Allen is the Megger CFL & HV Product Manager based at the Valley Forge facility in the USA, whereby he has been instrumental in introducing several CFL products for the worldwide market. He has over 20 years experience in cable fault location, having previously undertaken practical and theoretical training, worldwide. He held the role of Technical Support Manager in the UK, where his team provided technical support for all Megger products. Prior to that he was Sales Manager with responsibility for Russia, CIS, Scandinavia and Northern Europe.
If the cable slopes. Plastic cables can often perform when wet; paper cables cannot. Insulation resistance values vary considerably but tend to be of the order of a few kilohms. A change of characteristic impedance occurs at the wet section.

The Contact Fault

Also described as a short or shunt fault and is a connection, or part connection, between one core and another or others, or between core(s) and the metallic sheath.

The value of the fault resistance can, of course, vary between zero ohms and many megohms, a major factor in deciding the location method.

The Ground Contact Fault

This can be termed as an earth fault, sheath fault or serving fault and often occurs on unshielded multi-core control and telecommunications cables and plastic low voltage cables with no metallic sheath or armour. It is the connection between a core or cores and the mass of earth

The detection, location and repair of such serving faults are vital in preventing metal sheath corrosion leading to loss of oil (in oil filled cables) and/or core faults with the consequent damage and disruption to supplies or traffic. As a matter of interest, such faults which involve contact between a metal line and the mass of earth lend themselves to almost 100 percent successful pinpointing using high voltage d.c. or audio frequency methods. Conversely, pre-location can be very difficult as pulse echo/time domain reflectometry techniques cannot be used.

The Break

Also known as an open-circuit or series fault and can be a ‘clean’ break in a conductor, i.e., with an infinite or a very high resistance reading across the break and to adjacent metal. There can also be a ‘dirty’ break where there is a measurable resistance across the gap and/or to adjacent metal. A partial break can occur when some of the strands of a conductor are broken or burnt through.

Ingress of Moisture

Moisture usually produces a contact fault involving all cores. Water enters a cable at some point of damage and may be present in one limited stretch or it may spread many meters along the cable, typically as far as the next joint. Therefore, the site of the break down is often some distance from the point of entry, particularly if the cable slopes. Plastic cables can often perform when wet; paper cables cannot. Insulation resistance values vary considerably but tend to be of the order of a few kilohms. A change of characteristic impedance occurs at the wet section.

Flashing Fault

This is the type of fault that does not manifest itself at lower voltages but flashes over at a certain higher voltage threshold. This may be hundreds of volts or several kilovolts up to a maximum that is the accepted d.c. test voltage for the cable. Such a fault is acting like a spark gap. It can often cause a fuse to blow and then disappears! In fact such a fault is arcing over intermittently, the severity and frequency of this arcing depending on the applied voltage (near or at voltage peaks) and the state of the fault path, i.e., short/long, partly/heavily carbonized, wet/dried-out, etc.

Partial Discharge

This is a well-known phenomenon occurring on high voltage a.c. systems whereby small breakdowns occur at weak points in the insulation, i.e., voids. These discharges take place singly, in bursts or continuously, and do not cause breakdown. Their energy is measured in pC (Pico coulombs). Energy levels and general activity invariably increase with time until breakdown does occur. ‘Treeing’ is a common manifestation of partial discharge activity, see figure 2. This is produced by the lengthening incursion paths of the arcs.
Identify the Type of Fault

A multimeter (operating as an ohmmeter) or an insulation tester is used to determine the type of fault. This is important to help us decide which method of fault location is best suited (see figure 4).

Warning: On some high voltage insulation testers the lowest measurement range will not give the required resolution, i.e., if a fault resistance is less than 5k Ohm, we need a resolution down to low Ohms, typically 300 Ohms down to 0 Ohms.

If necessary, use a multimeter or the ohms range on the insulation tester.

Warning: A high-voltage insulation test does not confirm that the cable is healthy! For example, a 5-kV insulation test will not identify a fault that requires 8 kV to break down.

FAULT PRELOCATION

Fault prelocation is the first stage of the actual fault location and, as such, gets in the general vicinity of the fault. It is difficult to define, as within 2% of 100m is entirely different from 2% of 14 km. In some countries this is termed sectionalizing.

Low Voltage Prelocation

Description of Pulse Echo techniques

Pulse echo, also known as TDR or radar methods of fault location, use low-voltage pulses to locate changes in impedance along the length of the cable. From these low-voltage pulses, a small amount of energy is reflected back to the TDR from a change of impedance and is displayed on the MTDR screen as either a positive-going or negative-going pulse, depending on the impedance characteristic (negative pulse for low impedance to shield faults and positive pulse for high resistance faults).

With pulse echo, the time that the pulse needs to travel from the instrument to the end of cable and back is measured by means of a cursor which is positioned at the beginning of the reflection.

Mathematical representation:

\[ L = v \times t \]

Where: \( v \) = Velocity of Propagation, \( L \) = Length, and \( t \) = Time

Figure 5: Pulse echo, also known as TDR or radar method
High Voltage Prelocation

For faults that cannot be prelocated using LV methods, HV methods need to be applied. Currently these are divided into two groups: (1) arc reflection and (2) those using the transients generated at the point of breakdown.

Description of Arc Reflection

Arc reflection, in its many guises, has become the most popular and successful method now used. This method uses standard pulse echo techniques to prelocate high resistance faults which are not identifiable using pulse echo.

In arc reflection we use an impulse generator, arc reflection filter and a TDR (typically Megger MTDR100). The operator takes a standard pulse echo trace which is automatically saved as a reference file. Then, a HV impulse is applied to the cable. This impulse passes through the arc reflection filter, which “stretches” the length or time of the impulse. The outgoing pulse then ignites the fault, creating a temporary short or bridge to earth/ground. During this period, the MTDR sends out low voltage TDR pulses into what is in effect a short circuit. This trace is then studied and compared to the original trace. The point of divergence is the point of fault.

Note: This method is extremely effective and the traces are easy to interpret.

Differential Arc Reflection Technique (DART)

Equipment as previous. In DART, the reference trace is mathematically subtracted from the trace obtained during the arc. This removes unwanted and confusing reflection, leaving a clean trace with only the fault position being displayed by a positive pulse.

Note: This method is extremely effective and the traces are easy to interpret.

It should be noted that the first displayed pulse includes the “ionization delay” and should not be used for measurement. In general, the second or third pulse can be used. Later pulses can distort the measurement as they have been attenuated by the cable during the multiple reflections.
Description of Voltage Decay
Voltage decay uses the oscillating “transients” that are generated at the point of breakdown. However, it is probably only used around 8% of the time and is often overlooked. It is especially useful when a fault breaks down and reseals itself. This can be termed a “flashing” or “pecking” fault. Voltage decay can also be used where the voltage required to break down the fault cannot be achieved with the surge generator.

In voltage decay we typically use a high-voltage d.c. source, a voltage divider, and the MTD100 which is operating as a transient recorder.

High voltage d.c. is applied and the voltage increased until the fault breaks down and a flashover occurs. During this flashover (the point of fault) the resultant transients are reflected back and forward between the fault and the d.c. source. These transients are detected by the voltage divider and fed to the TDR where they are subsequently displayed.

Fault Conditioning
If the fault does not consistently break down, or is unstable, at the maximum allowable voltage, select the proof/burn function on the cable fault location equipment. Raise the voltage to either the maximum allowable voltage or until the fault breaks down in a relatively stable manner as indicated by stable current and voltage.

Continue this proof/burn function until the discharge current is stable; after a few minutes of stable discharge, return to arc reflection. Do not use proof/burn excessively as you could create a “dead short” to earth/ground that would be extremely difficult, if not impossible, to pinpoint using acoustic methods.

Pinpoint Fault Location
Once the fault has been pre-located by using any of the previously referred-to methods, the fault can be pinpointed either by acoustic, electro-acoustic, or electromagnetic methods.

Set the cable fault location equipment to impulse current and set the discharge voltage to a voltage similar to that used previously.

Note: The lowest possible voltage should be used (as long as it is high enough to ignite the fault and create a flashover) as this ensures that the maximum energy is available, making pinpoint location easier. Set the discharge rate as desired and use a suitable pinpoint receiver to pinpoint the exact location of the fault.

Figure 12: Typical Traces (loop-on far end)
Figure 13: Voltage decay
Figure 14: Typical Traces
Figure 15: Pinpointing made easy
CABLE FAULT PRODUCTS FROM MEGGER
Power cable fault locating and testing takes on a whole new dimension with the modular cable fault locating concept from Megger. We have geared our development to the industry requirements for a more tempered fault locating method and have developed more sophisticated methods that reduce the stress on insulation systems.

Portable Surge Impulse Generator
Model MIG16-2
- Rugged, compact, portable field impulse generator
- 8/16 kV, 1500 Joules surge output
- HV insulation testing to 20 kV
- Proofburn up to 20 kV, 115 mA

The MIG16-2 1500 Joule 2-range Impulse Generator provides a safe, efficient and easy-to-use solution for pinpointing various types of cable faults over a wide variety of power cables.

The unit is housed in a robust, rugged field-proven enclosure. The system delivers both a powerful 8 kV and 16 kV 1500 joule surge impulse capability with the added benefit of dc insulation testing up to 20 kV.

The MIG16-2 fills the field-portable gap where there is only a need for an impulse generator (thumper) and proof tester, but no need for the cable fault capabilities of an MTDR.

Portable Cable Fault Location and HV Test System
Model PFL22M1500
- Portable, rugged fault locating system
- Multiple fault locating techniques
- 8/16 kV, 1500 Joules surge output
- HV insulation testing to 20 kV
- Proofburn up to 20 kV, 115 mA

The PFL22M1500 is designed to provide quick, effective, accurate and safe fault location, thereby reducing system outages and minutes lost.

The instrument comes in a rugged, portable enclosure. Its IP64 rating makes it suitable for use in even environmentally hostile conditions.

All systems offer the facility to undertake cable testing: cable and fault diagnosis, pre-location of cable faults, fault conditioning, and pinpoint fault location using acoustic methods.

32-kV Cable Fault Location and HV Test System
Model PFL32M1500
- Powerfull 32 kV/16kV 1500 Joules surge output
- HV insulation testing up to 32 kV dc
- Portable, compact field-proven enclosure
- Comprehensive fault locating techniques

The PFL32M1500 is designed to effectively locate cable faults, quickly and safely, reducing “customer minutes lost” and system outage times. The CFL and HV test system is housed in a rugged and compact field-proven enclosure, that ensures its suitability for use in severe or even hostile environmental conditions.

The integrated MTDR provides pulse echo, arc reflection, arc reflection plus, differential arc reflection and current impulse. With these methods along with a TDR range of 34 miles (55 km) and a transient analysis range of 137 miles (220 km), the PFL32M1500 is suitable for locating the majority of cable faults, even on long cables.

Portable 4-kV and 12-kV Fault Locators
Models PFL4E-500 and PFL12E-500
- Compact, lightweight fault locating systems
- Battery or line operated power
- 4-kV or 12-kV output versions
- Automatic or manual fault location

The PFL4E-500 and PFL12E-500 portable fault locators are suitable for several applications including fault location on URD systems. They are housed in a high impact-resistant PP enclosure with an ABS lid, giving it an IP54 environmental rating.

The units can be operated either in the automatic mode, where the instruments will determine the cable end and fault position, or in manual mode where the operator has full control of all functions.

The automatic mode, in conjunction with the large 5.7” (145 mm) transflective color display, makes the PFL4E and PFL12E ideal for use in areas where speed, ease of operation, weight and economics are the driving factors.
Three-Phase Time Domain Reflectometer
Model MTD300
- Provides full 3-phase TDR-pulse echo capabilities
- Battery or mains operations
- Single jog-dial operation
- Logical menu driven performance
- Range: pulse echo 34 miles (55 km), transient 137 miles (200 km)

The MTD300 is a stand-alone 3-phase TDR designed to find faults in cable networks and provides several low-voltage and high-voltage methods of cable fault location. As a stand-alone TDR it provides full pulse echo capabilities, typically direct, comparison and/or difference between phases. TDRs can also be used to locate the position of “illegal” taps. Used in conjunction with an impulse generator and arc reflection filter (HV methods), the MTD300 provides arc reflection, arc reflection plus, impulse current and voltage decay (with a dc source) modes of fault location.

Portable 12-kV Sectionalizing Tool
E2-Restore Overdrive
- Rugged, compact and portable field instrument
- Automatic detection and localization of transformers
- Automatic cable end and fault detection
- Operation from integral battery or external 12 V/L A source

The E2-Restore Overdrive is a cost effective, portable, lightweight (47 lb/23 kg) and weatherproof sectionalizing tool. It is designed for rapid troubleshooting, easy identification and isolation of a faulted span or section of low- or medium-voltage networks.

The equipment requires little interpretation. Operation is controlled via a single jog-dial, an intuitive automated system or manual operation.

ADDITIONAL CABLE FAULT LOCATION SYSTEM PRODUCTS AVAILABLE FROM MEGGER

VLF 34 kV
The 34 kV VLF sinus tool is a lightweight, powerful low frequency ac VLF Tester, which features an exact sinusoidal wave shape and facilitates quick, easy and safe testing of power cables according to IEEE 400.2 & VDE 0276. (Other models and voltages are also available.)

SFX40
The SFX CFL and HV system offers up to 40 kV dc, 32 kV surge and burning up to 750 mA. Operation is via the integral TDR TI308. All parameters and menu selections are by way of a single jog-dial rotary knob.

Centrix
The Centrix is a completely integrated single- or three-phase system for fault locating and testing of power cables to international standards. The modular system offers surge energy of up to 2560 J, dc testing up to 80 kV, Insulation testing, ARM plus and the decay plus (optional). The Centrix system can be integrated with a VLF and/or a PD detection system.

Digiphone Plus
The Digiphone Plus is designed to pinpoint the exact location of cable faults using the acoustic and electromagnetic signals. By analysing these signals the Digiphone provides direction and “relative” distance to fault, all being displayed on a highly visible graphical display.

ACCESSORIES FOR CABLE FAULT LOCATION EQUIPMENT

Transit cases
These cases provide a safe and convenient way of transporting Megger cable fault location systems that share the same frame size and dimensions.

15-kV High-voltage Load Break Elbow
When space is restricted, the load break elbow (without extension cable) can be used. In this instance, the elbow is connected to the transformer in the normal way with the output cable of the CFL equipment being connected to it via the HV clips of the output cables.

15-kV High-voltage Interconnect Elbow/Pigtail
To connect to a cable, the HV interconnect elbow/pigtail is connected to the output cable of the CFL equipment via the output cable’s 10 mm MC connector.

High Voltage Vice Grips
These vice grips are ideal for use in areas where the connection point is corroded or where the clamps do not provide a secure enough connection. (Male) (Female)

High Voltage Clamps
These heavy-duty clamps provide a convenient way of connecting to the cable under test. Red (Female) Black (Male)

Mobile Power Source (MPS)
The MPS is a portable field proven mobile power supply for use where there is no suitable mains or generator supply available. It is a practical alternative where a “pure sine wave” with a low THD is required. The MPS, available in 120 or 230 V configuration, is ideal for powering any Megger instrument (typically PFLs, MIGs, dc HiPots, TRs and similar equipment), especially those that benefit from a clean portable power supply.

Discharge and Grounding Sticks
The Megger discharge and grounding sticks have a hook at the end which, when connected to the test piece, applies a resistance to discharge. The side hook applies a direct ground (earth) connection. The value and voltage rating of the resistor used for the discharge must be correctly rated for the capacitance and voltage of the test.

For information on products available from Megger, please visit www.megger.com.
Megger also makes high quality instruments for the following electrical testing applications:

- Insulation Testing
- Relay Testing
- Oil Testing
- Circuit Breaker Testing
- Power Quality Analysis
- Low Resistance Testing
- Battery Testing
- Watthour Meter Testing
- Transformer Testing
- Earth/Ground Testing
- Power Factor Testing
- Hi Pot Testing

Megger manufactures electrical test and maintenance instruments for electrical power, process manufacturing, building wiring, engineering services and communications.