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UNDERGROUND CABLE FAULT LOCATING USING THE ARC REFLECTION METHOD

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Use of the Arc Reflection Method combined with a high capacitance surge generator for URD cable fault locating will find faults in less time and with less risk to good cable than classical techniques.

The pulse reflection method, pulse echo method or time domain reflectometry are several terms applied to what is referred to as cable radar or a TDR. The technique, developed in the late 1940s, makes it possible to connect to one end of a cable, actually see into the cable and measure distance to changes in the cable. The original acronym Radar (**Ra**dio **D**etection **A**nd **R**anging) was applied to the method of detecting distant aircraft and determining their distance and velocity by analyzing reflections of radio waves. This technique is used by airport radar systems and police radar guns where a portion of the transmitted radio waves are reflected from an aircraft or ground vehicle back to a receiving antenna. For cable radar, when applied to underground cable, short time duration pulses are transmitted at a high repetition rate into the cable between the phase conductor and neutral. A liquid crystal display shows reflections of the transmitted pulses. Reflections are caused by changes in the characteristic impedance of the cable as determined by the formula:

$$r = \frac{Z - Z_0}{Z + Z_0}$$

Any reflections are displayed on the screen with elapsed time along the horizontal axis and amplitude of the reflection on the vertical axis. Since we can now measure elapsed time and if we know the pulse velocity as it travels down the cable, distance to the reflection point can be calculated. For airport radar and police radar guns the velocity of propagation (Vp) of the radio waves through air is the speed of light or 984 feet per microsecond. Pulses transmitted into the insulation of our underground cable travel at about half that or about 500 feet per microsecond. The Biddle® DART® Analysis System includes two movable cursors which when positioned at zero and a reflection point provide a measurement of distance to that point, in feet.

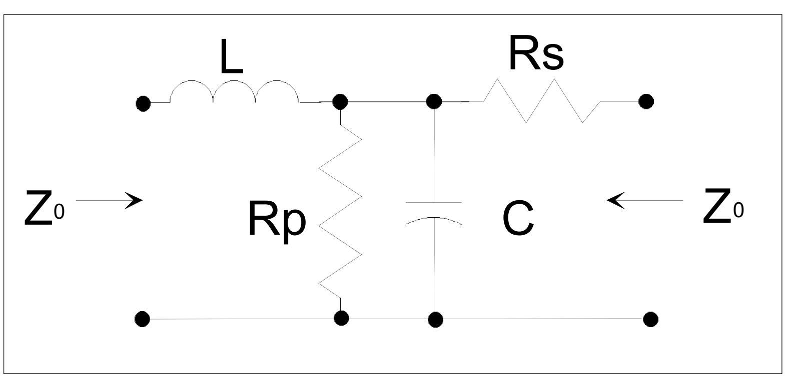

Figure 1: Cable Incremental Equivalent Circuit

A TDR sees each increment of cable, say each foot, as the equivalent electrical circuit shown in Figure 1. If every foot of cable is perfect and exactly the same, the equivalent electrical circuit of every foot is also exactly the same. This perfect run of cable will produce no reflections until the end of the cable appears. At the end of the cable the pulses see a high impedance, an open circuit, causing an upward (+1) reflection. See Figure 2. If the cable end is grounded, a short circuit, the pulses see a low resistance and a downward (-1) reflection is caused. See Figure 3. A low voltage TDR is an excellent tool for the prelocation of open circuits and conductor to conductor shorts. For cable faults on concentric neutral cables where the fault impedance is in parallel with the characteristic impedance the reflection formula becomes:

$$r = \frac{-Z_0}{2Z + Z_0}$$

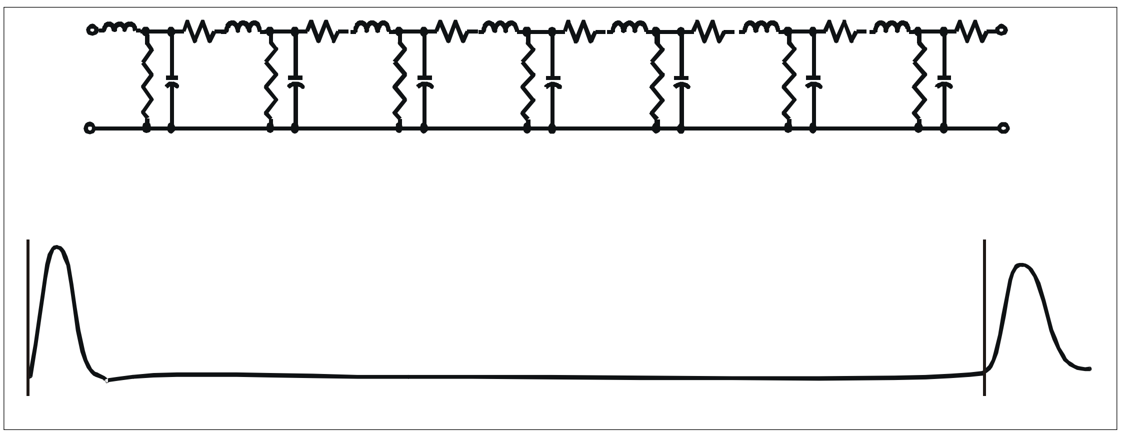

Figure 2: Equivalent Circuit and Low-Voltage TDR Trace with Open End

The characteristic impedance of a typical 15 kV, XLPE, #2 concentric neutral cable is

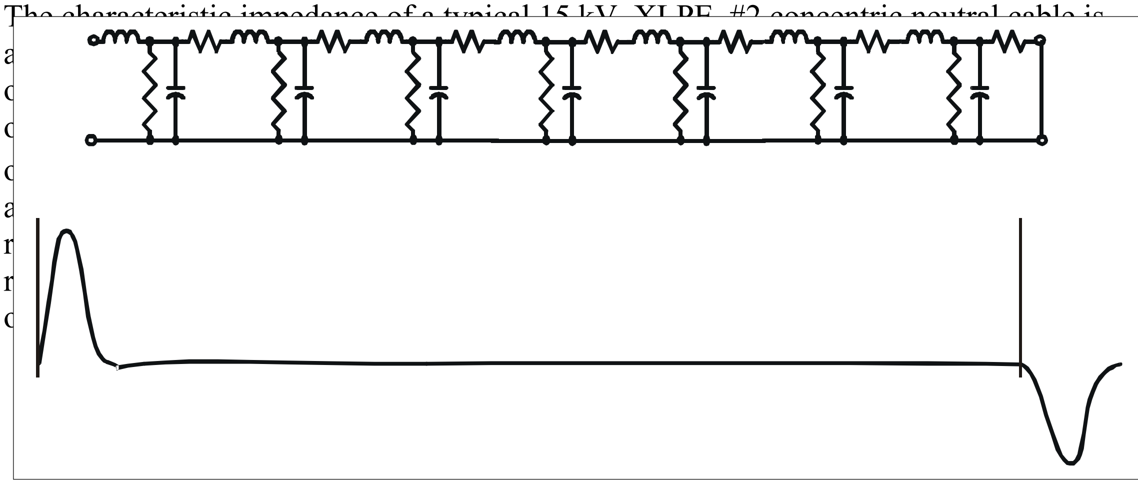

Figure 3: Equivalent Circuit and Low-Voltage TDR Trace with Grounded End

The Arc Reflection Method of fault prelocating combines the use a TDR (cable radar) and a surge generator (thumper). By using an arc reflection filter, a low voltage TDR and a high voltage surge generator can both be connected to the faulted cable and the TDR can be looking down the cable while thumping. The filter protects the TDR from the thumper high voltage pulses and routes the low voltage pulses down the cable. This method utilizes the fact that when an arc is created at the fault, its resistance is reduced to a very low value, less than 200 ohms, which will reflect radar pulses, as shown in Figure 4. The arc location will appear as a downward going reflection on the TDR cable trace. The Biddle DART Analysis System captures and stores the complete trace including the downward going fault location in memory so measurements can be made easily. Rather than thumping and walking the cable route to discover the fault location, the DART provides a prelocation measurement with as little as one or two thumps and about 95 percent of the time gets you within 10 to 20 feet of the fault. Pinpointing efforts can then be concentrated within that well-defined section of the cable. This technique substantially reduces the amount of high voltage exposure to the cable, preventing the initiation of new faults, which will surface after the cable is put back into service.

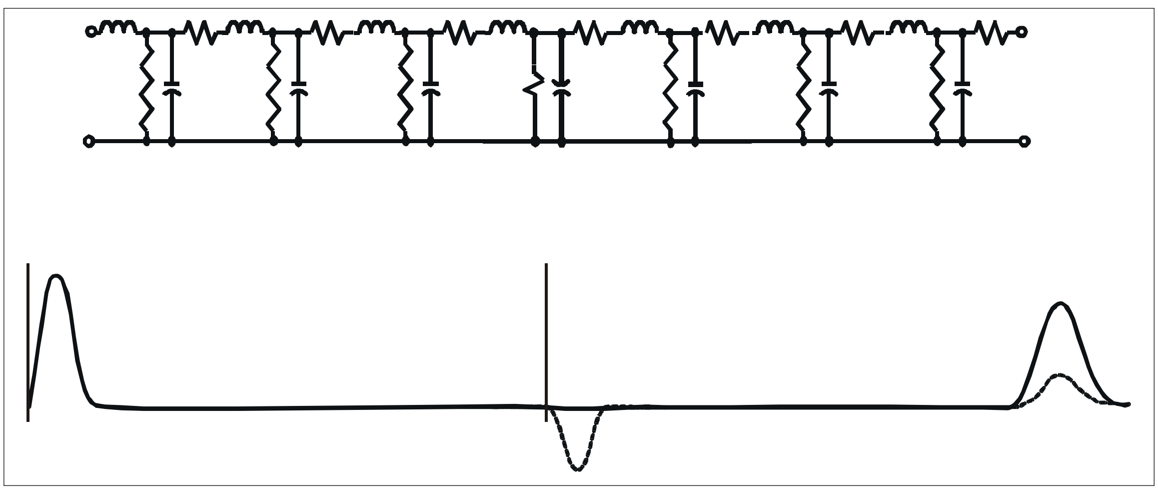

Figure 4: Equivalent Circuit and DART Low-Voltage and High-Voltage racing Showing Fault Location

The James G Biddle Company was first to provide commercially available surge generators or thumpers for underground cable fault locating in the late 1940's. The device is basically a pulse generator consisting of a high voltage dc power supply, a high voltage capacitor and some type of high voltage switch. The power supply is used to charge the capacitor to a high voltage and then a contact closure discharges the capacitor into the cable under test. If the voltage is high enough to break down the fault, the energy stored in the capacitor is rapidly discharged through an arc at the fault creating a detectable sound or "thump" at ground level. The important specifications of a thumper are how high a voltage can be developed and how much energy is delivered to the fault. The energy output of any surge generator measured in Joules (Watt-Seconds) is calculated as follows:

$$E = V^2 \leftrightarrow \frac{C}{2}$$

E = Energy in Joules, C = capacitor in micro-farads, V = voltage output in kV

The classical fault locating process is to hook up the surge generator, crank up the voltage and walk the cable route until the thump is heard or better yet felt. This process pinpoints the fault allowing a repair crew to dig a hole and repair the cable. The higher the voltage, the bigger the bang and the easier it is to find the fault. In some cases it takes hours (or days) to locate the fault and all that time the cable is being exposed to high voltage thumping. A few years after polyethylene cable started to be installed underground, evidence began to surface that due to "treeing" in the insulation, high voltage thumping of this plastic cable was doing more harm than good. Due to this information many utilities issued work rules reducing the voltage to be used for fault locating. Another fact of life is that from the point of discharge at the fault to the isolated end, the cable sees a peak-to-peak voltage wave of double the surge voltage at every thump.

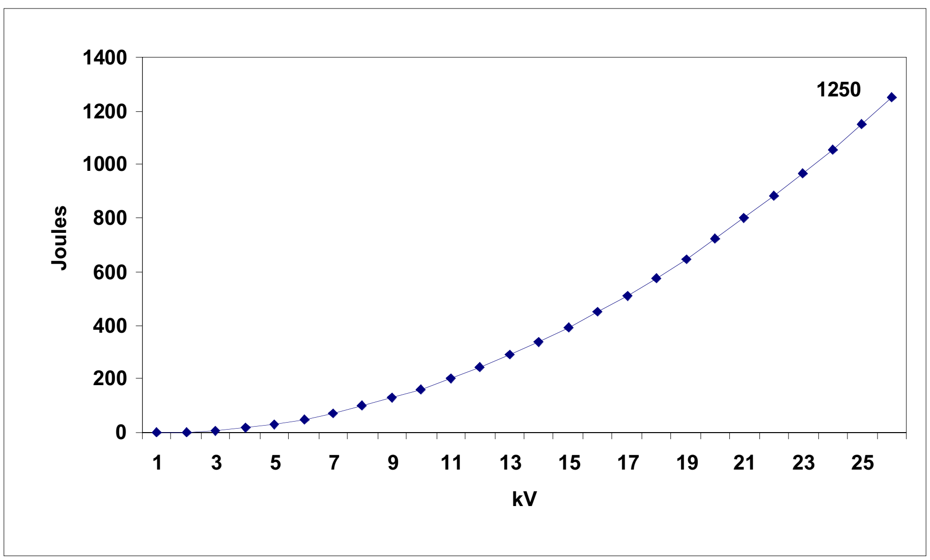

Figure 5: Energy Output vs. Voltage for 4 µF, 25 kV Surge Generator

Figure 5 shows the output energy curve of a typical 4-microfarad surge generator that generates 1250 Joules at a voltage of 25 kV. If the fault locating crew is told that the maximum output voltage of the thumper must be limited to 12.5 kV (one half of 25 kV), the output energy of their thumper is reduced by a factor of four down to 312 Joules. In a practical world, the threshold for hearing a thump at ground level with no acoustic amplification and no background noise is in the range of 300 to 400 Joules. If the thump at the fault can not be heard, voltage will have to be increased in order to find the fault, make a repair and get the lights back on.

Figure 6 shows the output energy curve of the PFL-4000 Surge Generator that uses a 12 micro-farad capacitor which allows thumping at lower voltages while still delivering reasonable energy to the fault. Thumping at 12.5 kV, as above, now produces a very hearable 937 Joules. The PFL-4000 also includes a built-in arc reflection filter.

Using a combination of the DART Analyzer and a PFL-4000 Surge Generator, the process of fault locating becomes more efficient, gets service restored quicker and minimizes the possibility of programming the cable for additional faults while finding the present fault.

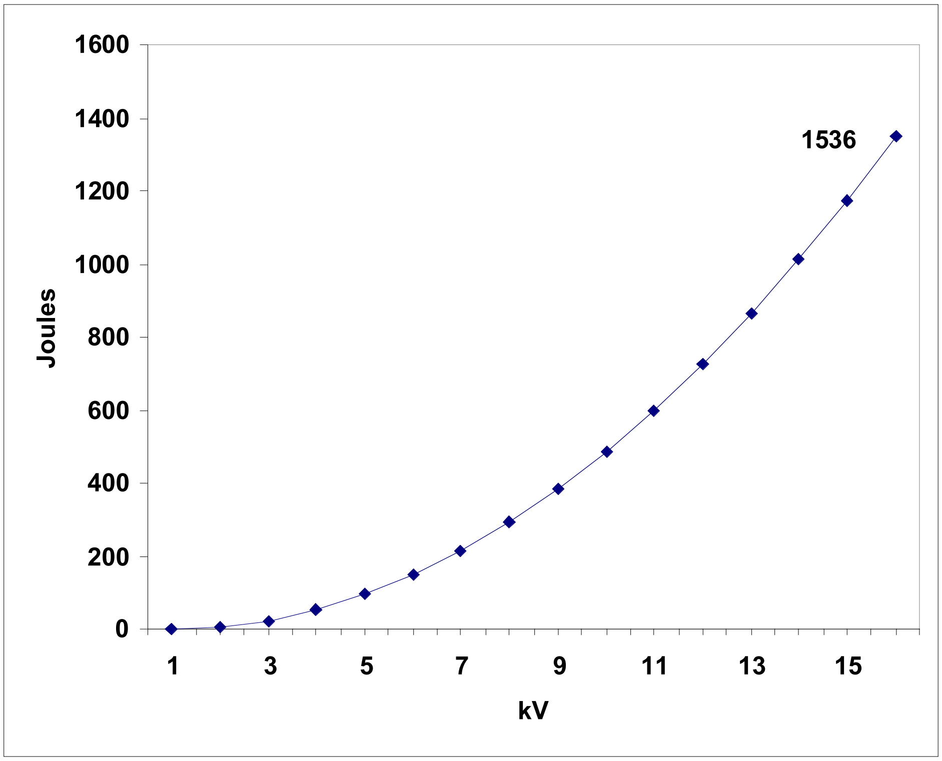

Figure 6. Energy Output vs. Voltage for 12 μF, 16 kV PFL-4000 Surge Generator

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