Excerpt from *Underground Cable Fault Location*

5 Pin-pointing

Pin-pointing has been defined in Chapter 3 as a test that confirms the exact position of the fault overground and the two main methods have been listed as:

- ***Shock wave discharge***, using a surge generator together with acoustic listening apparatus, and
- ***Audio frequency***, with instruments for injecting and receiving a tone

While these two methods account for most fault confirmations, we must not lose sight of the basics of pin-pointing. This means recognizing and taking into account ***any manifestation*** of the presence of a fault. Effects that can be noted at a fault site include:

- Change of voltage
- Change of polarity
- Change of current
- Modification of magnetic field
- Emission of sound / ultra-sound
- Temperature rise
- Chemical changes
- Olfactory changes
- Visual changes
- Partial discharge
- Emission of electromagnetic signals (HF, RF)
- Physical movement
- Microphony

Fault location is difficult and every possible means of pin-pointing should be looked at very carefully.

In this chapter, the headings under which pin-pointing will be

covered are:
• Acoustic
• Electromagnetic
• Pool of potential
• Magnetic field
• Audio frequency
Other methods such as ***thermal*** and ***partial discharge*** will be covered in Part Three, ‘specialized areas’.

5.1 Acoustic

In power cable fault location the vast majority of pin-pointing tests are carried out using a surge generator to create noise and vibration at the fault site. The surge generator used for this is basically a variable HV d.c. source connected to a high voltage capacitor bank, the output being via some sort of spark gap or triggered contactor.
In the early days of fault location the transformer, rectifier, capacitor and gap were discrete components mounted up and connected on site. The gap was not triggered. The contact separation was simply adjustable, and the length of the gap determined the rate and voltage at which it discharged. Figure 5.1 shows the basic construction of a modern surge generator.
All modern commercially available sets are enclosed for safety and a ‘dump’ switch (D) is incorporated which discharges the output to earth via a resistance (R) when the instrument is switched off. The rating of the transformer must be greater than that of a straightforward HV test set as it must have enough output capacity to charge the capacitor within a few seconds.
The surge generator works by charging up the capacitor C with the switch S open. This switch or contactor has hardened contacts for long life and is solenoid operated so that it can be closed and opened by a timing circuit T that enables the operator to vary the cadence of the switching to give a closure once every 1 to 10 seconds (approximately).

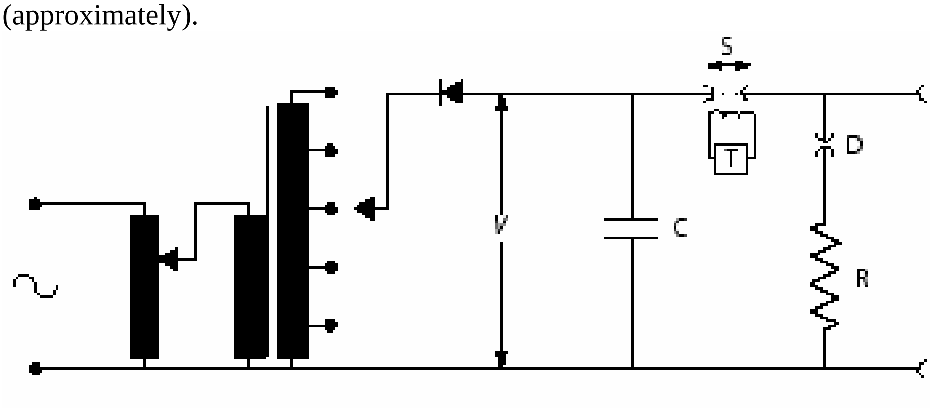

Fig. 5.1 The basic construction of a modern surge generator

The value of capacitance C is usually selectable between a few microfarads and over a hundred microfarads by series, parallel and series-parallel switching, this selection being linked with voltage tappings and suitably interlocked. The arrangement is designed to give a constant energy output either with low voltage / high capacitance or high voltage / low capacitance.

The energy available from such a circuit is given by:

12 CV_2 joules or watt-seconds

where C is in microfarads and V is in kilovolts.

When the stored energy in the capacitor is discharged into the cable, a very high energy steep fronted surge wave is launched, seeing an impedance of *Zo* ahead of it. Examples of such voltage impulses are shown in Fig. 5.2.

This is a series of curves with axes; V (kV) and t (µs). The heavy line represents a typical fault characteristic that shows that a fault will never break down instantaneously and that it takes a certain minimum voltage to break it down.

It is a common misconception that a fault must break down if a surge of a high enough voltage is applied to it. This is not so. A surge is not a steady d.c. potential but a wave with a very steep front edge and an exponentially decaying trailing edge as shown.

It should be clear from Fig. 5.2 that, while surge a has a high enough peak voltage, say 15 kV, for its tail to cut the fault characteristic at time t_1 and thus cause breakdown, it is possible to send a wave like b with a peak voltage of, say, 10 kV, that does not cut the fault curve and therefore does not cause breakdown. A voltage of 10 kV may well be above the already established withstand voltage of the fault but the problem is that not enough capacitance is in the circuit to ensure a slow enough decay of the wave. The curve c is that for a discharge at the same voltage as b but with more capacitance selected. This curve cuts the fault curve at time t_2 and causes breakdown.

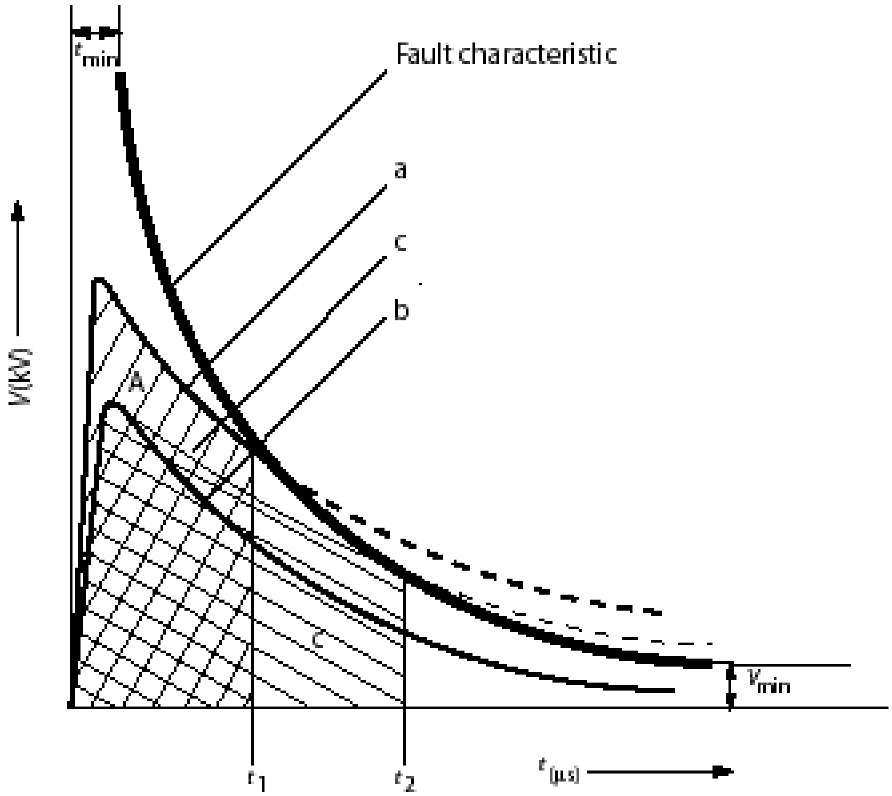

Fig. 5.2 Comparison of surges with different voltages and energy contents

An important point now becomes clear from these examples: more energy is dissipated by wave c than by wave a. In physics power is something waiting to be used. Energy is power being used; hence time is a major factor as evidenced by the units of energy: kilowatthour, watt- second. The energy under curve c is greater than that under curve a, which serves to illustrate that it is often better to increase capacitance primarily to create a breakdown and then to enhance the energy dissipation at the fault and thereby to create more noise / vibration.

In air, this is remarked as a very loud report or ‘bang’. The cable, however, is usually buried at a depth of half to one metre and therefore the sound is muffled, producing a ‘thump’, which can sometimes be heard unassisted overground but more often can only be detected using a sensitive ground microphone and receiver / amplifier. Because of the noises they produce surge generators are often called ‘bangers’ or ‘thumpers’.

As stated, this process is repeated every few seconds so that the operator can walk over the suspect zone to pin-point and mark the location exactly. Different people have different ideas on the best rate of discharge to use. Most go for a rate of one surge every three or four seconds. If the rate is over about ten seconds, it is possible to walk over the site of the fault without hearing the discharge. On the other hand, a rate quicker than approximately one surge every second does not give the d.c. source enough time to charge up the capacitors to the selected voltage before they are discharged again, thus putting an unnecessary limit on the energy available, remembering that this is proportional to V_2.

The features normally fitted to commercially available sets are:

- Safe enclosure
- Protected terminals
- Automatic 'dump' on switch-off
- Interlock to prevent high voltage appearing on switch-on if voltage control is not at zero.
- Selectable voltage and capacitance, interlocked
- Switch rate selector
- Voltage indication

Features that may or may not be included are:

- Dump to earth between surges
- 'Single shot' facility
- Use as HV test set
- Possibility of using HV with capacitors connected
- Remote control.

Generally, two sizes of surge generator are available: a smaller, portable type of unit for use on low voltage, control, indication and (some) telecommunications cables, and the larger set in more common use, which is transportable, weighing up to around 100 kg. The smaller versions tend to have a capacity of a few hundred joules and an upper voltage limit of approximately 5 kV, while the larger models can deliver surges of up to 2000 joules at voltages up to about 30 kV. Some US stand-alone models can have around 70kV and up to 7000 joules. Other, mainly European rigs, can surge at 70 kV or more but, of necessity, these are modular arrangements mounted in the protected rear zone of a test van.

Some instruments currently available are shown in Fig. 5.3a to c.

Given that a surge generator has been connected to a faulty cable, it is not good practice simply to switch on and rush up the route to listen.

Successful pin-pointing depends on:

- Vibration / noise ***actually*** being created at the fault site.
- The operator being ***certain*** that this is so and
- ***Standing over the cable*** while listening

These points may seem simplistic but they are absolutely vital. They will now be taken in turn.

ACTUAL NOISE OR NOT

The surge generator may be functioning perfectly at the test end but there will be no noise at the fault if it is a zero ohm short circuit or if its resistance suddenly changes and the chosen voltage does not regularly break it down. It pays, therefore, first of all to measure the fault resistance immediately before starting the surge generator and then to surge for a few minutes, switch off, disconnect and measure the fault resistance again. If the resistance has remained at a medium or high value or has risen from zero or a few ohms to a medium value of, say, a few kilohms, it is certain that noise is being created by the surging. If impulse current equipment is also connected at the time, evidence of ionization delay proves that arcing is taking place.

In any case, it is sensible to wait for several minutes to make sure that the surge generator is being discharged regularly into the fault. As already stated, a fault can be unstable and give rise to intermittent discharging which is evident when the surge generator voltmeter does not kick back towards zero after each shot. If such a situation exists, the surge voltage can be raised so that the fault discharges every time. A good tip here is to switch off so that the core is earthed before surging is restarted at the higher voltage.

For instance, if 10 kV is not breaking the fault down and the voltage is increased by 2 kV, the next surge is 2 kV on top of the 10 kV already standing on the core. This may be doubled by reflection from the far end, thus stressing the fault at 14 kV. If, however, the core is discharged, a new surge of 12 kV will be doubled to 24 kV which is much more likely to break the fault down. Even if the fault will ***still*** not co-operate, at least the operator knows to spend longer at each point when listening over the cable so as not to be misled by the occasional surge producing no noise.

CERTAINTY

While the foregoing precautions will contribute greatly to the operator's certainty that the surge is producing a noise, there still remains the possibility that the surge generator has ceased to operate. This may be due to a power failure, the surge generator having been inadvertently switched off or the fault having gone permanently 'high' so that the voltage is simply standing on the cable core and there are no breakdowns.

There are two remedies for these situations. The first is, perhaps obviously, ***communication***. The surge generator may be several kilometres away from the suspect zone but someone should have

been instructed to watch the surge generator carefully and to notify the field operator immediately should any of the above problems occur.
The second remedy can be provided by a facility built into some receivers / amplifiers. This is a pick-up coil and associated meter / indicator that indicates the presence of the magnetic field resulting from the surge current. This is an invaluable feature that, fortunately these days, has been incorporated by most manufacturers.

Fig. 5.3 (a) CET Controlled Energy Capacitive Discharge Fault Locator (*source:* Hipotronics, Inc., USA)

Fig. 5.3 (b) STG 600 LV Surge generator (*source:* Baur Prüf-und Messtechnik GmbH & Co. KG, Austria)

Fig. 5.3 (c) SWG 1000C Surge generator (*source:*Seba KMT, Germany)