

**Cable Fault Location
on long HVAC and HVDC Cable Systems**

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SUMMARY

The history of cable fault location starts in the early last century. The physical principles are very good known and the techniques for fault location have been improved by using electronic and computer based systems. The costs for not transferred energy in case of failure in an export cable system are immense. Also the costs for fault location and repair are very high due to the challenge of long cables and laying condition in case of subsea cables.

This paper will not describe the basics of cable fault location in detail. The major task is to point out the limitations of the several methods and to provide adopted and alternative solutions.

KEYWORDS

Cable fault location procedures and technologies, Fault Pre-location, Low and high resistance fault location.

1. Cable Fault Location Procedure and Technologies

The process of cable fault location is general the same for land and subsea cables. Special requirements and conditions are determined by the cable design. It is obviously a big difference between HVAC and HVDC cable design, but also subsea and land cables have different designs. Laying conditions and the system design of HVAC cable systems are also influencing the procedures for fault location.

The generic cable fault location process is shown in Figure 1.

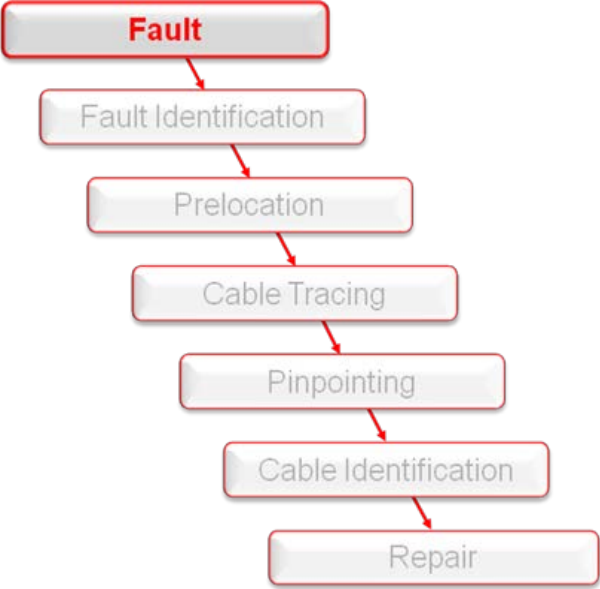


Figure 1: Generic Cable Fault Location Process

The detailed application of pre-location and pin pointing methods depends on the nature of fault, cable design and laying conditions.

Figure 2 shows the more specific course of actions.

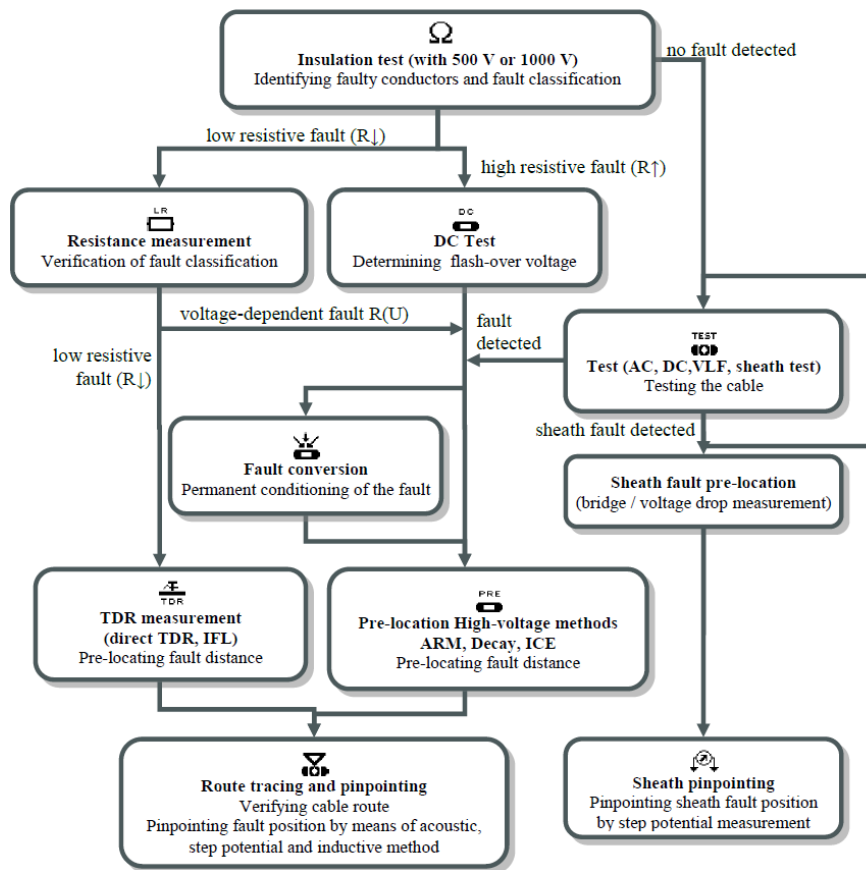


Figure 2: Procedure and methods for cable fault location

1.1 Fault Pre-location

Fault pre-location equipment shall provide the distance to fault as accurate as possible of the following types of faults.

1.1.1 Low resistance faults located with TDR measurement

Low resistance faults may be described as those that are of low enough impedance – from experience lower than 10 times of the cable impedance - that they cause sufficient reflection energy to be visible by a TDR.

The TDR measures the time between the output signal and reflected pulse.

The accuracy of the calculated distance to the fault l_x is strongly affected by knowing the exact propagation velocity $v/2$ of the TDR pulses.

$$l_x = t \frac{v}{2}$$

The propagation velocity for the specific type of cable should be determined by a measurement at a known length of cable or using a joint reflection with known distance as a reference.

The low pass characteristics of cables causes an attenuation and dispersion of the TDR pulses
 Figure 3.

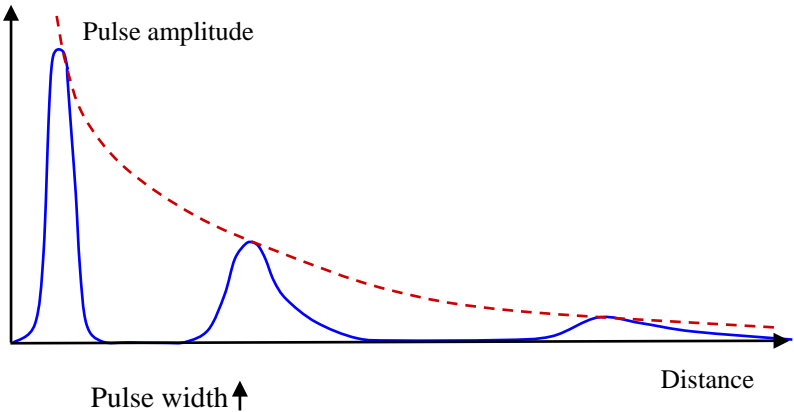


Figure 3: Attenuation and dispersion of TDR pulses

The TDR must have output pulses with a sufficient pulse amplitude and pulse width to cover long cable length.

It is very advantageous to compensate the pulse attenuation by a length depend gain adjustment (automatic and manually), to make small reflections from longer distances clearly visible, without over steering the signals from shorter distances Figure 4.

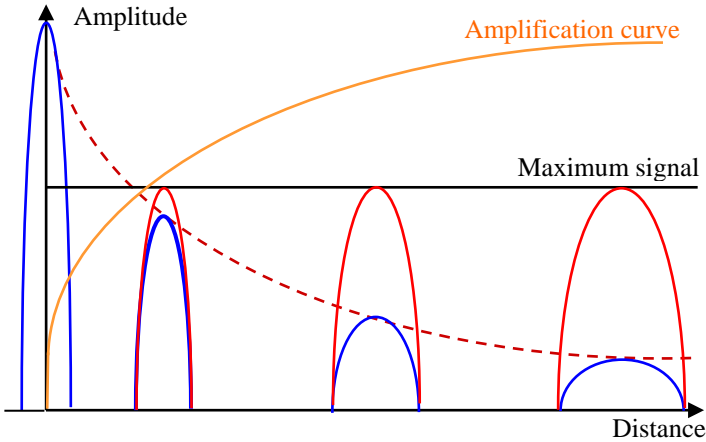


Figure 4: Principle of length dependent gain adjustment

With a well designed TDR the localization of low resistance faults on cable length up to 500 km is possible. For longer cables special external pulse generators with higher pulse amplitude and larger pulse width are commercially available.

TDR measurements should be used already during Commissioning of the cable system, to prepare a TDR “finger print” documentation. The cable length must be documented in defined cable sections and with an overview for the whole length Figure 5 and 6.

A suitable PC software should allow to retain these documentation indefinitely. The documented traces can be used as “healthy reference traces” in comparison to the traces in case of a fault event.

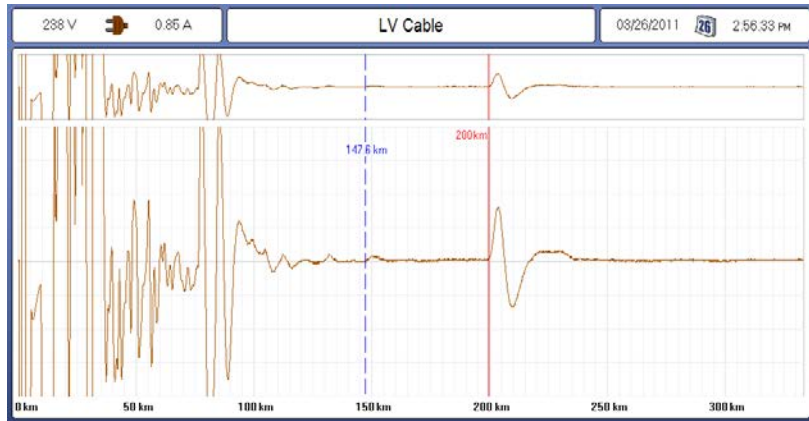


Figure 5: Overview TDR trace of a full 200km DC interconnect length.
 (Optimised to show far end, adjusted through use of length dependent gain adjustment)

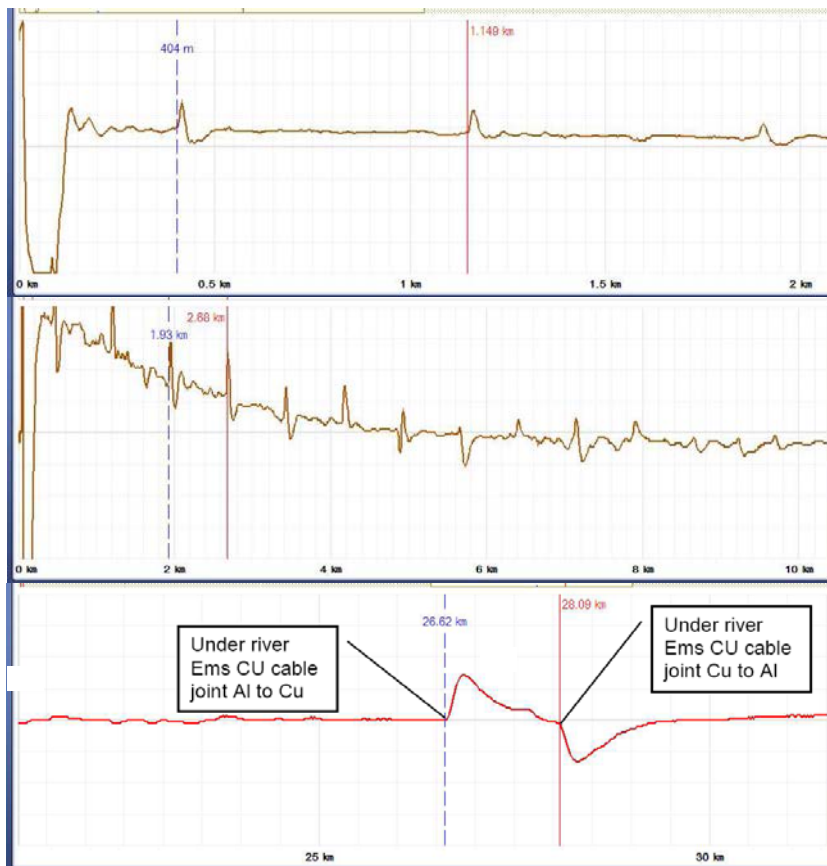


Figure 6: Detailed TDR documentation of the land cable section.
 The distinct reflections of the joints are impedance variations caused by the properties of the joint insulation material.

1.1.2 High resistance faults

High resistance faults may be pre-located using high voltage based methods such as ARM (arc reflection measurement), ICE, DECAY. Alternatively the fault has to be modified by a suitable burning system to become qualified as low resistance for normal TDR pre-location. Another option is bridge measurement technology.

Due to physical reasons the following methods are limited to locate high resistive faults with distances up to 40 km (in rare cases 50 km dependent on fault condition and cable properties).

a) ARM - Arc Reflection Method:

The fault is ignited by means of a high voltage discharge from a surge generator with sufficient high amplitude and the TDR pulses are coupled on the cable under test with a suitable HV Filter.

The coupling system must maintain the burning arc as long as possible to keep the fault low ohmic for the travel time of the TDR pulses. The temporary ARC must be low ohmic and stable enough to cause a negative reflection Figure 7.



Figure 7: Fault located with ARM at 32 km distance

The Arc burning time must be in case of long fault distances over app. 5 ms which is hard to reach and depends also on the fault condition.

Further the HV filter design should not reduce the amplitude of the HV pulse too much, to have a remaining HV amplitude at the fault position to ignite the fault. Inductive HV filters with a choke design have much better performance regarding fault ignition and stabilization than pure ohmic HV filters Figure 8.

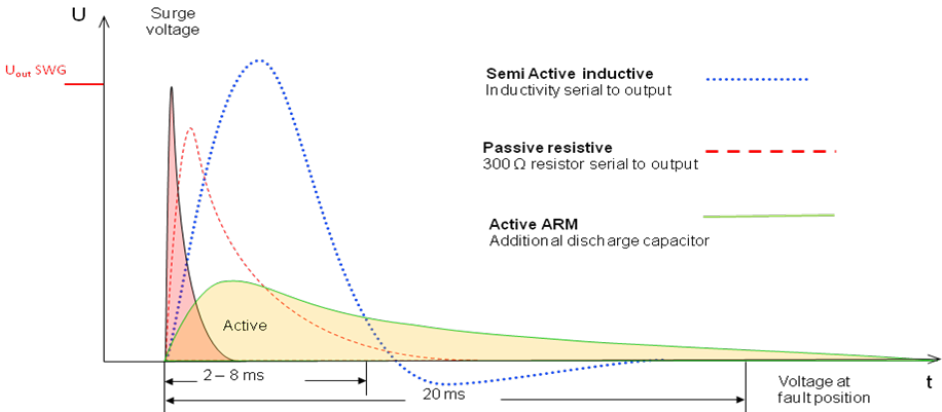


Figure 8: Arc stabilization voltage of different HV Filter design

Another real limiting physical fact for longer fault distances is the dispersion of the TDR pulses and the transfer function of the HV coupling unit. The strong dispersed TDR signals from longer fault distances would require a small value of the lower cut off frequency of the filter. But the cut off frequency cannot set arbitrarily low, because the energy transfer from the HV surge pulse becomes too heavy, which is impossible to be limited by voltage protection components to avoid damages at the TDR.

Nevertheless Arc reflection measurement is very useful for the land cable sections (which are normally not so long) and have a certain number of joints and the likelihood of workmanship failures is much higher than in the sea cable section.

b) ICE and DECA Y

Both methods are based on travelling wave principle.

ICE uses a surge pulse from the surge generator to ignite the fault. The current pulse caused from fault ignition must travel two times through the fault distance to create the travelling wave pattern Figure 9. That means the Arc at that fault position must burn double the time than at Arc reflection measurements. The Arc burnig time depends strongly on the fault condition and the surge energy. The fault ignition is better than at ARM, because there is no HF Filter involved.

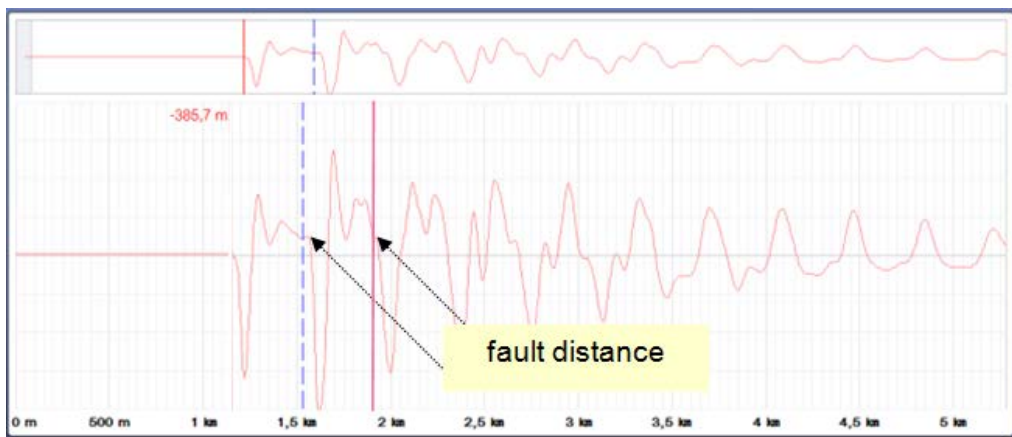


Figure 9: ICE Trace

DECA Y method is applicable in case the fault has a certain withstand voltage before flashing. Than the cable can be charged up to the flash over voltage and the travelling voltage transient is recorded. The condition for the Arc duration to obtain the travelling wave pattern is similar to ICE Figure 10.

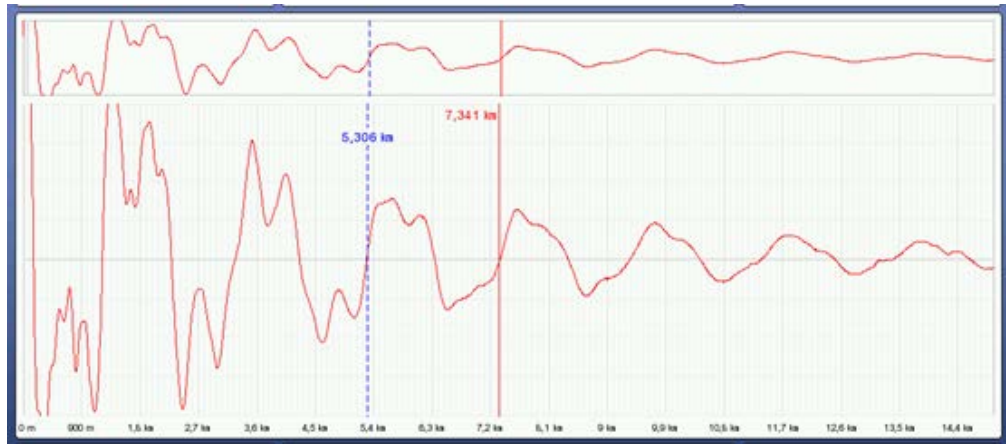


Figure 10: DECAy Trace

The Arc burning time is one of the most limiting factors for successful application of ICE and DECAy, but as well as the lower bandwidth thresholds of the coupling systems.

c) Longer distance faults located by TDR after fault conditioning with burning system

The assumption, that on long cables the high discharge energy in case of a service failure will lead always to low ohmic failures, is wishful thinking. It is known from several failures on DC cable systems in the North Sea, that the faults can often not be located directly only using a TDR.

To burn down a cable fault to low ohmic condition for TDR fault localization, a sufficient output voltage, to ignite the fault and high enough burn current to modify the fault is necessary.

A well proved burning system with 40 kV / 25 kVA is the most powerful cable fault location support device on the market Figure 11. The transformer is designed for continuous operation, which is very usefull in case of difficult faults. The 6 pulse rectifying system generates a perfect DC current with low ripple to maintain a constant burning Arc for efficient fault conditioning.



Figure 11: Burning transformer 40 kV DC / 25 kVA with integrated Rectifier

The cable fault may become possibly not permanently low ohmic, because of water ingress and other effects. To locate the fault pre and post burn TDR traces were overlaid and compared in the TDR. A small deviation between this traces is often good enough, to obtain a precise distance to the fault.

d) Longer distance faults located by bridge measurement :

The application of a Murray Bridge Method require for high accurate measurements that the faulty conductor and auxiliary conductor have absolute the same resistance.

In power cables the conductor resistances may deviate in several per mil and also connection leads and the loop at the far end are heavily influencing the accuracy. To overcome these problems the so called Graaf Method Figure 12 is most commonly used.

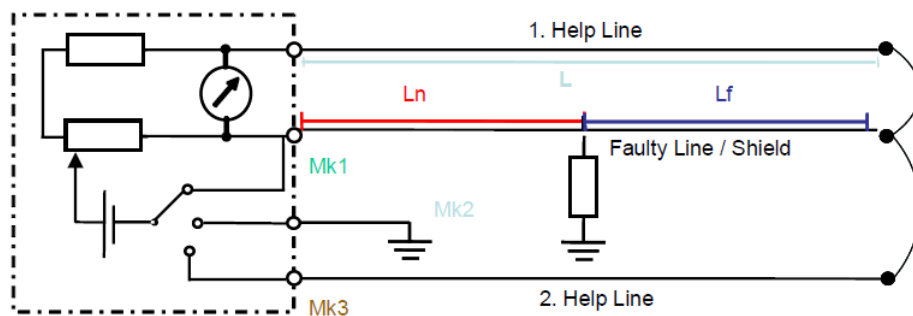


Figure 12: Principle of Graf Bridge

In AC cable systems the required two auxiliary conductors with good insulation properties are available by using 2 healthy phases.

But in DC cable systems only one auxiliary conductor is available, so that the Graaf Method is not applicable.

A way out of this situation can be achieved, when the resistances of the cable under test, of the connection leads and loop at the far end are exactly known. Then the connection leads and loop at the far end can be recalculated into "virtual length" correct calculation

Another version of bridge measurement is using the so called "voltage drop" method, to calculate the distance to the fault.

The advantage of the voltage drop method is, the auxiliary conductors can have totally different conductor sizes/resistances than the faulty conductor. That means, also the lead sheath/copper screen or armouring wires can be used to set up the bridge arrangement. A measurement with alternating bipolar voltage suppresses thermal contact effects and serves for a very accurate measurement.

The limitation is determined by the fault resistance and the cross section of the faulty core. In case of a high resistive fault the current through the fault is limited and create on big conductor sizes only a few μV voltage drop. The amplifier in the HVB 10 is able to detect such low values, dependent on noise conditions.

The pre-location of sheath faults with the voltage drop method is the most common and reliable technology. The values of cross section of screens are much lower than those of main conductors and a very good accuracy is achievable.

e) Interrupted cable

The TDR can locate open circuits easily similar to low resistance cable faults.

f) Sheath faults

Sheath faults are detectable on land cables with insulating outer sheath, when the lead sheath/copper screen is disconnected from ground. Pre-location is performed by the above described voltage drop measurement. Pin pointing is easy by the classical step potential measurement using ground spikes and the digital earth fault indicator. The step potential is created by the leakage current to the ground.

In case of armoured cables the outer protection, it is normally not isolating. An isolating layer between lead sheath/copper screen and armouring can be tested similar to outer sheath test. In these cases only a pre-location will be possible.

Pinpointing of cable faults on sea cables with step potential method is most likely not possible, because the armouring prevents a local leakage current to the ground.

1.2 Fault Pinpointing

Fault pinpointing equipment shall be provided using at least the following methods.

1.2.1 Acoustic location

Acoustic pinpointing is a method used in conjunction with a surge generator.

A surge wave receiver should have a background noise reduction technology and display besides the acoustic signal also the magnetic impulse generated by the surge generator. When the audio and magnetic signals are co-incident or near co-incident the detector is above the fault. In the event there is no audio signal detectable as is sometimes the case, the magnetic signal may indicate the fault location depending on fault characteristics.

Land cable:

Faults in direct buried cables can be located by acoustic methods without any problems. More experience is needed in case the cables are installed in ducts or pipes.

Sea cable:

Currently there is no surge wave receiver available for deep water application. To develop a new specific solution would cause R&D costs of about 30.000 up to 40.000 Euro.

That solution needs to be discussed in the WG to find out which number of units is the market potential..

From our experience of subsea fault location it is known, that the flashover noise can be identified without any equipment, if the cable is lifted up in the pre located area.

