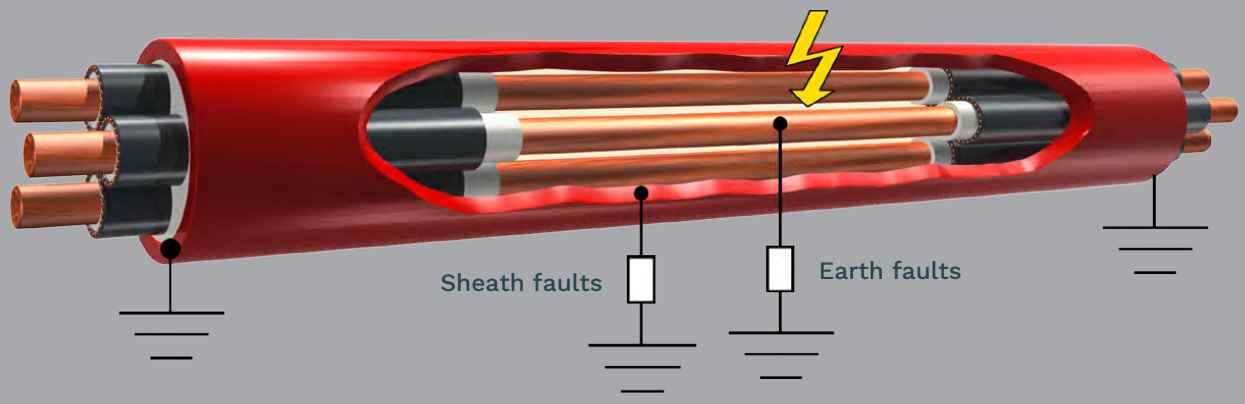
Appropriate Cable Fault Location



By Trevor Lord, Director, AVO New Zealand

Cable faults can and do occur.

Whilst the literature makes clear that about 30% of such faults might in some way be attributable to 'third-party damage', the majority of cable faults (including many those in the third-party damage camp) will not occur without some form of 'observable' prior warning signs. Were *suitable and appropriate* inspections to be done at initial installation, commissioning, and periodically during the cable life, then Industry stress levels would be greatly reduced. Missing out any of these inspection processes will almost certainly result in cable faults and failures appearing at *apparently* random times and almost certainly demanding an urgent response.

Suitable proactive interventions as above sadly continue to be in the minority and will be the subject of another paper. This article focusses on the unfortunate reality that cable faults will continue to be with us for a long time yet and will require the best of cable fault location methods to be on hand, ideally with enough user assistance built in to permit good outcomes to be reliably delivered by most technicians.

A Summary of the Essential Steps in Carrying Out a Cable Fault Location:

In commencing this conversation, we will look at the processes of cable fault location, the technical requirements of a suitable range of fault location devices, and how modern technology now exists to ensure excellent outcomes in most scenarios without the level of specialist training once required in the past. In so saying, the truth remains constant that the best results on the day will always be enjoyed by the wise and careful specialist who tackles the cable fault with a humble respect. This paper is merely an overview of where we are presently in the processes and concepts, not a training course in the art!

Upon responding to a cable fault, a process is followed that broadly covers the steps of Fig 1.

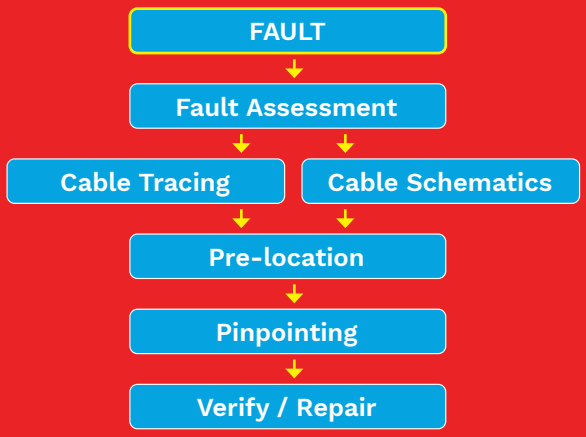


Figure 1: Overview of the essential steps in carrying out a cable fault location

Carrying Out the Initial Assessment of the Cable Fault...An introduction to the TDR and HV Bridge:

To conduct the fault assessment, the best first step is to determine the status of the fault. The best way is to apply an insulation tester to each core in turn at a low (say 20v) setting and note if the core is open or shorted. Raising the voltage in sensible steps allows the voltage-dependence of the fault to be determined and what the nature of the fault resistance at given voltages.

If we see a low fault resistance (e.g.: under 100 Ohms) at voltages below 50V, or an open circuit, we can likely begin with a Time Domain Reflectometer ('TDR') (Fig 2). TDR devices are: fast; safe and non-destructive (LV DC pulses less than 50 volts); portable; good for both open circuit faults and short circuit faults (especially when used with multicore cables when good core/bad core comparisons can be employed); an economic option; suitable for pre-location but not pin-pointing; but not suitable for high resistance faults (>100 Ohms). In other words, the TDR is a handy but somewhat limited tool in the kit, likely to leave one wondering where to go next!



Figure 2: A Typical Time Domain Reflectomer in Action

Were we to see a fault resistance that is higher than 100 Ohms and more likely in the 1 to 100MegOhm category, say, then we have the option of using a much older and rather complex-to-operate device called an Inverted Murray Loop Bridge. You have it in one! Such bridges are little used today as they require quite some training and skill. They did the job, however, and typically use a higher voltage to ensure suitable bridge sensitivity to ensure measurement (and location) of such High Resistance faults.

Fortunately, modern, automated versions of the traditional bridge technology exist and better known now as a High Voltage Bridge. These have up to 10kV DC of output and allow for the location of sheath and cable faults up to several hundred Megohms. They are an excellent and popular complement to the Arc Reflection and TDR type of cable fault locators which we will now discuss.



Figure 3: A modern High Voltage Bridge

Discussing the Arc Reflection Method ['ARM'] type of Pre-Location Device:

It is often the case that the cable fault effectively comprises a voltage-dependent spark-gap (not breaking down until perhaps more than 5 kV) in series with a fault of some nominal resistance. Thus, to get the fault to break down we need to introduce a source of high voltage DC, typically a DC impulse generator (discharging a large capacitor into the cable to break down the fault). The trouble is, that these impulse generators (in their basic form) have no measurement ability to pin-point the fault effectively. Instead, they simply carry on breaking down the fault and making a loud bang at the fault that can be heard with pinpointing acoustic detectors (or one's feet in extreme cases!) and this can cause a huge amount of additional damage to the cable if these impulses are left to carry on as the technician walks the cable route trying to hear the 'bang'. These 'blind' cable 'thumper' devices are seriously bad for any XLPE cable or cables with modern resin types of joints and terminations, and their application alone is no longer seen as suitable cable fault location practice.

What to do?

Well, the modern cable fault locator has been cleverly designed to combine a TDR, an impulse generator, and a high voltage bridge, so as to achieve an efficient pre-location in just one or two discharges. That is the essence of the new technology, and such devices are known under various names, including the acronym 'Arc Reflection Method' (ARM).

Their essential componentry is illustrated in Figure 4.

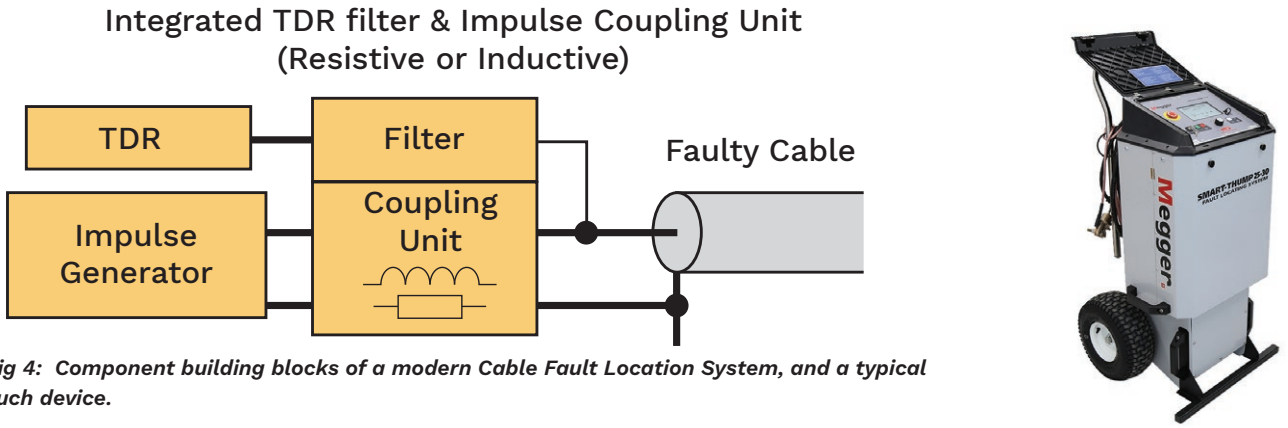


Fig 4: Component building blocks of a modern Cable Fault Location System, and a typical such device.

An Impulse Generator (also known as a Surge Wave Generator or 'Thumper') is at the heart of the device. This comprises of a source of high DC voltage (4 to 16 kV DC, but up to 32 kV for 66 kV fault location capability) charging up a capacitor which is then discharged into the cable via a resistive or inductive filter. We will review the construction of the Surge Wave Generator in more detail soon. Also present is a TDR device that sends out nominally 50V pulses on top of the high voltage impulse, doing this safely via a clever Filter.

The Arc Reflection method works as follows: when the HV DC impulse is such as to break down a fault and create an arc, the TDR notes this as a short circuit. The point where that occurs is the fault site. The distance to fault is determined by calculating the speed that the waveform has travelled down the cable, this being determined either by the cable type, or by calibration (in cases where the cores are complete and achieved by opening and shorting the end of the cable and entering the known distance to that point to determine the propagation speed). The distance to fault is usually automatically determined by the TDR display instantaneously and displayed on the front panel screen...all with just one impulse of suitable breakdown voltage being needed and causing minimal damage to the cable as a result. See Figure 5.

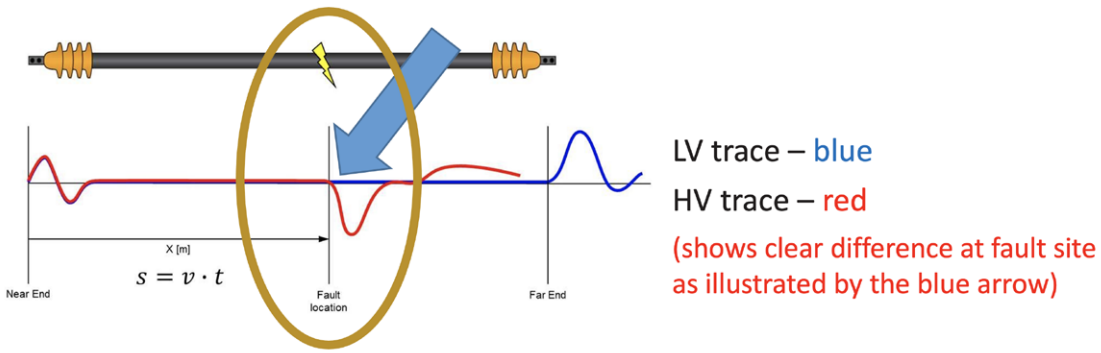


Figure 5: The Arc Reflection Method. The LV TDR response (blue) and the HV DC response (red) diverge at the point of fault.

A Conversation on the Optimal Makeup of the Impulse Generator Device:

Because the impulse generator device is now the heart of a modern cable fault locator, we really cannot move on without some study of how these are built and what makes up the right set of features to ensure it is right for your cables.

Whereas older Impulse generators only had a single capacitor, they were limited in their ability to locate faults on both HV cable and LV cable...the compromise lay particularly with their performance on the LV cable faults.

To explain the above comment, the energy stored by a capacitor is expressed in Joules and is determined by the formula: ½ CV^2, where C is the Capacitance in Farads, V is the voltage to which the capacitor is charged. Thus, if we have a 1200 Joule set at 16 kV (typically used for 11 kV cable), the Joules at 4000V (i.e.: maximum for LV cable work) is only 1/16th of this [i.e.: $(V/4)^2$], or just 75 Joules. The threshold for audible discharge of a cable below ground is around 250 Joules, so the cable fault would be unlikely to be found at a 4000V impulse. So, predictably, operators then turned up the impulse voltage on LV cable until they got a breakdown. Given this, the unwary operator was traditionally tempted to increase the test voltage until the cable broke down with a good 'thump', however that may have meant some 8000 volts (or more!) was applied to an LV cable so as to achieve this! Sadly, major cable damage would certainly result by such actions. **The 'V' (Voltage) knob on a cable impulse generator must never be considered as the 'Volume' control!!**

Fortunately, in a modern cable fault locator, we now are likely to find multiple operating voltages (say 4, 8, and 16 kV) which typically are each able to give 'full Joules' at each voltage selection setting. This is achieved by the sets typically having 4 capacitors, each of equal size. For the lower range, all 4 are in parallel, for the middle range they are connected in series/parallel, and for the high voltage range they are connected in series. By using this more modern design of impulse generator, for each of the 4/8/16 kV impulse voltage ranges on the impulse generator the cable will see the same Joules of energy, but with much less risk of 'over-voltage' cable damage when pre-locating a fault. See Figure 6.

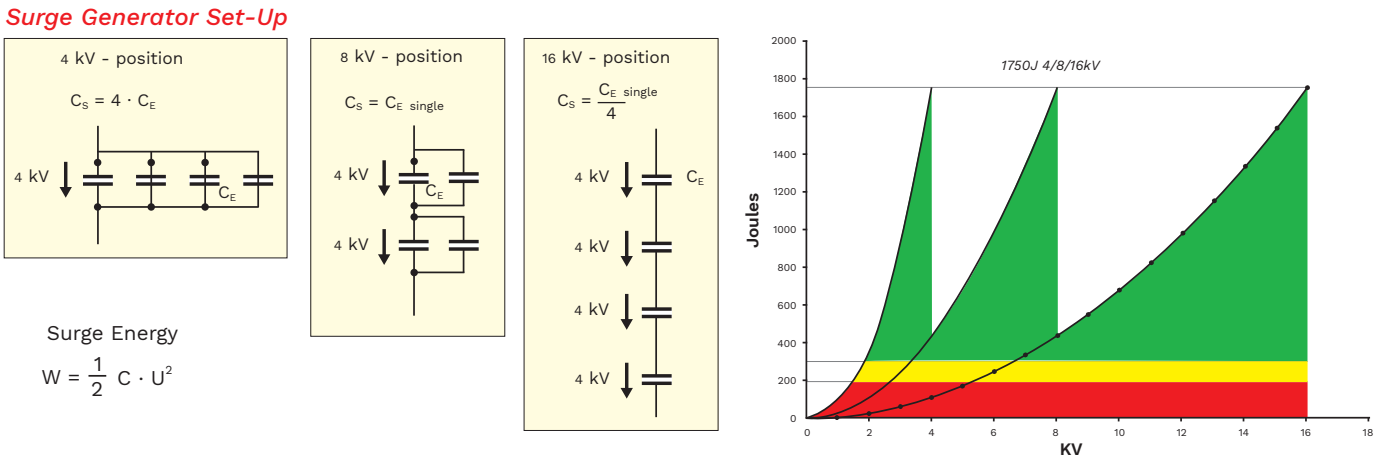


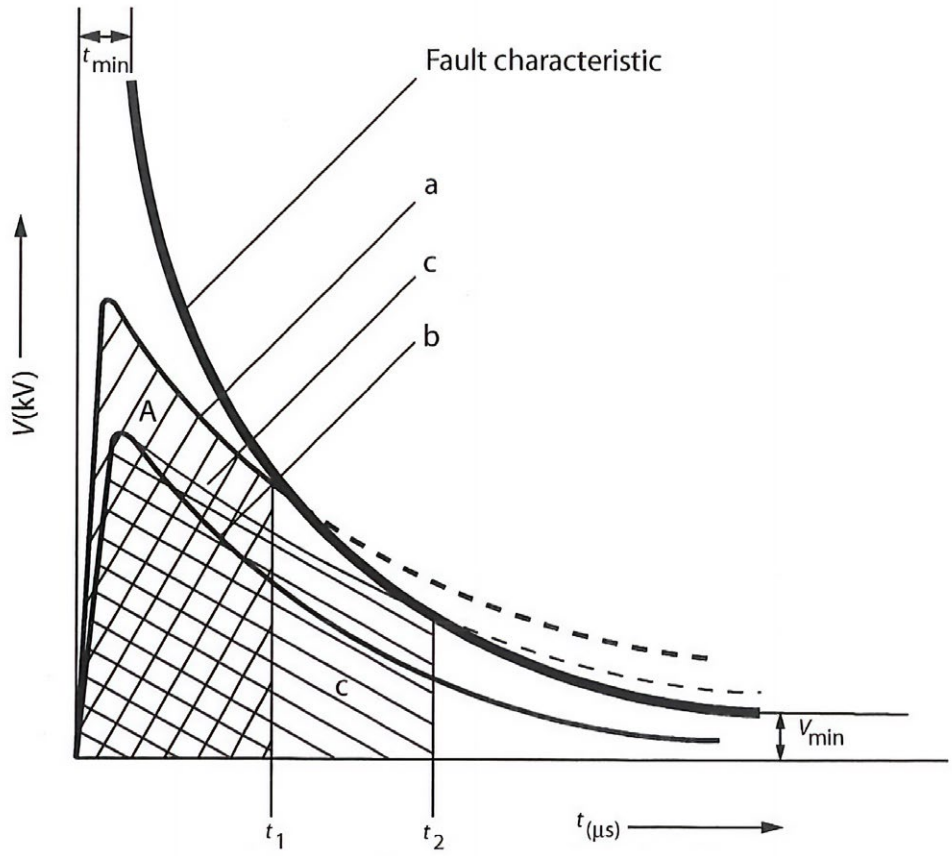
Fig 6: Capacitor connections to ensure same maximum Joules of Impulse Energy exist at each of 4, 8, 16 kV of a modern Cable Fault Locator Impulse Device. This is achieved by dividing the capacitance by 4 for each successive doubling of the maximum test voltage. Energy for each configuration shown at right. Were the energy of each of the 3 ranges to be 1750 Joules as illustrated in this example, a quick calculation shows each CE to be 54.7 microfarads.

Correct Specification of the Cable Fault Location 'Impulse Generator':

An important matter to understand when breaking down a fault on cables of varying lengths and voltages, is that in each situation the cable has what is known as a 'fault characteristic' that establishes how much voltage and energy is needed to break down a fault (and thus get a location) with distance down the cable. See Figure 7. Such a characteristic will be inherent with all cables exhibiting a 'flashing fault' behaviour.

Thus, a successful fault location with minimal cable damage in the process requires a combination of an effectively-designed impulse generator PLUS the skill of the operator in selecting the correct combination of the set's maximum impulse voltage range position on the impulse generator AND the operator-controlled impulse voltage actually applied to the cable.

Unless the effective capacitance, Joules, and applied voltage is suitably established from the impulse generator, the fault may not break down and thus not be located by this method! Worse still, if not operated correctly, the impulse generator could well greatly damage the cable under test through insulation stress! In the case of longer cables, say 5-10 km in length, a larger voltage impulse of a good level of energy must be applied (from a large capacitor), so as to break down the cable well down the fault curve.



[Diagram courtesy of Mr Barry Clegg, UK]

Figure 7: Cable Fault Characteristic Curve and Various Impulse Scenarios. This gives a valuable impression of the realities of breaking down a cable fault (and thence obtaining a location) via a DC impulse derived from an Impulse Generator (or 'Thumper').

The impulse produced by these devices is a sharp-rising waveform which tails off exponentially with time. The area under the impulse curve represents the number of Joules of energy comprising the total impulse until it finally decays away with time.

Time on the bottom axis is a representation of distance down the cable (based upon the speed the impulse waveform propagates in the cable).

Waveform 'b' illustrates that if the impulse is not of sufficient peak voltage, backed by sufficient Joules of energy, it will never break the fault down.

Waveform 'c', on the other hand, illustrates that if we have the same peak impulse voltage but provide a higher number of Joules with the impulse (via a larger capacitor), then it will in fact break down the fault and, indeed, could do so were the fault to be at any point along the cable length beyond time t_2.

Waveform 'a' illustrates that if we apply an even higher impulse voltage, giving us a good number of Joules by virtue of the "voltage-squared" contribution, we could initially break down the fault much earlier than either of the other two scenarios BUT the danger here is that the level of voltage applied may in fact be damaging to the cable's voltage ratings.

SUMMARY: Always be mindful, when specifying and operating a cable impulse generator, of the need to balance optimally and carefully the applied peak voltage, the risk of cable damage during the location operation, and the desired optimisation of achieving a fault breakdown along the cable length in question.

Concluding this discussion, it is very important to purchase a cable impulse generator which can offer the optimal balance of internal capacitance, impulse voltage, and overall Joules of energy to ensure that faults can be broken down along the *intended maximum cable lengths being managed*, without undue cable damage due to excessive impulse voltages being applied in the process. Further, the selection process for such a device is a balance of size, weight, practicality of operation, performance, intended maximum cable lengths to be tested, range of desired cable operating voltages to be serviced by the equipment, fault location aids included, and of course, price. Luckily, compared to only 5 years ago, many choices of impulse generator configurations now exist, and the right device may now be readily purchased to meet all combinations of the above factors underpinning the final specification.

Advancements in Portability, Performance, and Software in Modern Cable Fault Location 'Thumper' Devices:

Users now have unprecedented access to powerful and effective combinations of features in their cable fault location devices. A typical modern Impulse Generator ('Thumper') will allow the operator to capably manage the required balance of location effectiveness with minimisation of cable damage during the entire location sequence. Users may now expect a design based on optimised impulse voltage and Joules of Energy, an extremely powerful and intuitive Arc Reflection capability, and a selection of other relevant features, outlined below, that assist the operator perform the required tasks in the most efficient manner yet seen in the history of such equipment.

The selection process is now essentially a choice between two main architectures:

a) A versatile single-box multi-voltage multi-Joule CFL device, typically:

- 80-120kg (usually van-mounted)
- 2000 Joules per voltage range selected (sufficient for most cable lengths)
- 4/8/16/32kV (allows very capable coverage from LV to 66 kV cable), otherwise 4/8/16 kV for up to 33kV cable is adequate.
- Powerful Arc Reflection Method('ARM') display device for managing all likely fault types



Illustration of a modern, compact 4/8/16/32 kV 2000 Joule ARM prelocation device

OR:

b) Smaller compact, cost-effective devices, now able to be purchased as specially designed solution for a given cable voltage and fault characteristic curves:

- 30kg single person lift
- A choice of configurations for specific applications: 4kV 500J for LV cables, or 12kV 500J for up to nominally 2.5km of 11kV cable
- Battery-powered operation...no need for mains voltage power source
- Simple, intuitive operator interface on each device, permitting easy transition from LV to HV models.
- This concept is well suited for doing the majority of the 'mainstream' cable fault work in both smaller and larger networks (thus reserving the larger, heavier cable fault locators for the longer or higher voltage cables).



An example of a modern 'optimised' self-contained, simply operated, battery-powered pre-location 'thumper' device designed for all typical LV faults, or, in another identical-looking package, for nomally 2.5km of 11 kV cable.

Acoustic and electromagnetic impulse detectors for 'pinpointing' faults:

After completing the pre-location steps outlined above, acoustic, and electro-magnetic impulse 'pinpointing' devices are the vital 'next step' in the cable fault location process.

Recent advances made in this field include:

- Enhanced combination of electromagnetic detection capabilities and optimised geophone design to avoid stray noise pickup.
- Simple operator-assisted operation.
- Improved level of operator comfort and operational effectiveness.
- Optional facility for sheath fault location in some brands.

Importantly, pinpointing of a cable fault still requires the controlled use of a cable impulse generator, the operator of which should ideally be in radio contact with the operator of the pinpointing device. This way, the pin pointer operator would call up a single impulse, confirm receipt at site or move location, then call for another impulse when ready, until the fault is ultimately pinpointed by this method. This process minimises the number of HV impulses applied to the cable during the total cable fault locating process, a major contribution to minimising cable damage during the total cable fault location process.



Fig 8: Modern 'pinpointing' devices employed for the final stage of cable fault location. These are used once the 'pre-location' stage has been completed [via a comprehensive impulse generator with integrated arc reflection capability], and the cable route traced physically via a cable route tracer device to the area of the fault. Pinpointing devices now incorporate many ergonomic features and operational capabilities only dreamed of in comparatively recent years.

Conclusion:

Cable fault location technology is now at a very advanced level. Modern equipment is now highly capable, permitting both cost and time-effective cable fault location with minimal cable damage in the process.

Modern self-powered cable fault locator configurations are also offered to the market which have been optimised for the requirements of the majority of daily cable fault location requirements of a distribution network, while at the same time also simplifying the complexity of the task and the associated operator training requirements.

Care must still be taken to purchase and apply the correct specification of cable fault location device, and pin-pointer, to ensure the fault location requirements of the client are met.

Cables can be greatly damaged by over-voltage and excessive exposure of the cable to HV DC impulses over the course of carrying out a cable fault. Effective communication between the operator of the cable fault location pre-location device, and the operator of the pin-pointing device, can result in the whole cable fault location process only requiring a few impulses in total of the correct energy and voltage.

When assessed against historic levels of required rigour, training, and experience required, as well as the level of inadvertent cable damage routinely done in the process and just the amount of time taken on the average to get the job done, cable fault location truly has reached a very significant zenith. These are indeed exciting times!



