Selecting a Surge Generator for Maximum Efficiency

Introduction

The surge generator or 'thumper' is one of the oldest and most widely used tools for locating failures in underground power cable. The origin of the surge generator dates back to the mid/late 1940s when the James G. Biddle Company introduced the first commercially available underground fault-locating instrument to the world. The instrument used a technique known as capacitor discharge and was used to both trace and pinpoint underground cable failures. Today the surge generator serves as the backbone of many cable fault locating techniques and systems. Before discussing surge generators and how to select a proper unit, it is important to first understand cables and cable faults.

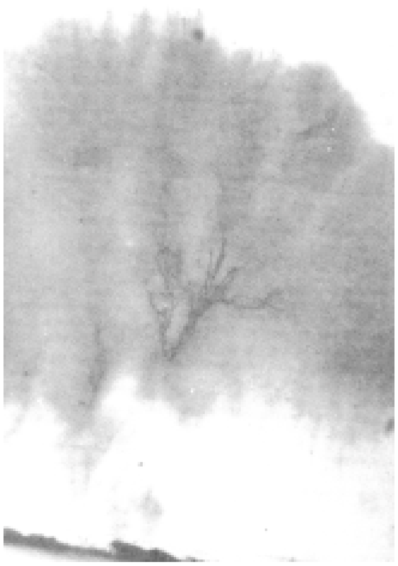

Photo 1. Water tree in an extruded dielectric

What is a Cable Fault?

The most common electrical cable fault occurs as a breakdown between one of the system phases and ground. Typically this breakdown results from a process known as 'treeing.' In the case of extruded dielectric cables the treeing results from water ingress within the cable and is commonly referred to as 'water treeing.' For laminated cables, treeing results from the burning of insulating paper thus leaving carbon tracks or 'carbon trees' in the insulating material. Regardless of whether the fault begins as a water tree or a carbon tree, a simplified diagram of this failure can be represented by resistance R in parallel with a spark gap G as shown in Figure 1. Resistance R, as it exists in the fault, may vary in value from a bolted solid short circuit to a very high resistance due to surface leakage. The spark gap G is likely to be a jagged hole in the insulation caused by the fault current. Its spacing may range from near zero to larger than the original thickness of insulation, and the gap space maybe filled with air or other gas, water, oil, or the burned remains of insulation. Resistance of a fault can be found by measuring the insulation resistance of the cable; the gap by measuring the minimum dc voltage applied to the cable that will cause it to flash over. Cable faults display a wide range of values for R and G. The basic strategy of all fault location is to determine where R and/or G differ from normal. In the technique of capacitor discharge applying a high enough voltage to flash over the gap G creates a detectable audible ballistic event.

Breaking down a Cable Fault

The capacitor discharge technique is performed with a surge generator. This device converts line power into high voltage, unidirectional, impulses that are transmitted into a faulted power cable. A simplified circuit of a surge generator connected to a faulted cable is shown in Figure 2. Capacitor C charges to the voltage of the power supply. When switch S_1 closes the capacitor C discharges into the cable under test in the form of a high voltage impulse. The red curve of Figure 3 depicts the way that time affects the voltage at which a gap will flash over. The gap G in Figure 1 will behave in this manner. Applying successively higher voltages to the gap and plotting the time lag until it sparks over develops the curve. The curve shows that:

1. The higher the applied voltage, the shorter the time lags before flashover occurs.
2. There is always a minimum time lag, as indicated by the 'Minimum Breakdown Time,' under which the gap will never flash over.
3. There is a minimum voltage, shown by the 'Minimum Breakdown Voltage,' below which a gap will not flash over within a typical test period of several minutes.

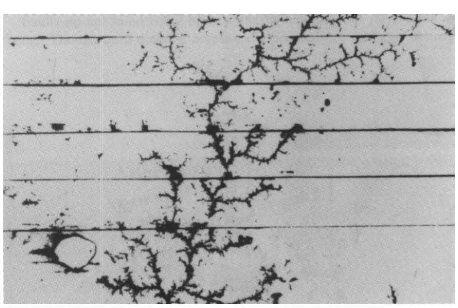

Photo 2. Carbon tree in a laminated cable.

The curve demonstrates that for breakdown to occur in any particular cable fault the applied impulse must reach a particular voltage and it must last for a definite period of time to flash over.

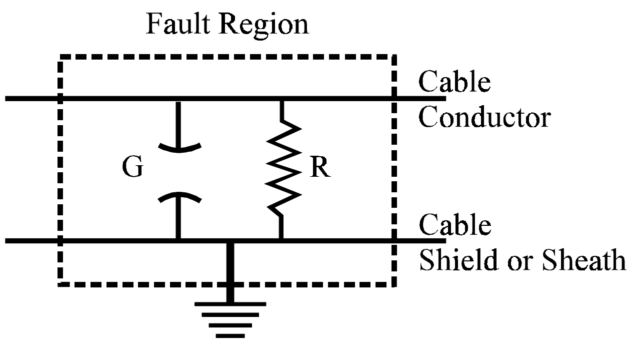

Figure 1. Simplified Diagram of a Cable Fault

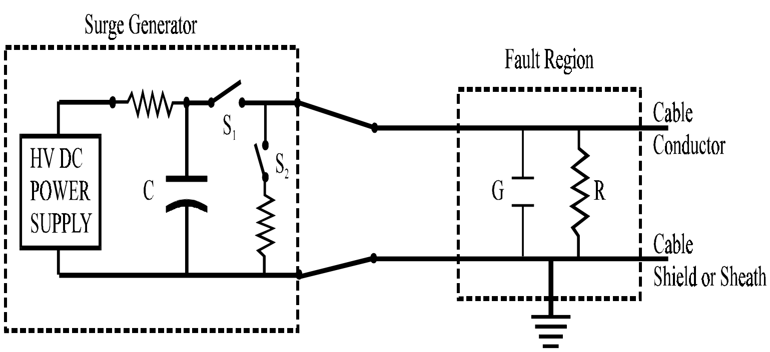

Figure 2. Simplified circuit for a surge generator connected to a cable fault.

Figure 3 also shows three different fault-locating impulses applied to a spark gap. Note that the rise times are short and, after reaching a controlled peak, their amplitudes decay at varying rates. Impulse (a) has sufficient voltage and duration to cross the bold curve at a point A and cause flashover. Impulse (b) has sufficient peak voltage but is too short in duration to intersect the bold curve and will not flash over; impulse (c) has the same peak amplitude as (b) but is long enough in duration to cross the bold curve at point C and achieve flashover.

Although the shape of the flashover characteristic curve is typical of all such gaps, the actual curve will vary with each cable fault and will be unpredictable. To locate a fault with the capacitor discharge technique, the surge generator must be capable of generating an impulse of sufficient voltage and time duration to create flashover. Performance of a surge generator is based on its output voltage and energy capability. As mentioned earlier, when switch S_1, of Figure 2, closes the capacitor C discharges into the cable under test in the form of a high voltage impulse. The larger the value of capacitor C, the greater the amount of available energy for discharge in to the fault. The greater the probability of intersecting the characteristic flashover curve of Figure 3, the greater the signal level at the fault. A surge generator's available energy can be calculated as follows:

$$\text{Energy} = \left(\frac{C}{2}\right) V^2 \quad \text{Joules or Watt Seconds}$$

Where C is the capacitance in microfarads and V is the applied voltage in kilovolts.

Effects of Cable Length on a Surge Generator

The length of the cable will effect the peak amplitude of the voltage that reaches the fault. Effects of cable length on an applied voltage can be calculated as follows:

$$V_E = V_A \left(\frac{C_S}{C_S + C_C}\right)$$

Where

V_E = The effective voltage at the fault,
V_A = The voltage applied to the cable,
C_S = Capacitor value of the surge generator, and
C_C = Capacitance of the cable under test.

Cable capacitance will vary and is calculated based on unit length. Figure 4 illustrates the effects of cable length on an applied 16 kV voltage. Cable capacitance in this example has been valued at 100 pF per foot (0.3048 m).

The typical application for a surge generator is to find faults that have occurred during service. The vast majority of faults that occur within a cable typically breakdown at voltages lower than 8 kV, however there may be situations where higher voltages are required. As a general rule the voltage capability of the surge generator should be equivalent to the cable

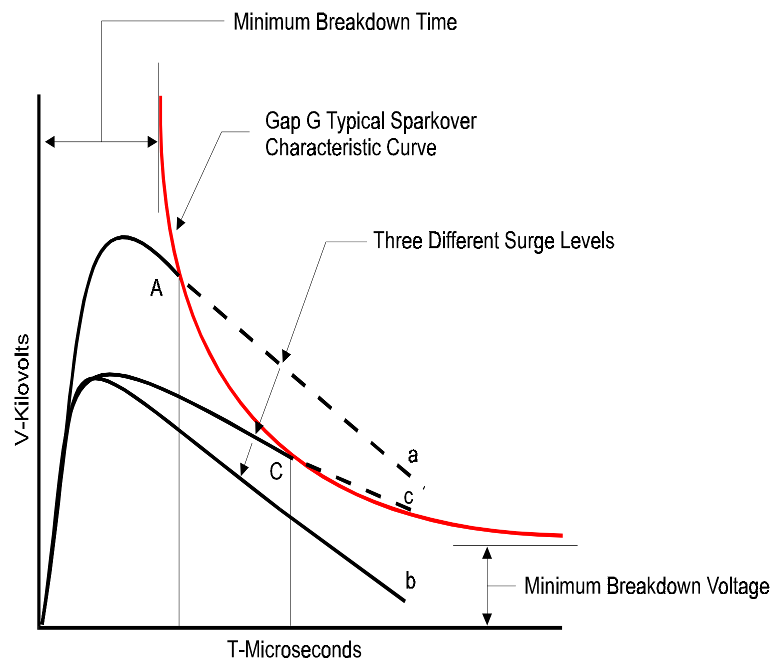

Figure 3. Typical Flashover Characteristics of Gap G.

system's peak operating voltage to ground to obtain maximum efficiency in fault locating.

As an example, if a cable system were rated at 15 kV phase to phase, the effective range of maximum performance for a 16 kV surge generator would be 40,000 ft. (12.2 km) based on Figure 4. To determine this the 15 kV phase to phase rating is converted to peak operating voltage phase to ground as follows:

$$V_{P-E} = \left(\frac{V_{P-P}}{\sqrt{3}} \right) \sqrt{2}$$

$$12.2 \text{ kV} = \left(\frac{15 \text{ kV}}{1.732} \right) 1.414$$

Where

V_{P-E} = Peak operating voltage, phase to ground,
V_{P-P} = Phase to phase voltage rating of the cable under test,
/ 3 = Converts the phase to phase into a phase to ground, and
/ 2 = Converts RMS to Peak.

At 40,000 ft. (12.2 km) Figure 4 shows effective voltage to be 12.2 kV. Beyond this distance the effective voltage reaching the fault will be below the peak operating voltage, phase to ground, of the circuit. This is not to say that the surge generator in incapable of breaking down a fault beyond this distance, it merely points out that efficiency will begin to degrade.
The stored energy of a surge generator is also effected by cable length. To accomplish a maximum level of efficiency in fault location the surge generator should offer a sufficient capacitance to overcome the capacitance of the cable under test. Sufficient energy provides strong arcs used by detection equipment such as cable radar, acoustic and electromagnetic detectors. Figure 5 shows the effects of cable length on a surge generator equipped with a 12 m F capacitor. The applied

voltage in this example is 16 kV and cable capacitance is given as 100 pF per foot.

Summary

The surge generator or thumper serves as a critical element in cable fault location. The device's voltage and energy capability determine the efficiency at which faults can be broken down and located. When selecting a unit consideration must be given to the type of cable and overall length being tested.

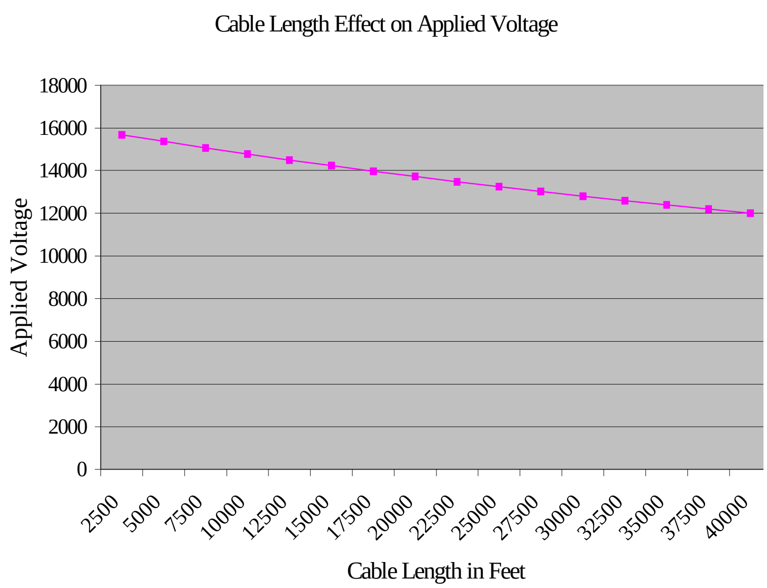

Figure 4. Effects of cable length on an applied voltage.

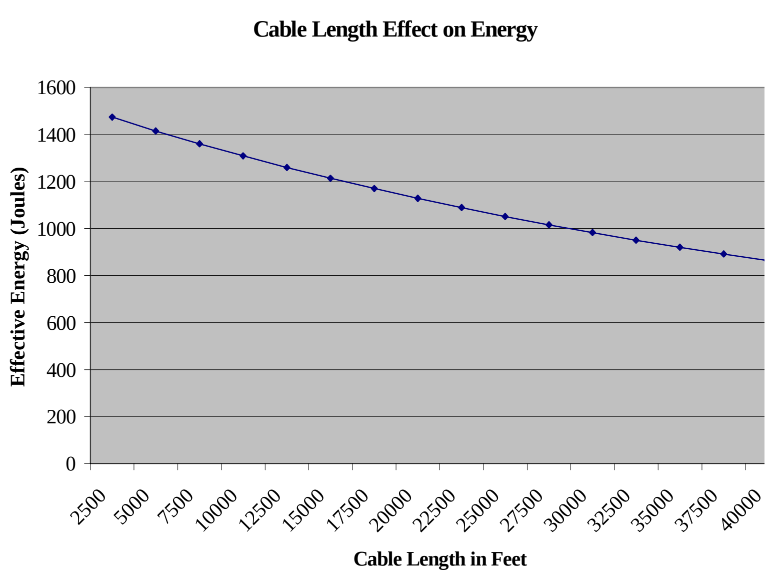

Figure 5. Effects of cable length on stored energy.