and L-147 had to be monitored but line L-148 is normally out of service and only used if L-147 is switched out. The resulting high terminating impedance at end E meant that the capacitor PT technique was used to monitor the voltage component of the travelling waves on L-147 and L-148. The standard 'current' method was used at end A.

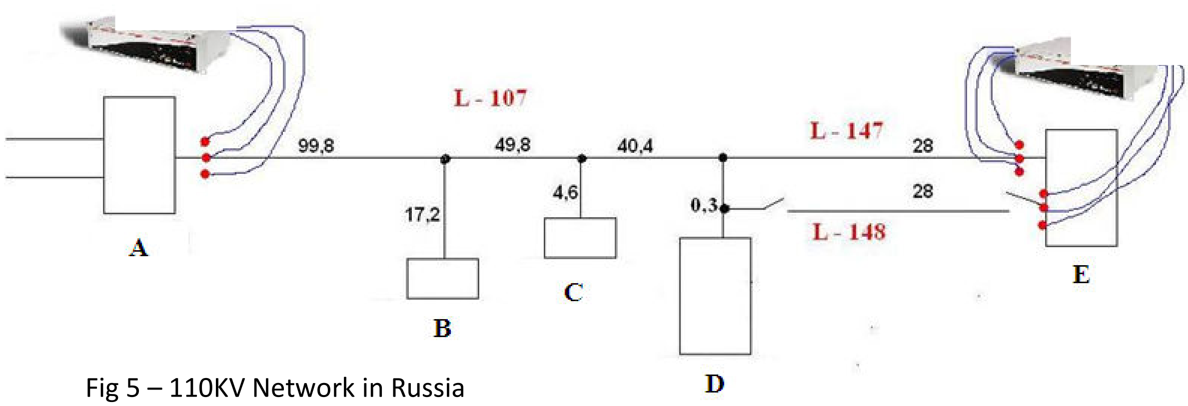
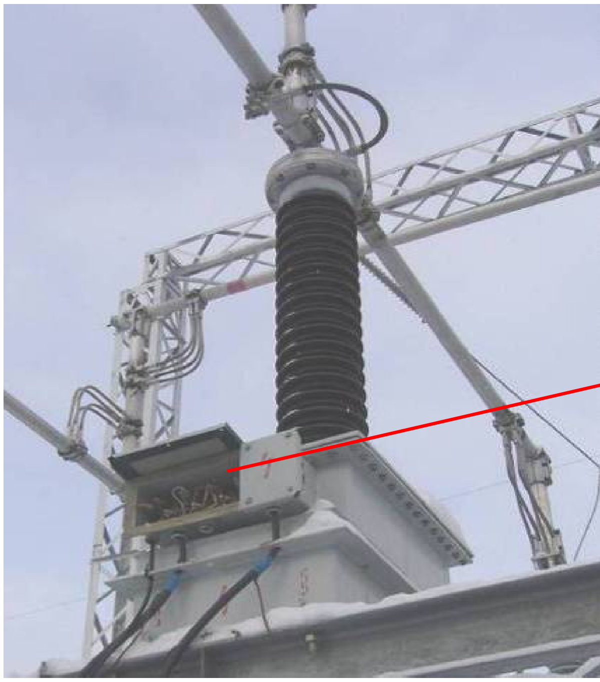


Fig 5 – 110KV Network in Russia

An example of one of the capacitor PTs with the toroidal CT installed in the marshalling box is shown in Fig 6.



Marshalling box - Toroidal CT around the earth connection of the bottom capacitor

Figure 6 – Installation of Toroidal CT on a Capacitor PT

A fault was located in December 2011 just after midnight at 64.5Km from end A. Phase B conductor snapped in the extreme cold of -51˚C. Repair crews went directly to the site.

At sites where CVTs are not present, an alternative travelling wave coupler has been developed using the transformer bushing tap point. The transformer bushing is a capacitive path to ground and it is possible to measure the current in the ground connection at the tapping point in a similar way to the capacitor PT technique. Fig 7 shows an example of a bushing coupler to fit an IEEE compliant type A test tap.

Tap point on lower part of bushing

Different views of the bushing coupler (not to scale)

Fig 7 – Transformer Bushing Coupler for TWS Fault Location

Note that different adapters are available for different types of bushing taps.
The outputs from the three couplers are connected to a marshalling box on the transformer and a single cable laid to the relay room where the TWS device is located. Unfortunately, as per the capacitor PT, an outage is necessary to fit the bushing couplers.

Conclusion

Travelling wave fault location is becoming more widely used because of the accuracy and consistency of the distance to fault results. Virtually all installations to date have been at transmission where it is normal to have more than one circuit connected to a busbar. As such it has been possible to base the TWS fault location on current transients derived from the secondary of the protection CT. However, when deploying TWS fault location in sub transmission networks it is more common to encounter transformer feeders at some line ends where the voltage transients must be monitored due to the high terminating impedance. Two methods are available that allow this without the need to install extra high voltage components. One uses a standard capacitor PT and the other is based on the tapping point on a transformer bushing. The development of such techniques to allow the monitoring of fault generated travelling waves at these locations allows the benefits of TWS fault location to be fully realised on sub transmission systems.

Authors Notes

David Cole obtained an honors degree in Electrical and Electronics Engineering followed by a two year graduate training program at a UK Distribution Company. He then spent three years at the High Voltage Laboratory of BICC Power Cables developing a method of locating partial discharge sites in drum lengths of polymeric cable using travelling wave techniques and four years of applications engineering with a company specializing in underground cable fault locating. He has been with Qualitrol for twenty five years working with fault recorders, sequence of events recorders, circuit breaker test sets and travelling wave fault locators. He is currently a Senior Technical Applications Specialist for Qualitrol's IP range of products. David is a member of the IET and has authored several papers.

Mark Diamond received a Bachelor of Engineering Degree from Queens University Belfast in 1998. Following his graduation he worked in the telecoms industry focusing in high speed fibre optic communications. He has since moved across to the power industry and has 8 years experience in travelling wave fault location. He currently works as an applications engineer developing, promoting and supporting fault location and fault recording products on transmission and distribution networks.