A toolbox approach to fault location in LV power cables

Megger

Background

Low voltage (LV) power cable circuits (<600 V) are the backbone of electrical distribution systems in almost all parts of the world, with the notable exception of North America, where this function is typically provided by medium voltage (MV) power cable circuits (5 to 35 kV).

Nevertheless, worldwide there are many more LV cables in use than MV cables, which is one of the reasons that failures in LV cables are more numerous. Aside from the statistical inevitability of more failures occurring in LV cables simply because there are more of them, there are other contributory factors. These include the multitude of types of cable construction, the wide variation in splice designs and the variety of assembly and work procedures that are in use.

This wide range of variations in construction means that locating faults on LV cables can be challenging. Unlike MV cables, where the vast majority of problems are pinhole or flashover faults that can be found using just a small range of test methods, LV cables require a much wider range of faultfinding techniques. Traditionally, this has made it necessary to use several separate pieces of test equipment as, until now, there has been no integrated LV fault locating system on the market, even though integrated systems for use on MV cables are readily available.

Megger's positioning

Megger in Valley Forge USA started to offer its 4 kV EZ-Thump cable fault locator about ten years ago, followed by a 3 kV dual-capacitor version which was originally designed for EDF subsidiary ENEDIS (formerly ERDF), the French utility that operates much of France's power distribution grid.

Both of the EZ-Thump models are integrated TDR (time-domain reflectometer) based systems that adopt the 'tool kit' design concept. In a single device, they provide all of the technologies needed for fault location on LV cables and circuits of all types, with the exception of highly branched circuits. In practice, these exceptions are infrequent: it is estimated that 80 % of circuits worldwide are point-to-point circuits or circuits with very short T branches of around 5 to 10 m. The preponderance of these types of circuits means that TDR-based fault location technologies are preferred by many network operators.

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Despite widespread belief to the contrary, fault location on LV cables is by no means the same as fault location on MV cables but at a lower voltage. One reason for this is that almost all LV cables are multiconductor cables. It is important to understand the differences in the arrangement of phase and neutral conductors, cable design, insulating materials and, in some cases, the shielding and armor arrangements. These parameters, together with the resistance of the fault, influence which method of fault location is likely to be the most successful.

This article describes a step-by-step protocol for locating faults in LV cables, showing how this protocol was used in a real fault situation. The protocol is based on the use of Megger EZ-Thump 3 kV and 4 kV fault location systems.

The fault

The fault involved a section of four-conductor (three phase conductors, one neutral) residential LV cable with steel armor, as shown in Figure 1. The section of cable was approximately 100 m long and ran between two fuse cabinets (Figure 2). It serviced three homes, each via a T-splice. The splices were around 30 m apart.

Figure 1: Four-core LV cable with steel armor

	L1	L2	L3	N	AR
L1		5 kΩ	45 kΩ	<20 kΩ	X
L2			<2 kΩ	<2 kΩ	X
L3				<20 kΩ	X
N					X
AR					

Table 1: IR test results for insulation between unique combinations of conductors (N = neutral lifted, AR = armor bonded, X = measurements not performed)

Location protocol

Before fault location commenced, the fuses in each individual house service box within the cable section were removed (see Figure 2, where a typical box on the opposite side of the street is highlighted with a red arrow). Care was taken to maintain adequate clearance between the contact points in the fuse box (or termination box) so that the test voltage, which was higher than the normal operating voltage, could be safely applied.

1. The insulation resistance (IR) between all unique combinations of conductors, including the armor, was checked by applying 500 V DC and the IR measurements were recorded (Table 1).

Typically, the armor is bonded to the system ground (earth). In equipment that incorporates the F-OHM safety feature, the IR measurement is made in high voltage mode and requires a bond between HV return

Figure 2: Typical residential three-phase fuse cabinet

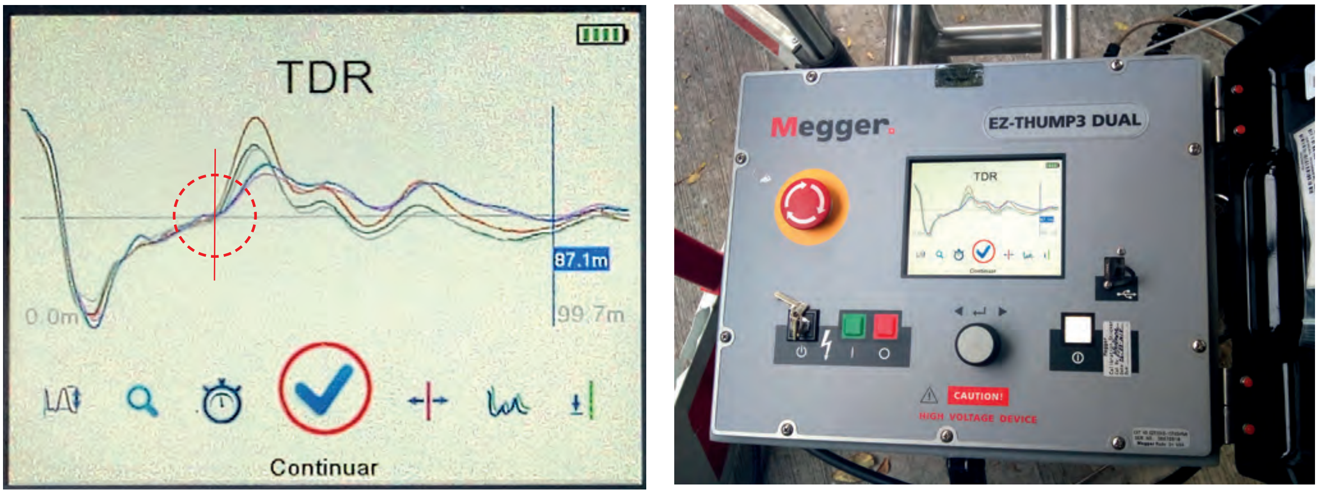

Figure 3: TDR traces, comparison of conductor pairs

and system ground (earth) to close the safety loop. All measurements are therefore made between the selected 'hot' conductor and the HV return, which is de-facto grounded. This is not quite the same, however, as a measurement between the selected conductor and the armor (i.e. L1 to L2 ≠ L1 to armor), as the measured paths are different.

In this particular case it was somewhat surprising that all of the IR values were between 50 kΩ and 2 kΩ, which is lower than expected. Theoretically there could have been cable faults in several different locations on all four onductors, but it was more likely that all of the faults were in the same location – in a splice, for example. This was the first indication that the cable fault was potentially in one of the T-splices.

2. A similar routine was adopted with the TDR, comparing the traces of all ten conductor pairs with each other, as shown in Figure 3.

Because the TDR mode is not an HV mode, it could be activated without the HV return bonded to ground, so the results reflect the true impedance between conductors and between all four conductors and the armor (= ground). The TDR could see the cable end at about 110 m, and the traces showed very good

Figure 4: ARM localization of fault

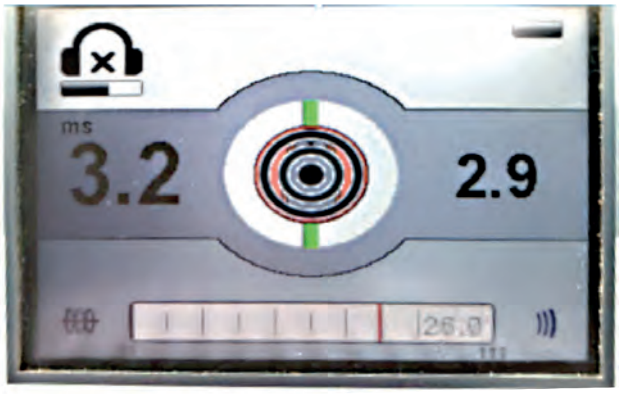

Figure 5: Bull's-eye image after pinpointing fault

Figure 6: Splice body is located and uncovered

superimposition from left to right as far as the vertical red line, which represents a distance of about 29 m from the connection point. At this distance, all traces (representing the conductor pairs) showed an increase in impedance to varying degrees. This corresponds with the measurement of different IR values between the pairs. This result confirmed the suspicion that all conductors had a fault at the same location, which was once again a strong indication of a possible failure in one of the T-splices.

3. For the fault under investigation, all insulation resistance alues were low, potentially preventing a flashover between two conductors, which would therefore make it impossible to use the ARM (arc reflection method) technique for fault location. However, it is always worth trying, because if it works, the ARM technique provides independent verification of the results obtained from the impedance comparisons between pairs.

In this investigation, the two conductors with the largest IR difference (L1 and L3) were selected in order to have the best chance of creating a flashover (see Figure 4). The capacitor of the EZ-Thump 3 was charged to the full 3 kV, which provides 500 J of surge energy. With the aid of an energy-efficient inductive-type ARM filter, the ARM fault trace showed the fault at almost the same distance – 29 m – as previously identified by the conductor pair comparison method.

4. It is always desirable, when possible, to pinpoint the exact fault location, which means placing it within an area of around 3 ft^2 (0.25 m^2). Because this fault delivered an ARM trace, it had to be flashing 'fault' and would therefore respond to the magnetic/acoustic pinpointing technology, which is also called the 'coincidence' method or 'thunder-and-lightning' method.

The EZ-Thump 3 was switched to thump (surge) mode at a voltage of 3 kV, delivering 500 J. Based on the TDR and ARM results and knowledge of the cable path, pinpointing was started at around 29 m and the exact fault location was quickly found, showing as a 'bull's-eye' on the display of the DigiPHONE+ Pinpointer (see Figure 5). The location of the defective splice is shown in Figure 6, and the splice itself in Figure 7.

Summary

The EZ-Thump 3 kV and 4 kV are fully featured cable fault locating systems based on the toolbox concept for use on LV cables of all designs and constructions. In the case described, four of the five fault location methods provided by the EZ-Thump were used successfully in a systematic fault location process. These were:

- IR testing mode
- TDR conductor pair comparison
- ARM pre-location
- Surge/thump pinpointing

The fifth method, the step potential or voltage gradient method, could not be used to pinpoint this low-resistance fault because the fault was in a splice and the armor was bonded to the metal splice case. Generally, this method cannot be used with armored cables.

As this example has shown, EZ-Thump test sets provide a convenient, effective and user-friendly solution to the challenge of locating faults in the huge variety of LV cables that are at the heart of so many of the world's power distribution networks.

Figure 7: T-splice showing 'trunk' cable and smaller 'branch' cable (feeding house service)

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