April 29, 2000

BicoTest Time Domain Reflectometer (TDR)

Results of Demonstration

On
Typical Underground Cable Fault

for

Van Rijn Electric Ltd.

Radiodetection Ltd

EXECUTIVE SUMMARY

Time Domain Reflectometers (TDR) are well proven and long used technology in the telephone and CATV industries. Increasingly, users in the electrical industries are finding TDRs provide information on cable status much faster than traditional methods. This report shows one typical application.

TDRs work similar to RADAR but instead of air, they work through wires. By transmitting a pulse and measuring the time it takes to return, the distance is automatically calculated. The pulse returns from the end of a wire and from wiring faults such as open circuits, short circuits, and changes in the series and parallel resistance.

TDRs are typically used to find existing faults on cables and have more applications in related areas such as:

- proving an installation has been done correctly, this may relieve the contractor of future warranty claims
- creating a ‘benchmark’ to more easily find future problems
- easy inventory of cable left on a reel
- locate and evaluate buried splices
- detect utility theft

TDRs are limited to cables with two or more individual, insulated conductors. Multiple single conductors, even when laid in a common, narrow trench usually show too many impedance changes to give useful data. This problem could be overcome by simply installing multiple conductor cables or even by securing single conductor wires together with tape at the time of installation.

There were no problems encountered that a trained technician would not be able to easily work through. The job will go marginally faster if the cable impedance properties are known but there are methods to easily get around this requirement. A method of measuring the distances encountered is required to get us to the fault. This can range from a vehicle odometer, to a utility measurement wheel, or even to a handheld Global Positioning System (GPS) receiver. A method of tracing the route of the cable such as a standard cable locator is also often required.

The BicoTest TDR proved itself valuable by leading the user to the problem, and again after the repair, it proved that there were no other faults in the wire and it was ready for service. Considering the cost of personnel, equipment, replacement wire, notifying and waiting 2 days for Alberta 1-Call, **TDRs have an excellent return on investment.**

The TDR proved to be an easy to use and accurate method of locating cable faults.

THE PROBLEM

An electrical contractor, specializing in irrigation work, received a call from a customer that had a broken 'kill' wire running from an irrigation pivot back to the natural gas fired pump. The purpose of the wire was to shut down the pump in case a malfunction stopped the pivot arm from turning. If the pump doesn't stop in these cases, water will continue to be sprayed in one area resulting in possible flooding and/or crop damage.

In fact this owner had exactly this happen to his system the previous fall. When he bought that section, the wire was out of service from the previous owner. The owner was in the habit of looking out to the pivot on occasion to see if the lights were on, as usually any electrical malfunction would also kill the lights on the arm. Unfortunately on this occasion, only one of the three-phase power shut off. This stopped the motors but left the lights on. Water was sprayed in one area for at least 8 hours straight resulting in approximately 30 acres being flooded.

When the electricians arrived on site, the layout was approximately as shown below in Figures 1 and 2.

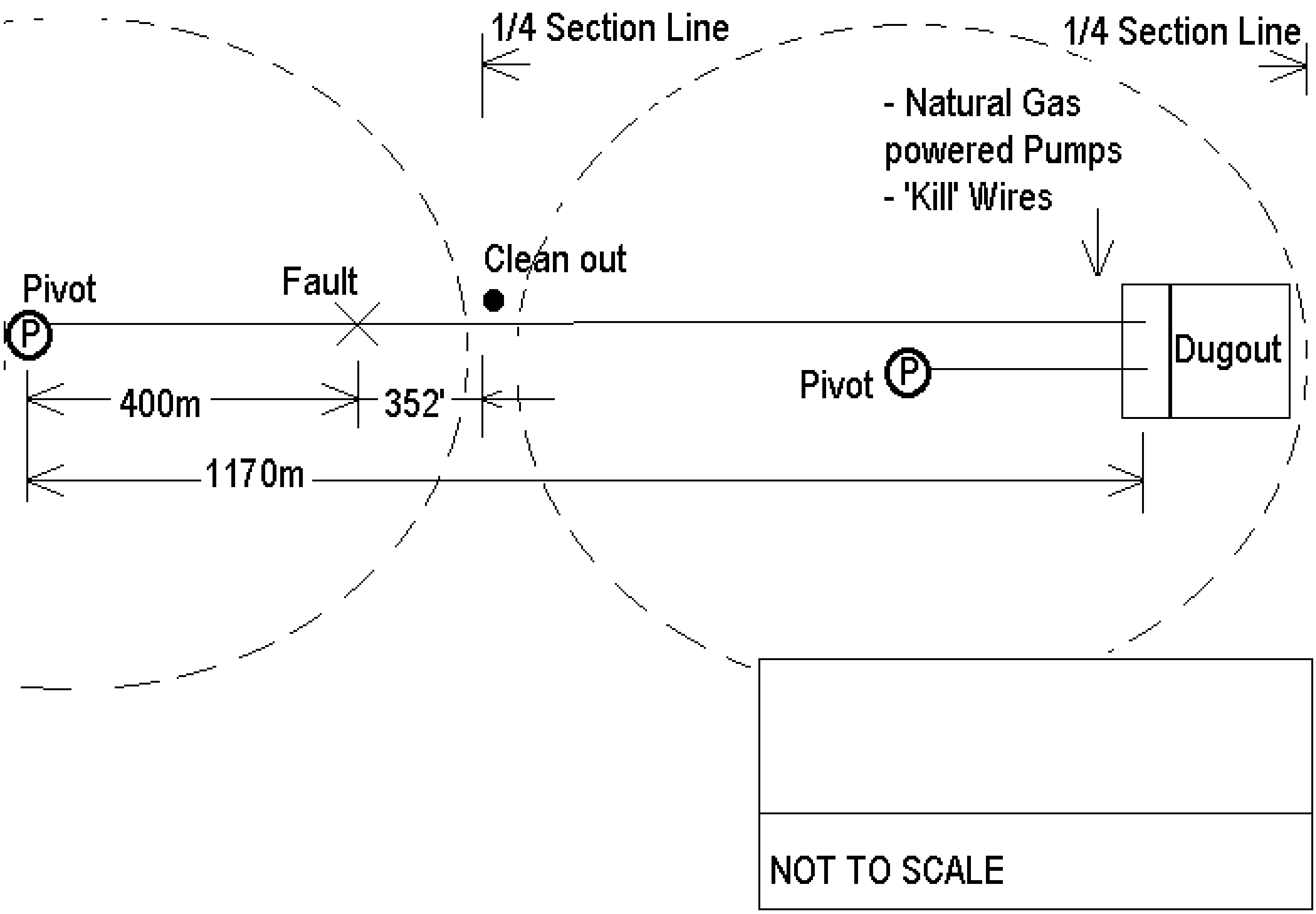

Figure 1

The wire to the far pivot was open circuit somewhere between the pumps and the pivot. After using an ohmmeter and a helper at the far end, it was determined that the white wire of the pair was open circuit. Further complicating the problem was that the wire was not grounded at any point in its length. If it was in contact with ground which happens to some faulted buried wires, a traditional ‘A-frame’ type earth fault detector could often be used to locate the problem. Using that method would require the technician to walk along the cable path sticking the a-frame into the ground perhaps as often as every five (5) feet, which results in a slow survey. On the positive side, the accuracy of an a-frame is usually very good indicating the fault within inches where as a TDR may not have enough resolution to have this accuracy. TDRs and a-frames are actually often used together to speed up the fault location process. If a TDR shows a fault say 600m out on a 1300m run of cable and the fault is going to ground, we can drive out 550m and start the a-frame process from there, resulting in a much faster location.

In this case without using the TDR, the only option would have been to do a series of tests consisting of excavating the cable at the ½ way mark, cut the wires and see if the fault was ahead or behind the present position. Repeat as necessary until the cost of the wire to cover the span was less than the time it would take two electricians to repeat the test. With wire suitable for underground installation costing well over one (1) dollar per meter to install or the cost of an electrician and a helper, this is an expensive solution.

This is an ideal application to use a TDR to find the open wire.

TIME DOMAIN REFLECTOMETRY 101

A TDR is similar to RADAR or SONAR except working through wires instead of air or water. A very narrow pulse of electricity, usually from 1 nanosecond (nS) to 1 microsecond (1 uS) is applied to the cable. (A nanosecond is a billionth of a second, a microsecond is a millionth of a second.) This pulse will travel down the cable at a rate determined by the cable construction. The electrical characteristics or impedance of the cable affects the speed. These characteristics include:

- The dielectric of the cable, what insulation material is used.
- The spacing and other construction techniques, this also affects the impedance
- The wire diameter
- The area the cable is in, in wetter cables the pulse travels more slowly

As stated earlier, TDRs are limited to cables with two or more individual, insulated conductors. Multiple single conductors, even when laid in a common, narrow trench often have too many impedance changes to give useful data. This problem could be overcome by only installing multiple conductor cables or even just by securing single conductor wires together with tape at the time of installation. Direct buried triplex type wire without an over wrap will also result in tough to interpret responses. Coaxial and concentric type cables give the cleanest responses as their construction is very repeatable.

In a vacuum, electricity, like light, travels at about 300,000 km/second. In cables, it travels slower than this and we refer to the speed as a percentage of the speed of light. This is usually expressed as the Velocity of Propagation or VOP. You may also see it referred to as Propagation Velocity Factor or PVF. Typical VOPs for electric cables are from 50 to 68 (50% to 68% of the speed of light).

As the pulse travels along the wire, any noticeable change in the impedance of the wire will cause a portion of the energy in the pulse to be reflected back. If the fault is resulting in an increase in impedance, such as an open circuit, the returning pulse will increase in amplitude. If it is a short or lowering of impedance, the pulse will decrease in level. The outgoing and reflected pulses are usually shown graphically on a display. Cursors are moved to the same, leading edge, of both pulses to measure their positions with respect to time. When we know how long the pulse takes to return and we know the speed of the pulse in the wire, it is very easy to calculate the distance to the feature that caused the reflection. In fact TDRs automatically perform that calculation every time the cursors are moved.

Some TDRs do not show the outgoing pulse, the user just knows it is the left side of the display. In most cases though, the reflection caused by the change from the test leads to the cable under test is visible. Setting the cursor at that point will subtract the length of the leads from the distance shown. In addition to considering the length of the wires, users must also perform their distance calculations using the length of wire that is going down into and up out of the ground when appropriate. As the TDR gives a distance to the fault, every foot of wire out of the ground and going down into the ground obviously means the fault is one foot back towards the user.

The TDR has a two-conductor lead coming out of it that is simply connected to a pair of wires in the cable under test. It is a rugged piece of test equipment designed to be used outdoors or indoors. (Figures 2 and 3)

Figure 2

THE SOLUTION

STEP 1: Set up the TDR to match the VOP for the cable type. If this is unknown you can start with a typical value for that type of cable, this will usually be within 5%. However, even 5% of 1000 meters may result in a lot of unwarranted digging so we should try to get more accurate. In this case, we knew the distance from the other pump to the other pivot (close to 1200 feet, or ½ of a ¼ section minus about 100' that we were in front of the fence line). By connecting the TDR on to that kill wire and setting the cursor to the reflection at the far end (we knew the cable to be good), all we had to do was adjust the VOP until the display read 1200 feet. This resulted in a VERY accurate reading further on in the test. If that method can not work, the user simply has to look at the fault from both ends, add the distances together and either adjust the VOP or use a ratio calculation to find the position. Now connect the TDR to one end of the cable under test as shown below in figure 3.

Figure 3

The resulting trace we found is reproduced below in figure 4.

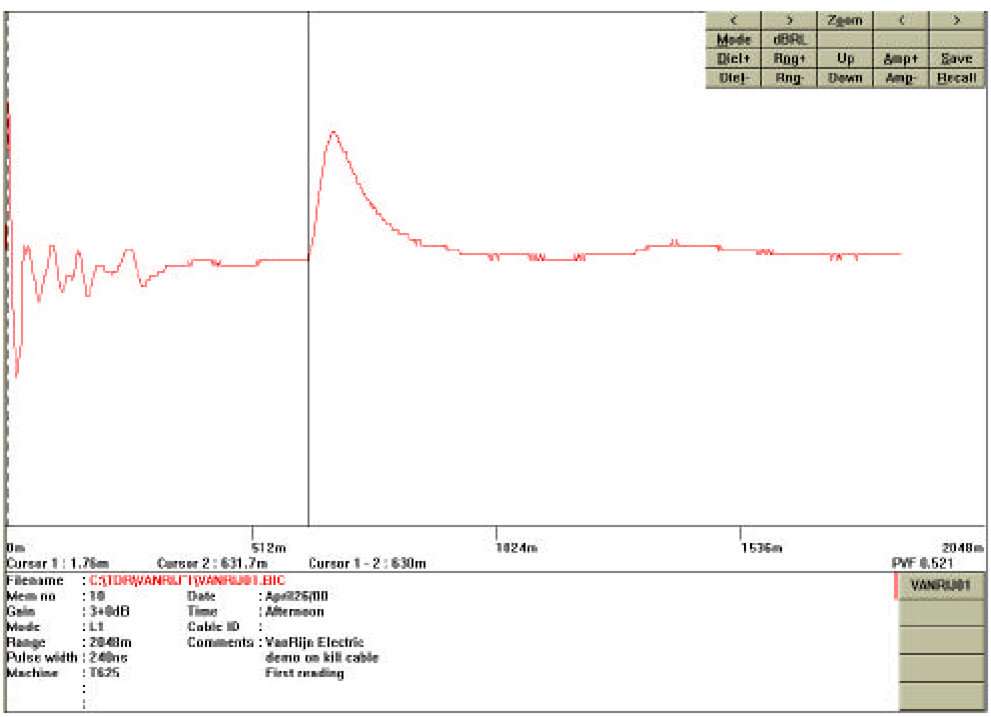

Figure 4

This easily shows a very clear open circuit (trace goes up) 630 meters out from this end. The other responses close to the start of the display may be unnerving to new users but experience will let users recognize them as normal reflections caused by the large outgoing signal and high sensitivity. The real response is still the largest pulse (width and amplitude) on the screen. Start with the big problem and solve that one before moving on. Now disconnect the TDR and attach a cable locator to this end and follow the cable out 630m. Unfortunately, we did not have either a measuring wheel, a GPS, or a vehicle odometer that we felt was suitably accurate. We instead chose to drive to the ¼ section line where there was a clean out (drain) fitting on the pipe and we suspected there might be a splice. After locating and excavating the cable (see figure 5), we did not see a splice and decided to cut the cable and re-test it with the TDR. It is important to note that this step would not have been necessary if we had a suitable measuring tool.

Figure 5

At this point we found the open to still be in front of us 352'. We had switched to feet as we did have a 100' tape measure available. The traces we recorded are below in figure 6. The display shows a number of traces that we recorded to show how repeatable the information a TDR provides is. There are three pulse widths displayed from 120 nS to 480 nS, all of them show the reflection in exactly the same place. There are two different distances shown which also show the fault in the same place. Some of the traces stop at around 1500' and two others continue further, showing the end of the cable at approximately 1700'

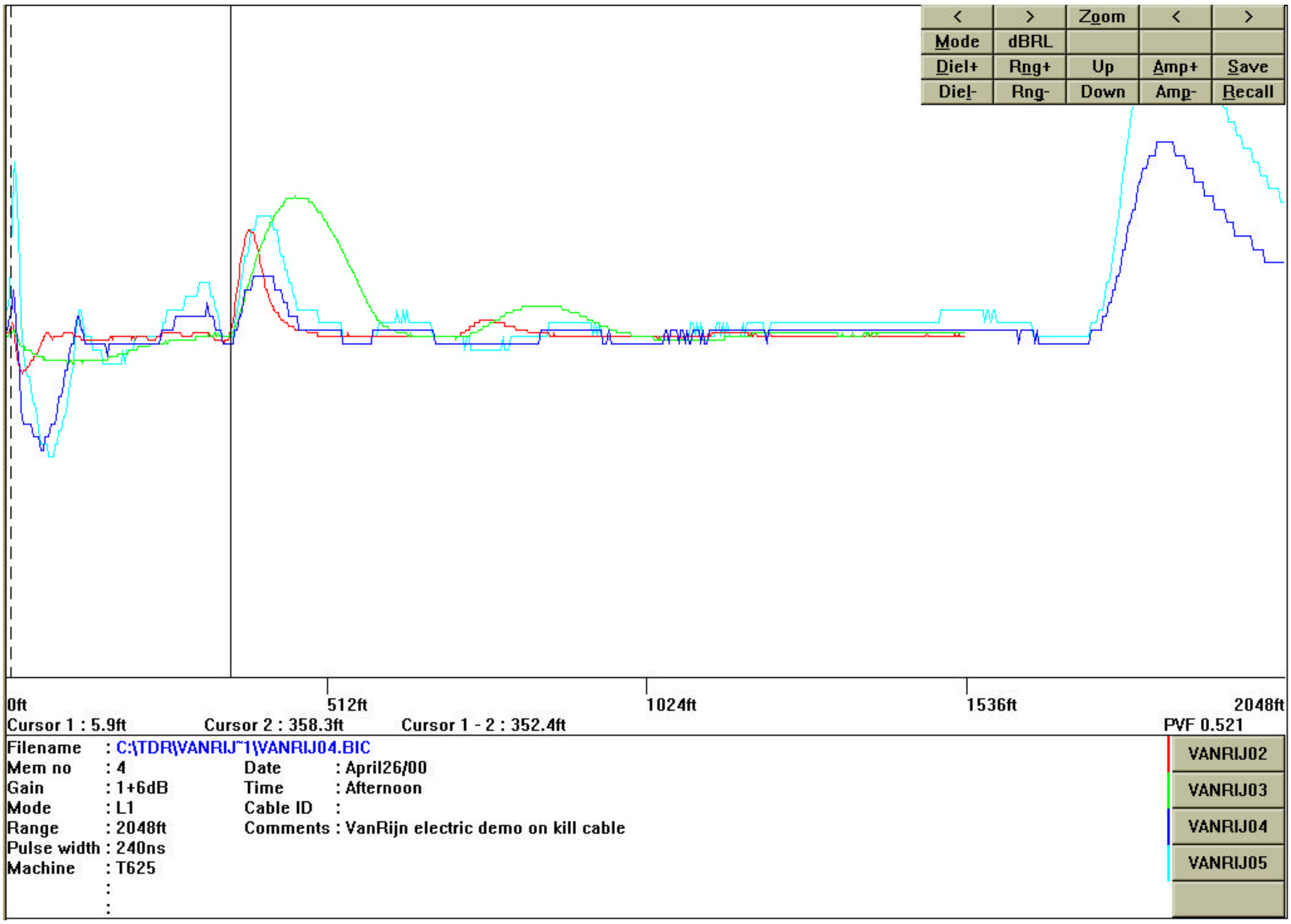

Figure 6

The excavation was repeated 352’ out with resounding success. After a bit of excavating, the wire and splice literally fell out of the ground in the side of the hole within a foot of the expected location. See figure 7.

Figure 7

The electrician cut the splice out of circuit (fig. 8) and tested it with an ohmmeter. As expected it was open circuit on the white conductor.

Figure 8

As the splice looked to be in perfect condition from the outside, for our own interest we opened it up to see why it had failed. The cause was a very poor crimp and non-professional grade supplies on the conductors at the time of installation. The wires are shown in figure 9. The original crimps on the white conductor were the same as the crimps on the black wire, very shallow with poor pressure. The deep crimp on the white conductor was done at the time of the photograph to show how a proper crimp should look. There is a very good chance that it never worked from the start.

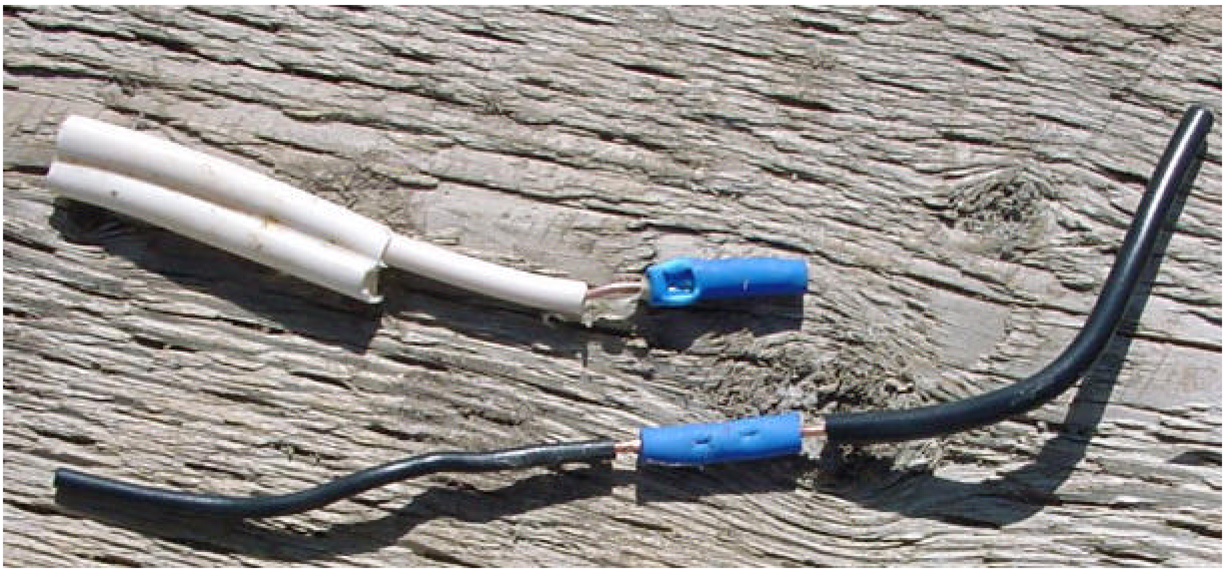

Figure 9

As a final test, the repaired wire was re-tested with the TDR as the final splice was being completed. Figure 10 shows two traces virtually identical for the first 2060’ where they change. The first reflection is the cable before the electrician got the splice finished so there is still a large open at the original failure. The other traces show the same cable a few minutes later when the splice is completed and we see the far end of the cable 3873’ away, nearly ¾ of a mile (exactly where we expect it as it goes just about 1½ ¼ sections). Notice how both traces are exactly the same up to that point. Also notice the shape of the 2^{nd} reflection. It is a little lower and wider. It is lower as it lost a little more amplitude because it now has much further to go. We also expect it to be wider as the added capacitance and inductance of the extra length of wire filters the pulse a bit more

The splices were protected with heatshrink, the wire was reconnected, the system was energized and everything worked perfectly.

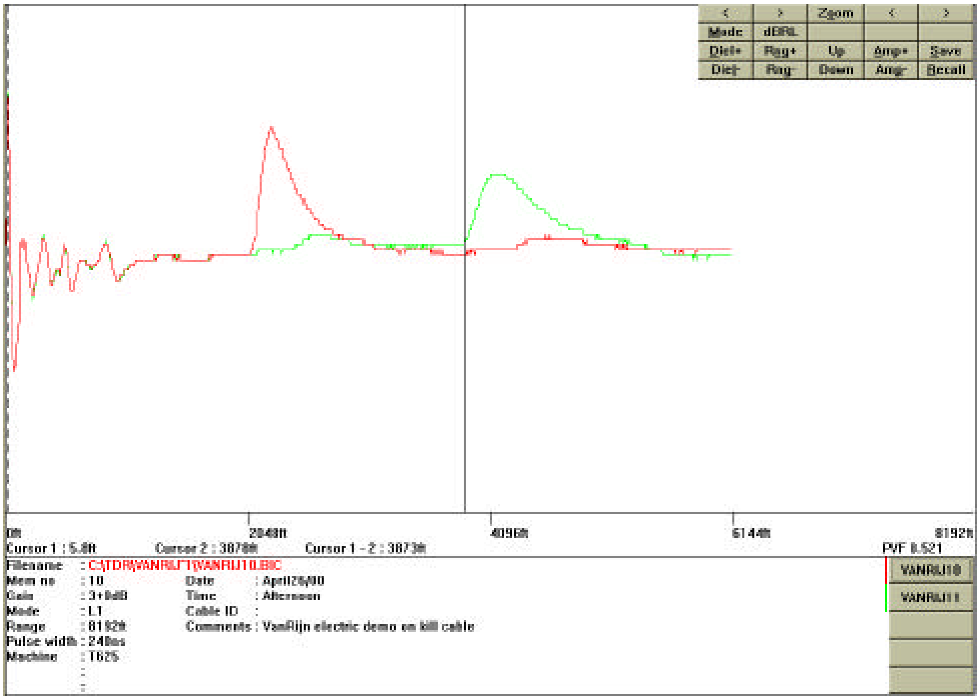

Figure 10

MISCELLANEOUS POINTS

A few other points to consider before starting on a project such as this.

Excavating Safely - All ground disturbances, even on private land, must be reported to Alberta 1-Call at least 48 hours before the work is to begin. They will notify all registered owners who will locate their facilities that may be in the area to be excavated. Not all facility owners are registered with Alberta 1-Call and the onus of responsibility lies on the operator of the excavating equipment to research the area and proceed safely.

Damp Earth – An a-frame type fault locating survey will have a much greater chance of successful operation in damp ground as the moisture provides a much better path for the returning fault find signal.

ECONOMICS

An educated guess is that using a TDR instead of cutting and testing and replacing cable probably saved the customer about 2/3 of the possible bill. One technician could go out, use the TDR, find the problem, locate and measure the cable, excavate and/or supervise the excavation, repair the damage and re-commission the system within about 3 hours. As the excavation was the longest part of the solution, having to do several cuts and required excavations would add on substantial time. Replacing perhaps 200 meters of wire would also be quite expensive.

CONCLUSION

The key conclusions of the examples described in this report include: The TDR is an easy to use tool that can provide comprehensive data on the condition of a variety of conductors. In the hands of a trained user, excellent results can be obtained very efficiently.

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