Pre-Locating Faults with Alternative Method to Arc Reflection

Jason Souchak
Megger
Outline

While the share of installed cables without a jacket generally continues to decrease, the unjacketed cables that remain continue to age. As they do so, it is increasingly likely that a fault will develop on these cables. It can be particularly troublesome to locate faults on unjacketed cables as normal Time Domain Reflectometry, or radar, based fault location techniques often do not work, due to the corrosion of the neutral wires. While there is no guaranteed action that would result in locating the fault, this paper will outline some advanced methods, based on field experience, that can help when locating these types of faults. This paper will discuss the Impulse Current method, which does not rely on the neutral wires being intact, in both a theoretical and practical light.

Introduction

Finding faults on shielded primary power cables is part art and part science. No two faults are exactly the same. But by developing a logical process, it is possible to minimize the amount of time spent finding the fault, minimize the customer minutes lost, and minimize stress and damage to the cable system. The current state of the art method for finding faults relies on a two-step process utilizing a TDR (Time Domain Reflectometer) to find the fault location. The first step is to identify the end of the cable using a Low Voltage TDR, typically in the 20-30 volt range, but with some models extending far above or below this value. Once the end of the cable is known, an attempt is made to find the location of the fault. This is accomplished by initiating an arc at the fault location with a high voltage surge, which is quickly followed by another Low Voltage TDR pulse. This low voltage pulse will then reflect off the temporary arc, and allow the user or the analysis software to identify the fault location. This technique is known by various trade names, but can be broadly classified as Arc Reflection.

Arc Reflection has found prominence in the fault locating world due to its high reliability and ease of use. However, this technique has a critical weakness. For this technique to work, it requires two separate but parallel conductors to be intact for the entire length of the cable. This is usually not a problem with shielded power cables, as the center conductor forms the first conductor, and the concentric neutral shield forms the second conductor. These are held in parallel for the entire length of the conductor due to the mechanical construction of the cable. When one of these conductors is broken, the TDR cannot measure beyond the break, and will report the break as the end of the cable. If the fault is located beyond the break in the cable, the pulse will be reflected back by the end of the cable, and not the arc, making it impossible to analyze the resulting trace to find the location of the fault. While a number of circumstances can produce a break in one of these conductors, one of the more frustrating and common circumstances is encountered when attempting to locate faults on cables without an outer jacket.
Cables lacking an outer jacket have not been manufactured for many years, however there remains a significant amount installed and in use throughout the electrical system. These cables have been in the ground for many years by the time they begin to have faults. During the years between installation and the formation of a fault, the copper concentric neutral wires have been in direct contact with the ground, and due to a galvanic reaction, the copper has been slowly corroding away. In the worst of these cases, the corrosion is so severe that a portion of the concentric neutral wires are simply no longer there. In this case, there no longer exists a second parallel conductor to use for Arc Reflection, which shows this missing section as the end of the cable, and another technique must be substituted.

In situations where the neutral wires of a cable have been corroded away, another method must be used. One such alternative is Impulse Current. This technique is significantly different from Arc Reflection, in that there is no low voltage reference trace, the TDR equipment is set to a passive recording mode, and the full energy of the surge generator or “thumper” is released without the intensity limiting effect of the choke filter. Due to the lack of a choke filter, this technique is not suitable for pre-locating a fault in a system with transformers connected, as Arc Reflection can be used. This technique is also inherently less accurate than Arc Reflection, as it requires an operator or software to accurately identify unique points of a trace, but it can still provide a useful pre-location distance.

**Impulse Current Method**

The process of fault pre-location using the Impulse Current technique relies on three primary pieces of equipment. First is a surge generator capable of releasing a controlled surge of energy, commonly called a “thumper”. Second is a transient recorder capable of recording the resulting signal from the release of the energy from the surge generator. And finally, a coupling device is necessary to couple the sensitive electronics of the transient recorder to the high voltage and high current surge. The energy is built up in the surge generator, and released once the transient recorder is armed and the voltage is at the desired level. The surge of energy leaves the surge generator, and travels down the cable to the fault where it flashes over at the fault. The energy is then reflected back to the surge generator where it will again reflect off the end of the cable inside the equipment, heading back to the fault. This “standing wave” will continue to oscillate at a particular frequency until the resistive losses in the cable consume all the energy.
A distance to the fault can be found by selecting an easily identifiable point on two consecutive oscillations of this standing wave. These points are often the positive or negative peaks, but the wave is very rarely sinusoidal, and other unique features may present themselves in field applications. Once these two consecutive points are identified, the time between them is determined, usually in the order of some microseconds. It is then simply a matter of converting the time difference into distance by multiplying by the known velocity of the cable (see the example calculation below).

In Fig. 1 below, an idealized Impulse Current trace is shown. This shows the major features of a trace that would be captured in the field, such as a periodic oscillation of the trace and an exponential decay of the amplitude of the oscillations, but is much cleaner than would be recorded from a field case. All of the oscillations have the same frequency, so it is unimportant which oscillations are chosen to take the measurement. However, it is very important to note that the first oscillation should never be taken, it is during this time that the fault channel is ionized, and this will slow down the first oscillation by a few microseconds – enough to alter the calculated distance. In this case, two clearly identifiable peaks are measured, with a time of $\Delta T$.

![Figure 1 - Idealized Impulse Current trace](image)
The current impulse travels down the cable at speeds comparable to the speed of light. The speed of light in a vacuum is 983.6 ft/µs (299.8 m/µs). Typically, primary power cables affect this pulse speed so that it travels at approximately 50% of the speed of light in a vacuum, or about 491.8 ft/µs (149.9 m/µs), although actual speeds will vary between about 45% and 55%. This is one potential area of measurement error, as an incorrect scaling factor for the cable velocity will affect the measured distance to the fault. The percent error between the cable velocity that is used and the real cable velocity will be constant, but at longer distances it will result in larger absolute errors. It is also necessary to account for the pulse travelling through the cable to the fault, and the return trip back to the surge generator, so this number must be divided by 2, to give 245.9 ft/µs (74.9 m/µs).

The time it takes for the pulse to travel to the fault and back to the surge generator is measured, and the speed that the pulse is travelling is known, so with the understanding that speed is equal to time multiplied by velocity, the distance to the fault can be found. So, if the $\Delta T$ found above is 10 µs, the fault will be approximately 2,459 feet (749 meters) away.

Figure 2 below shows two idealized Impulse Current traces that have been superimposed on each other. The red trace has a faster oscillation compared to the black trace, which corresponds to a fault location that is closer to the equipment. For example, if the $\Delta T_{\text{Red}}$ is 8 µs, and the $\Delta T_{\text{Black}}$ is 10 µs, this will result in fault distances of 1967 feet (599.5 meters), and 2459 feet (749 meters) respectively.
**Practical Application**

Figure 3 below shows a trace captured from a real fault in the field. The first thing to notice is that it is not as clean as the idealized traces above; it contains many more bumps and valleys on the decaying waveform. It is then very important to be sure that the points on the wave that are selected for the measurement are easily identifiable, and represent the same point on the wave. The example below show the “blue” cursor at 8,264 meters (271113 feet) and the “red” cursor at 9,602 (31502 feet) meters, meaning the fault is 1,338 meters (4390 feet) away, or the difference between the two cursors.
The transient recorder must be set to a range 10 to 20 times greater than the length of the faulted cable. That is, if the cable is 1000 meters (3280 feet) long, the transient recorder should be set for 10,000 to 20,000 meter (32800 to 65616 feet) range. This is because it is necessary to see multiple oscillations of the standing wave, and if the range is too short, it may not be possible to get the necessary measurement. It may also take some time for the amplitude of the wave to decay to a level that no longer saturates the transient recorder, as the example in Figure 3 shows. The first (left) third of the trace – approximately 4,500 meters (14763 feet) - is not particularly useful, as it saturates the measurement, or “clips” off the top and bottom of the trace. The trace continues on past the end on the screen, with a range of 15,000 meters (45212 feet). If the range were increased beyond 15,000 meters (45212 feet), it would show additional oscillations at decreasing amplitudes, and eventually these would decay to essentially flat lines.

Another concern for the field application of this technology is shown in Figure 4 below. Depending on many factors of the particular fault, it may take some time for the insulation material – usually air or oil – to ionize and produce the arc necessary for this process to work. If this time were
included in the measurement for distance, it would result in a pre-location distance that is much farther away than the actual location of the fault. This source of error can be avoided by simply not measuring the distance between the first and second oscillations, as that is when the ionization occurs. Any subsequent oscillations will not be affected by this, as it the fault channel will remain ionized.

Figure 4 - Real Impulse Current trace showing a long ionization time

Figure 4 shows this long ionization time. The signature on the left side of the trace is the discharge of energy from the surge generator. A very long time later, the faulted insulation ionizes and breaks down. The measurement is then taken between the 2 subsequent oscillations after the fault breaks down.

For field use, the length of the test leads must be taken into account by subtracting their length from the measured value. For example, in Figure 4 above, the fault distance is 778.9 meters (2555 feet). If there is a test lead length of 50 meters (164 feet) that would suggest that the fault is approximately 729 meters (2391 feet) away from the connection point.

The Impulse Current method measures the time between oscillations of a standing wave, and calculates a distance with a conversion factor. This factor represents just how fast the energy surge travels through the cable, and is on the order of 50% of the speed of light. The more accurate this is to the actual speed of the cable, the more accurate the Impulse Current method will be in pre-locating the fault.
Conclusion

When an underground cable faults, the goal is to restore the circuit as safely and as quickly as possible, with as little stress and damage to the cable as possible. The best way to accomplish this is to pre-locate the fault, or use a method to get near the fault location, before pinpointing the fault with thumping. The preferred method of pre-location is Arc Reflection, as it is effective and easy to use. However, due to certain limitations of physics and cable conditions it may not always be possible to use Arc Reflection, and so an alternative is needed. The Impulse Current method is one powerful and effective alternative to know and understand for those times when Arc Reflection is not effective.