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Improvements in Fault Location Capability at CenterPoint Energy to Reduce Response Time and Improve Accuracy of Fault Reporting

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Overview

As part of CenterPoint Energy's drive to reduce the response time to a line trip and gather more precise information to determine cause of fault, a program was initiated in 2006 to improve the accuracy and reporting time of fault location on the 345 kV and 138 kV networks. The project goal was to automatically deliver distance to fault results accurate to one span within minutes after a line trip to drive remedial actions and reduce downtime. This is not possible with impedance-based calculation techniques. The project has been ongoing for 9 years. The 345 kV network is now fully equipped. The 138 kV network is planned to be fully covered in the next two years.

This paper describes the double-ended traveling wave based system that is being deployed, the results achieved so far and the challenges that had to be overcome to extend coverage on the more complex 138 kV system. These include the management of multi-ended circuits, the development of a new sensor to collect the voltage component of the fault induced traveling wave on transformer tap circuits, and overcoming the effect of looped tees in a circuit. To date 129 devices have been installed in 119 substations monitoring 175 circuits. Sixty additional devices are needed to fully cover the network. Results so far have produced a reduction in the time to reach the actual fault site and more accurate identification of the cause of fault resulting in a reduction in the 'unknown' category of fault reporting. Accurate fault location has also been used to drive preemptive remedial work such as faulty insulator replacements based on locating repeated faults at the same tower.

Future work, as well as completing the deployment of the remaining units, will focus on the commissioning of a link to SCADA whereby fault results generated by the central server of the traveling wave system are automatically integrated into the SCADA host to drive automated responses. Enhanced signal processing will also be developed to improve accuracy of results for lightning events.

CenterPoint Energy Practice in 2006 – 345 kV and 138 kV Networks

CenterPoint Energy patrol guidelines after a line trip and sustained outage was to deploy ground and/or helicopter patrols, analyze fault location from DFR devices, run FALLS study, pinpoint location with patrols, implement repairs and submit a trouble report. The time to restoration was directly linked to how quickly the fault site could be identified.

The guide lines for a line trip and momentary outage was to analyze fault location from DFR devices, run FALLS study, deploy ground patrol next work day, pinpoint location with patrol, determine root cause, implement repairs if necessary, submit trouble report.

The primary fault location was provided by DFR devices using single-ended impedance functionality. Not every line end was monitored but at least one, and often two, devices would trigger for every fault. Following a line trip it was necessary for the DFR records to be downloaded to the Master Station, opened in the viewer and the distance to fault function enabled. Accuracy obtainable with single-ended impedance is variable depending on the type of fault and the degree of compensation included in the algorithm, for example mutual coupling on double circuit lines. The best accuracy on low resistance phase to phase faults is 1 to 2% of line length. For a 40 mile 345 kV line this equates to about 0.6 mile. However, on phase to ground faults with variable fault and zero sequence impedances and strong remote end infeed the error can reach 20% or 8 miles.

On 138 kV circuits where line lengths tend to be shorter, the physical error will be less but other factors will affect the accuracy. Information from relays was used as a backup, but data had to be downloaded by a relay technician from the substation site and emailed to others for analysis.

The effectiveness of finding the correct root cause, especially for momentary outages, is highly diminished without accurate fault locations. It is important to get to the site quickly to confirm some avian issues before any evidence is removed by scavengers and faulty insulators can be hard to detect without exact structure locations. Consequently many of the causes of fault in the trouble reports were 'unknown' making it difficult to initiate any follow up.

Improvement Goal

The improvement goal set in 2006 was to reduce the number of outages categorized as 'unknown' cause and further improve transmission reliability by getting to fault sites faster and initiating repairs.

There was also a concern that 'cause of fault' coding needed to be improved for the NERC TADS reporting for AC circuits ≥200 kV that was to commence in 2008.

The main contributors to the long response times to get to the fault site and failure to determine cause of fault was the low accuracy of the fault location method and the length of time needed for engineering analysis.

To meet the goal, a method was needed to automatically deliver distance to fault results accurate to one span within minutes after a line trip. The traveling wave method of fault location was considered the best method to achieve this goal.

Traveling Wave (TW) Method of Fault Location

Traveling 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. The advantage of the technique is that it is not affected by factors that impair the performance of impedance methods like mutual coupling, changes in line impedance, fault resistance and far end infeed. All types of fault can be accurately located.

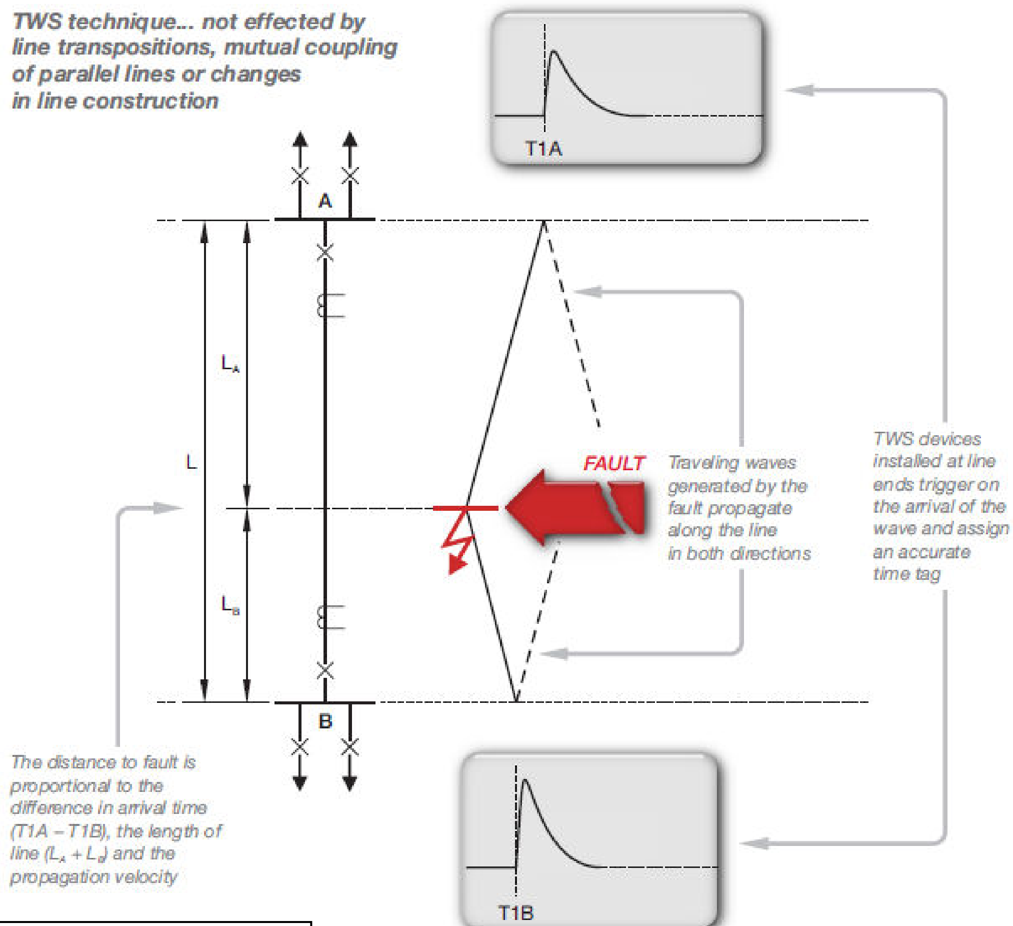
Modern traveling wave systems (TWS) use a double ended (Type D) method for fault location that does not rely on operator intervention to determine distance to fault. Results are automatically calculated and immediately available for use. The power arc at the fault site and the resulting step change in voltage generates a traveling 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 Figure 1.

The velocity of propagation is fixed provided the dielectric is constant along the route length. For overhead lines the dielectric is air meaning the velocity is very close to the speed of light, 186,000 miles / sec. The accuracy of the calculated distance to fault is set by the GPS time stamp assuming the line length is known. Earlier TW devices had an accuracy of 1μs with a resolution of 0.1 μs. Fault results accurate to 0.1 miles were achievable. TW devices released in the last few years have time accuracy of 100ns with a resolution of 10ns. These have the capability of returning better fault accuracy, the limiting factor now is knowledge of the line length and correct identification of the arrival of the TW at the line end.

As stated, communication is necessary between each substation and a central location. The minimum requirement is for the TW devices to upload the time stamp of each trigger logged. The central analyses software holds the circuit information and calculates distance to fault from the relevant trigger time stamps. Results are displayed in a filtered list view or sent as an email.

The communication overhead to transmit time stamps is low. However, the TW devices also capture TW waveforms for each trigger that can be used for manual off line analysis if required. These files are larger in size but only events of interest are downloaded to the central software for archiving / analysis.

To improve cost effectiveness it is possible to monitor up to 8 lines with one TW device.



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

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

Figure 1 Type D Traveling Wave Technique

Deployment on 345 kV Network

CenterPoint Energy first deployed the TW fault locators on the 345 kV network after a successful trial installation. This network consists of simple two ended circuits terminating in substations where other 345 kV lines are connected to the busbar. The presence of other lines at the circuit end results in a low terminating impedance compared to the line surge impedance meaning it is effective to monitor the current component of the traveling wave using split core linear couplers connected to the secondary of the protection CTs. The advantage of this method is that the sensors are non intrusive and can be installed with the circuit live. An example of a linear coupler installation retro fitted onto CT secondary wiring is shown in Figure 2.

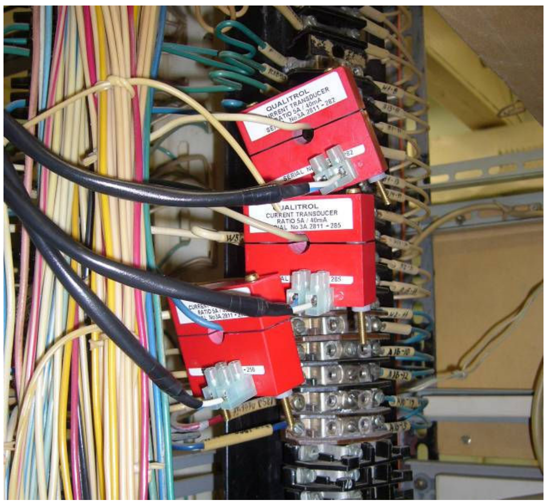


Figure 2 Linear Couplers Retrofitted to Protection CT Secondary Wiring

CenterPoint Energy uses telephone lines and dial up modems for communication between the central software and the remote sites. Although some network connections are now available it has been decided to continue with modem communications until the requirements to comply with NERC security standards are better understood.

The deployment of the TW devices on the 345 kV network was completed in 2010. Fifty four lines are being monitored by thirty three devices in thirty one substations. From 2008-2011, the 345 KV TWS network was successful in locating 93 out of 100 faults of which 56 had a confirmed cause of fault for the trouble report and 37 were unknown. The data was not available for 7 faults due to telecom or TWS hardware issues.

All results are analyzed by the Grid Performance Division in CenterPoint Energy. Circuits can be manually interrogated after a line trip to update results. In addition, devices are automatically polled on a daily basis to archive all events and check the health status of the System. Fault locations are routinely compared with lightning detection results from the FALLS system to better confirm the ‘cause’ of fault.

Deployment on the 138 kV Network

Based on the success on the 345 kV system, it was decided to deploy TW devices on the 138 kV network as well. Initially CenterPoint Energy deployed devices on the straight forward, interconnected, two ended circuits where conventional current monitoring of the transients produces good results. About 20 units have been installed per year since 2011. All communicate to the central station via modems.

However, the 138 kV system has more complex circuits as demonstrated in Figure 3. There are many instances of branches and tees resulting in multi-ended circuits as opposed to simple two-ended circuits. For full circuit coverage, it is necessary to monitor at the end of the branches as well as the main line. There are also instances when single lines terminate on transformers feeding local load. Such transformer feeders have a high terminating impedance compared to the line surge impedance meaning it is necessary to measure the voltage component of the traveling wave rather than current.

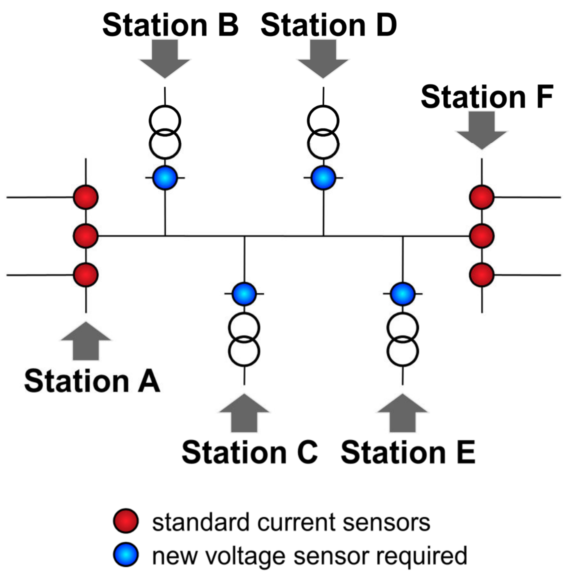


Figure 3 Typical Sub Transmission System with Transformer Feeders and Multi Ended Circuits

To allow full coverage of the 138 kV system, new analysis software was developed for the central station to allow the configuration and results analysis from circuits with up to six ends. One such six-ended circuit configured in the central software is shown below in Figure 4

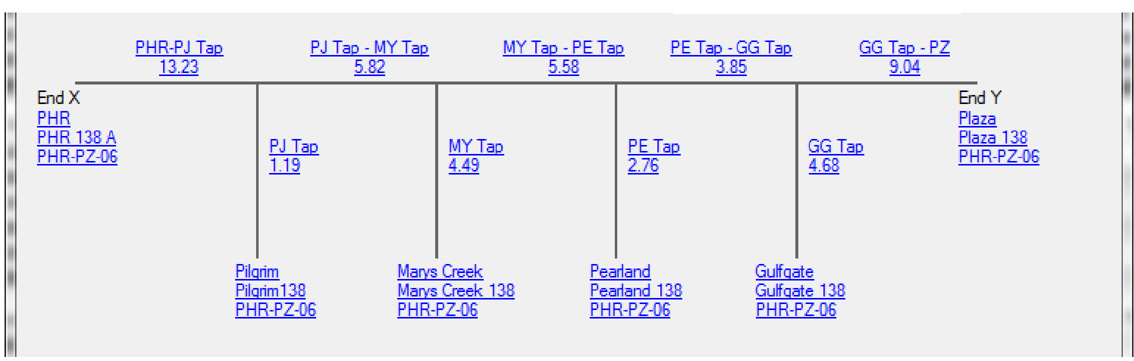


Figure 4 Six Ended Circuit Configured in the Central Software

The analysis software breaks the multi-ended circuit into each of the constituent two-ended circuits, calculates results from each of these and plots them on a graph. An example of an event during a lightning storm is shown below in Figure 5. Red circles denote results from different two-ended circuit combinations. TW devices positioned either side of the fault site will give the correct distance to fault. TW devices on the same side of the fault will give a location where the traveling wave entered the two-ended circuit being monitored. This is normally at a 'tee' position. The red cross marks the actual calculated fault site. A detailed distance is given in the list view where the faulted section is identified and, where possible, the length from each end of the main line and the closest monitored tee is given.

Note that due to attenuation of the traveling wave as it passes through each 'tee' point there may be instances where not all devices at the circuit ends will trigger for the same event.

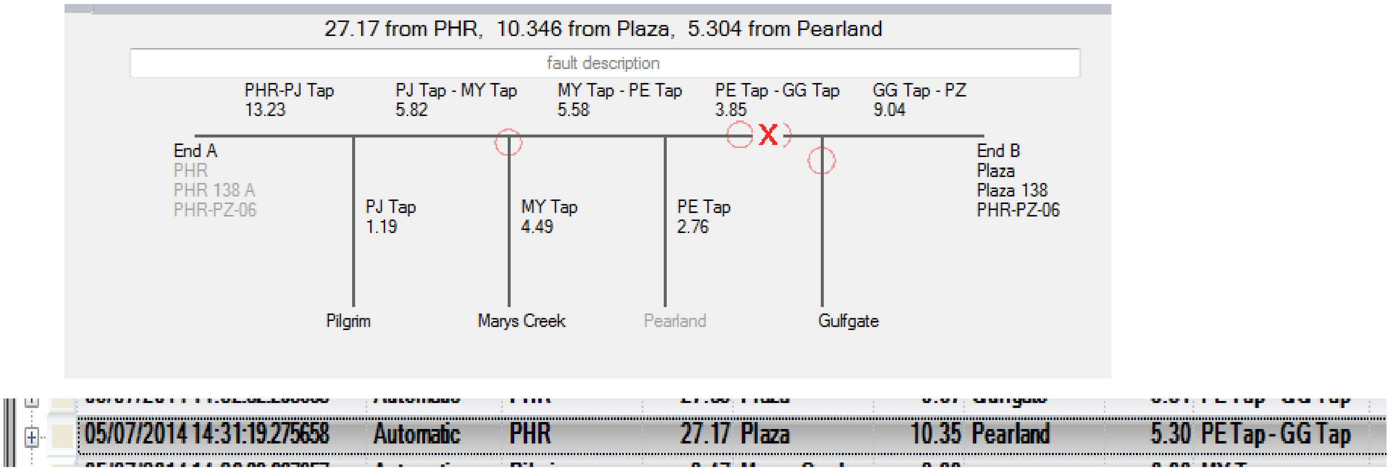


Figure 5 Results from a Lightning Event Plotted Graphically and a Listing of the Actual Site

In the above example many of the line ends being monitored are transformer feeders where the voltage component of the traveling wave is being monitored. To achieve this in a practical manner the resulting current from the voltage transient is being measured through the capacitance of the HV transformer bushing. A special coupler has been developed that fits to the test tap on the HV bushing and acts as the sensor providing a signal to the TW device. Most of the bushings so far encountered at CenterPoint Energy have been to the ANSI Type A standard. Pictures of the coupler are shown in Figure 6.

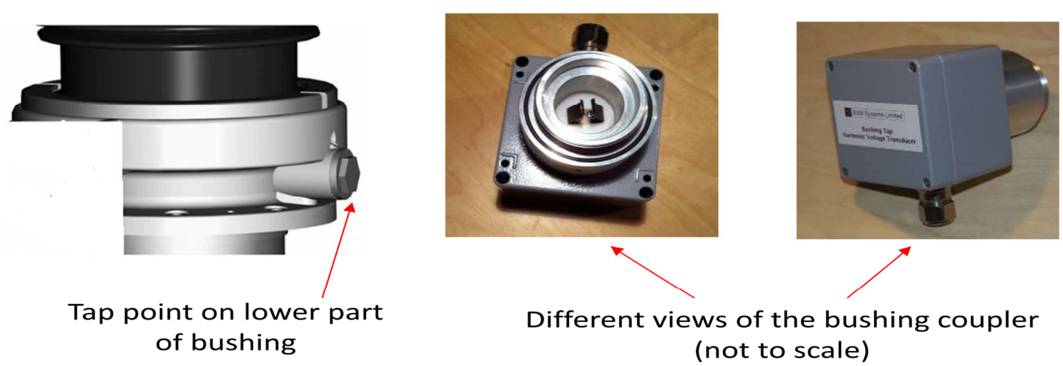


Figure 6 Bushing Coupler for ANSI Type Standard Bushing

Installation of the bushing couplers requires a line outage for fitting the couplers to the transformer, a marshalling box to combine the outputs of the three phase bushings and a new cable laid to the relay room to connect to the TW device.

About 70 transformers are being monitored in this way. Note that to date about five older transformers have been discovered on the system that have different types of bushing tap points that are smaller in diameter compared to the ANSI standard. A special adapter has been made to allow connection to these. Some oil filled Westinghouse bushings have also been discovered on some customer sites but there is no practical method at present to connect to these for permanent, on line fault location.

To date 96 TW devices have been installed on the 138 kV network in 88 substations covering 119 circuits. Another 60 are required to complete the deployment. Those circuits have had a total of 150 TWS fault events captured. With the exception of lightning events (see below) the observed accuracy is typically within 1-2 spans of the actual fault location.

Operational Experiences

For all voltage classes, the percentage of outages with an 'unknown' cause has reduced to 20% compared to 40% before the TWS fault location method was available.

One major fault on the 138 kV network, where a crane jib hit a line, highlighted a problem on a two-ended circuit containing one or more looped tees. Figure 7 illustrates a looped tee. It is where a line diverts to another substation and then returns back to the main line. Very often the start and end of the looped tee are on the same structure as the main line.

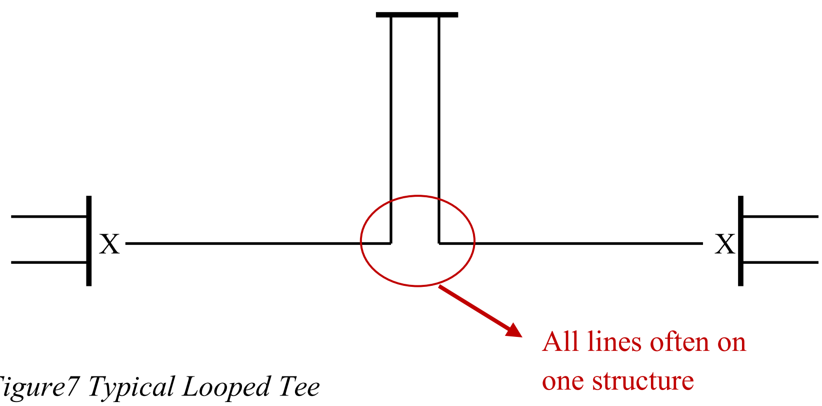


Figure7 Typical Looped Tee

The initial automatic distance to fault calculated when the crane hit the line had an error of 3.3 miles. The actual fault site was far from one side of a looped tee between the two ends of the circuit. After analysis of the circuit and TW waveforms, it was concluded the large traveling wave generated by the low resistance crane fault travelled to the structure with the looped tee and coupled across directly to the main line leaving the larger signal to propagate around the tee as expected arriving at the circuit end later than the coupled signal. The TW device triggered from the coupled signal rather than the main transient resulting in the error. Figure 8 illustrates this further.

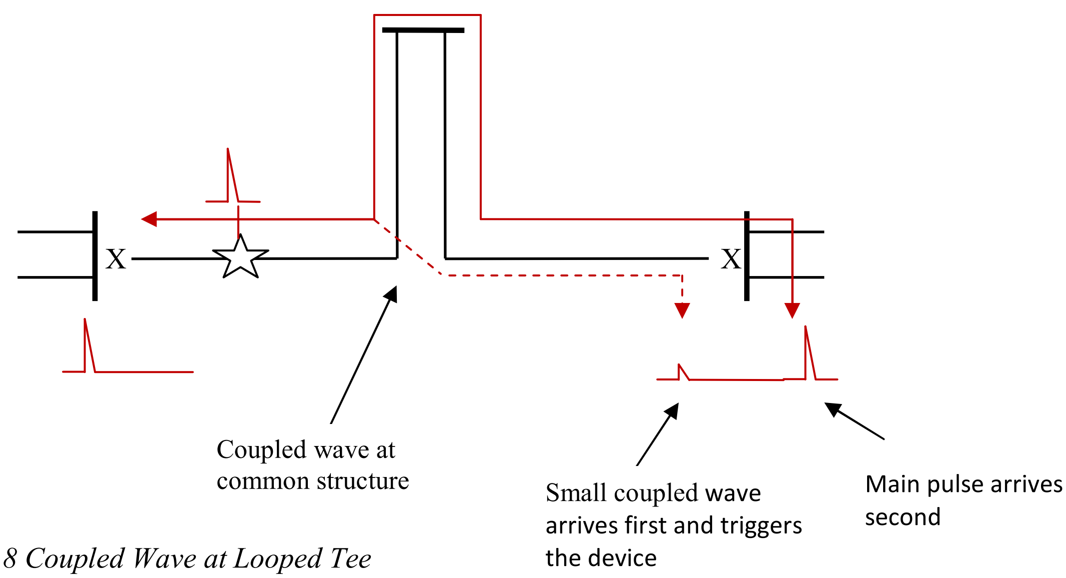


Figure 8 Coupled Wave at Looped Tee

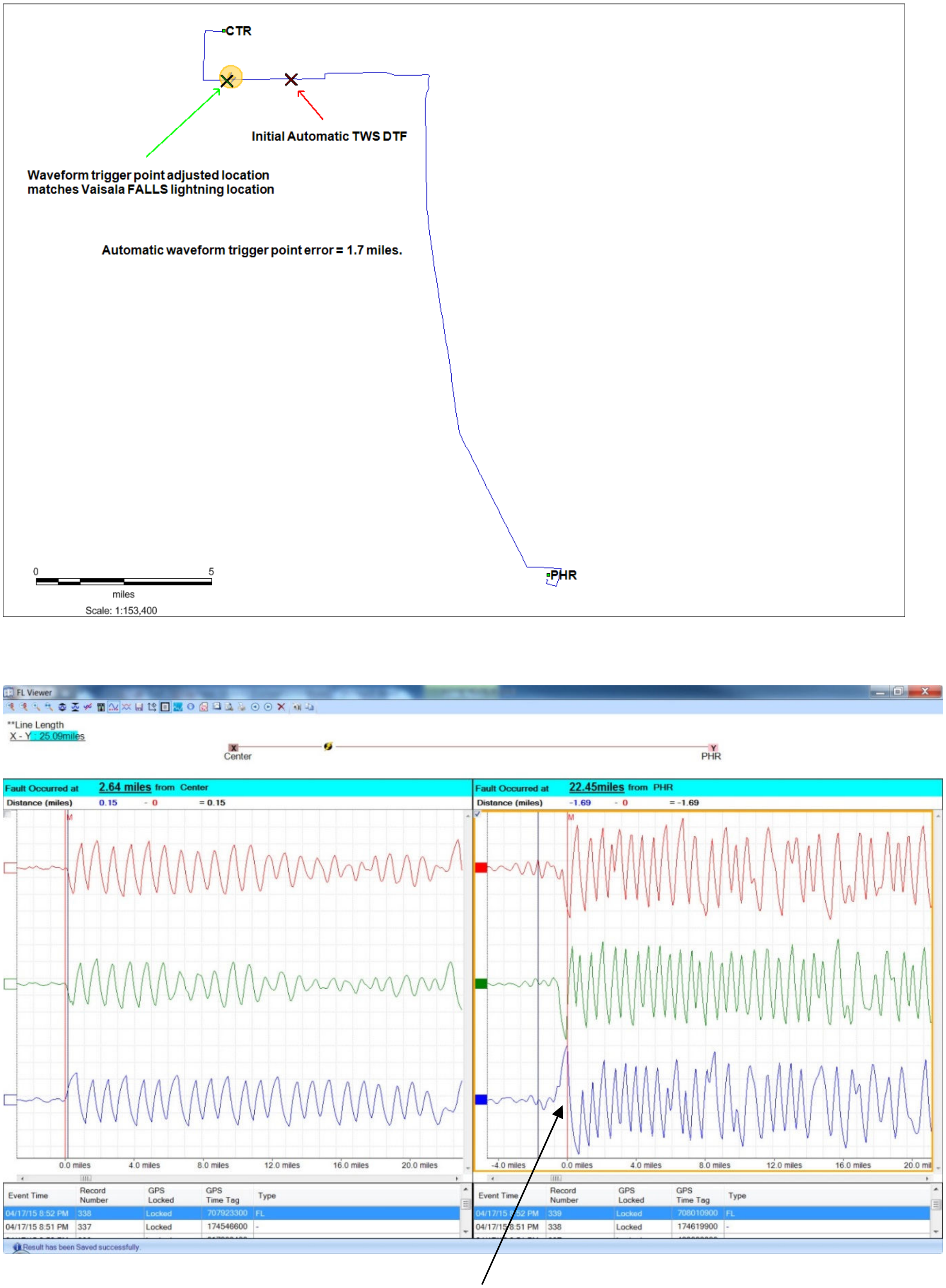
The TW waveforms for the crane fault are shown in Figure 9. The error of 3.3 miles can be accounted for by the difference in the trigger point between the first smaller coupled wave and the main pulse

Difference in Coupled Wave and Main Pulse Equates to Error in Fault Location of 3.3 miles

Figure 9 TW Waveforms from Crane Fault

One way to avoid this error occurring again is to add another TW device at the end of the looped tee dividing the single two-ended circuit into two separate circuits. However, when the 138 kV network was examined it was discovered that there were 51 circuits with looped tees but only 10 suitable monitoring points. Due to the costs involved and the lack of suitable monitoring points a software algorithm was developed to automatically compensate an error should coupling occur in the future. The algorithm is designed for a maximum of two looped tees at different points on a two-ended circuit. The compensated results for the crane fault are good, but more examples are needed in the future to fully test the solution. Note that only faults that generate large traveling waves are likely to result in coupling across a looped tee, and even then the magnitude will depend on the proximity of the circuits on the common structure.

It has been noted that certain lightning events have resulted in errors on the automatically calculated distance to fault of approximately 0.5 mile or greater. Examination of the TW waveforms has shown a small leading transient prior to the main breakdown. In many cases it is possible to manually adjust the trigger point to improve the fault location result. An example is shown in Figure 10. It is planned to assemble a library of these events that will be used to study the phenomena with the aim of producing an algorithm to automatically compensate the results. Lightning is an issue in the CenterPoint Energy operating area with 217,000 strikes being recorded in July 2014.

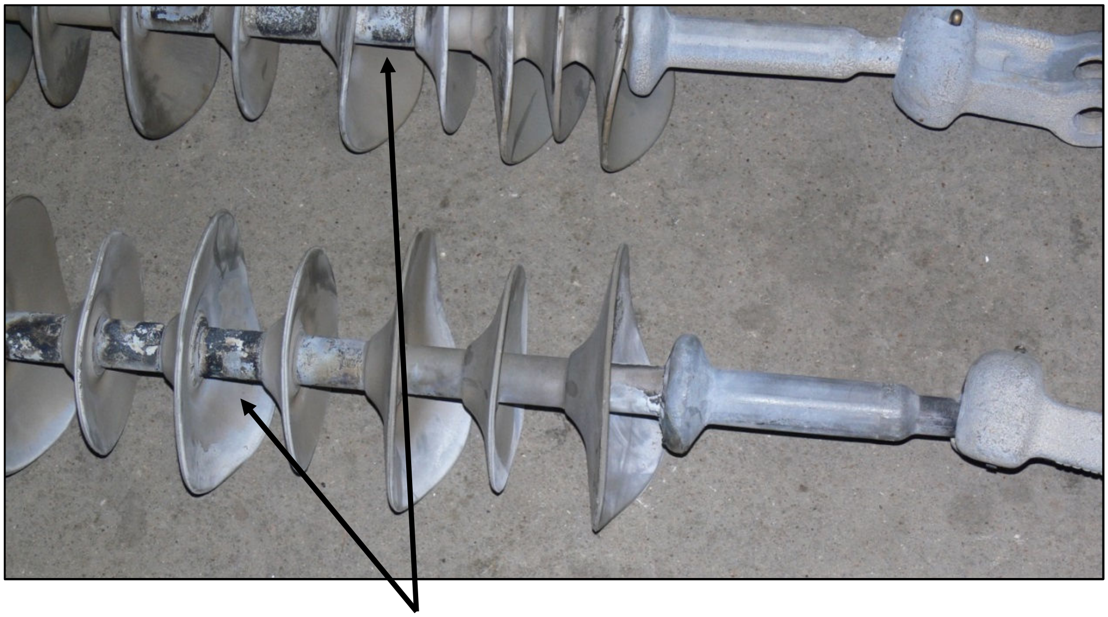


Manually Compensated Trigger Point

Figure 10 Circuit Details and Compensated TW Waveform for Lightning Event on 345 kV Circuit

Other Benefits of Traveling Wave System

Accurate fault location allows identification of specific insulator strings that flash and cause momentary outages. If this occurs multiple times at the same location then it is indicative of non recoverable damage meaning the insulators should be replaced before they cause a sustained outage. Figure 11 is a picture of damaged polymeric 138 kV insulators. The flash marks can be clearly seen when laid out on the ground but difficult to spot whilst still in service unless the specific structure can be identified for close examination.



Track Marks from Flashover

Figure 11 Photo of Flashed 138 kV Polymer Insulators

Future Link to SCADA

At present the results from the TW system are analyzed by the Grid Performance Division and passed on to the Control Room and patrol teams. The last stage in the automated link is to present results automatically in the Control Center.

The process to be deployed involves interface software that receives a signal from SCADA that a circuit has tripped. The TW software then polls the circuit ends, retrieves data and calculates the distance to fault. This value is then passed back to SCADA. Implementation is expected the end of this year.

Note that the latest version of the TW device contains digital inputs that can be used to monitor protection trip outputs. Activation of a digital input flags a significant event (a line trip). Any triggers that occur in a time window preceding the digital status change are marked as high priority and are automatically sent to the central software for analysis. This simplifies the process of automatic update of results minutes after a line trip but it is only available on the latest devices.

Summary

In 2006, CenterPoint Energy was faced with two problems. The first was the lengthy response times to pinpoint the fault site after a sustained outage. This meant it took longer to get repairs underway and longer to ultimately restore the line. The second was the low accuracy of fault locations made it difficult on momentary faults to know exactly where the fault occurred. This meant that at times it was not possible to determine a true root cause for an outage.

To address these issues a traveling wave system for fault location was first trialed and then deployed across the 345 kV and 138 kV networks to dramatically improve the locating accuracy. The TW installations have allowed for quick fault locations to be provided to the field patrols directly from the Control Center. The accuracy of the fault locations has been within one or two spans in many cases. A root cause is much easier to identify and is typically found by the patrols that can now take time to climb the one or two structures identified. For all voltage classes, the percentage of outages with an 'unknown' cause has reduced to an average outage rate of 20% compared to 40% before the TWS fault location method was available.

Future work will involve implementing a direct link with SCADA and developing an algorithm to compensate for some errors noted on some lightning events due to fast leaders before the main strike.