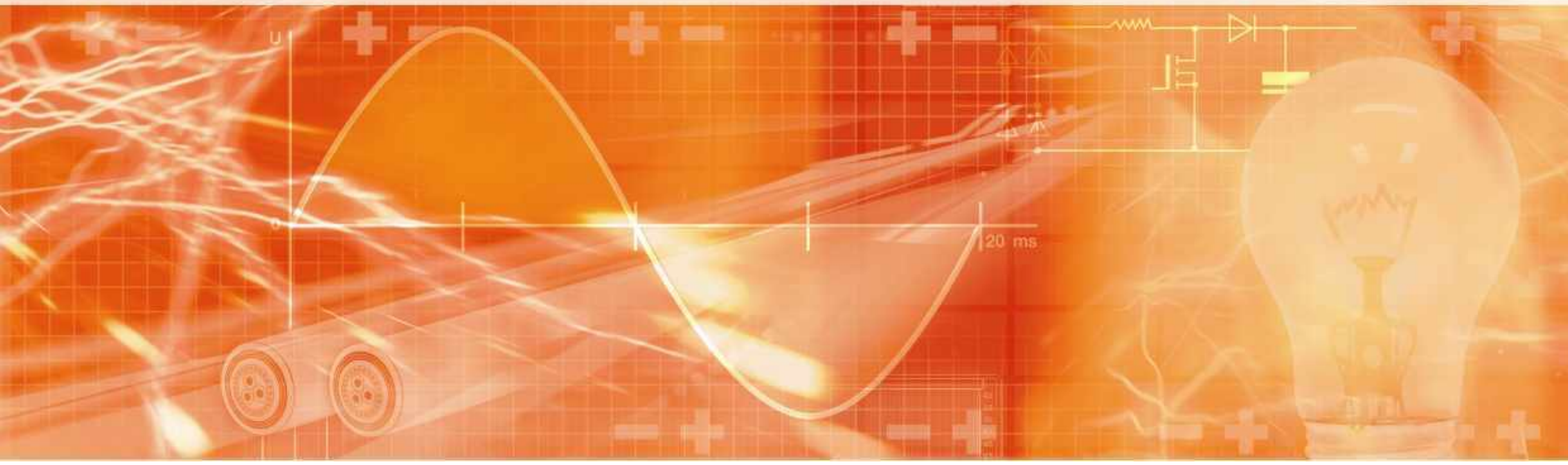
Sheath fault location on power cables



Sheath testing,
Sheath fault location
and
Location of earth faults

sebaKMT

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1. Introduction

Since many years the main reason of faults in cables with plastic insulated outer sheath is the damage of this sheath. This permits the penetration of water into the cable and as a consequence it enhances the growth of „Water Trees“ and other corrosion based damages in power cables. Water trees are one of the primary reasons of cable faults.
In communication cables the ingress of water significantly reduces the transmission quality which is in today's high performance data transmission requirements almost equal to a loss of the line.
In cables, which are not protected against longitudinal water migration there is the additional danger of joint faults due to water spreading though the conductors into the joints.
The following article describes the different test procedures for plastic insulated and the prelocation and pinpointing of sheath faults.

2. Why Sheath testing

A perfect, non disturbed operation of a cable system requires in addition to the stated requirements for data transmission and energy transfer, good insulation values between the conductors as well as between conductors and shield. Prerequisite for this is also the intact outer sheath (Jacket), which is today mostly consisting of PE.
The damage statistics of cable faults published in the recent years, especially for medium voltage cables, indicated a significant amount of sheath faults, which were obviously the triggering cause for a breakdown of the cable.
Resulting the sheath testing permits in a certain context also a diagnostic information about the condition, resp. the expectable state of the cable

Additionally the sheath test is one oft he most important tools in combination with all diagnostic technologies, since a diagnostic evaluation of a cable requires that the cable to be tested has to be in a good and faultless condition

A diagnose without a combined sheath test is a relatively unreliable valuation of the cable condition, since entering water as a result of a sheath fault and the following damages result in a fast decrease of the condition quality.

This again will decrease the value and reliability of any diagnostic evaluation

Fig 1: Cable with sheath faults

The test of the integrity of the outer sheath provides almost the ideal condition for the early detection of damages and provides the possibility of an early elimination of beginning cable faults.
With a simple insulation and voltage breakdown test between cable shield and outer soil, it is already possible to conduct a commissioning test directly after laying and to confirm the integrity of the outer plastic sheath.
With regular tests, especially in areas with high construction activities, it is possible to detect damages of the outer sheath at an early stage, where an immediate repair will prevent further damages, and where it is still possible to locate the cause of the damage and to claim an according compensation.

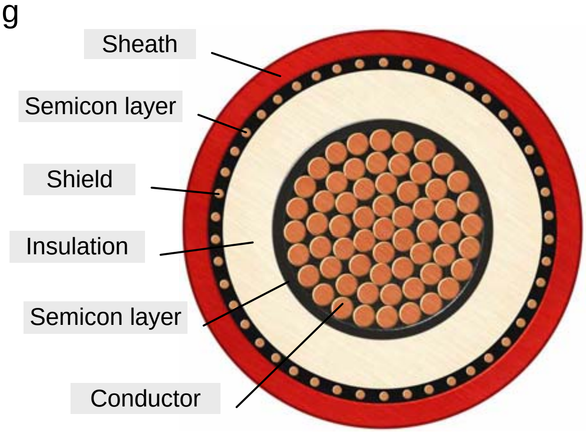


Fig 2: Cable construction details

A sheath damage, if not associated with a direct damage of the cable insulation, will seldom lead to a fast breakdown and failure of the cable installation. From the moment of damage until the appearance of the real breakdown, many months or even years can pass

If the sheath is damaged by a manual impact or a by penetrating stone, the shield beneath can be driven more or less through the semiconducting layer into the insulation. In this location the homogenous field distribution is distorted and partial discharge sources develop. This partial discharge will then, depending on its intensity, destroy the insulation and lead to a breakdown

2.1 Sheath test devices

For the testing of the cable sheath High voltage generators with an adjustable voltage of 0 to 5 resp. 0 to 20 kV can be used. The commonly available insulation testers, which are sometimes recommended for this purpose by some local regulation are not usable for such a measurement, since they do not provide a current measurement and the measured insulation values are not based on sufficient criteria, like current and voltage. Most likely an insulation test with 1 kV will not reveal a problem!
The test voltage should be applied continuously for a test duration of 10 minutes, which is not possible for a normal insulation tester. There should be an adjustable limitation of output power / current, or at least a possibility to control this, to avoid an over current during a sudden breakdown of an insulation fault, which could result in further damages of the cable and especially its semiconducting layer.
On the other side, the output power of the HV Test Generator has to be sufficient, to serve the high cable capacity as it exists in long cables, because in this case the high leakage current may lead to a breakdown of the test voltage due to an overload.
As Sheath test generators, there are models which can deliver several milliamps test current. The supply of these unit happens through integrated rechargeable batteries as well as from mains supply. For the field use in new, un-commissioned systems, a battery operated, mains independent system is certainly the better choice, since a mains supply is seldom available. Combination units, which are capable to deliver a test current of several 100 mA will normally also provide the possibility of prelocation and pinpointing of sheath faults.

2.2 Norms and regulations for sheath testing

The testing of cable sheaths is regulated in different norms, IEEE, IEC 60229, VDE 0276 part 620 and part 632, also their Harmonised document HD 60602 and 60632
The VDE specifies the following details:

Voltage tests at the cable sheath		
Test Voltage	Test Level	Test Duration
DC at cables acc. to VDE 0276 Part 620 (Extruded cables from 6 to 36 kV)	PVC–Sheath 3 kV PE – Sheath 5kV	Not specified
DC at cables acc. to VDE 0276 Part 632 (Extruded cables above 36 to 150 kV)	5 kV	1 min

2.3 User definitions

Several local power utilities have already defined own regulations for sheath testing, where the main idea was to define measuring criteria.
Connected with this test is a „quality test", which has to be proven by external contractors.
This factory norm operates outside the normal regulations and defines more details, that are shown in the following table below. The test duration for this test is defined with 10 minutes.

Cable length		Leakage current	Leakage current
Metres	Feet	PVC	PE
50	164	0,04 mA	0,001 mA
100	328	0,08 mA	0,002 mA
250	820	0,2 mA	0,005 mA
50C	1640	0,4 mA	0,01 mA
750	2460	0,6 mA	0,015 mA
1000	3280	0,8 mA	0,02 mA
2000	6560	1,6 mA	0,04 mA
5000	16400	4,0 mA	0,1 mA

Fig. 3: Permitted leakage current for new installations

Here it has to be observed, that an increased amount of joints, the ageing and other influences will have a direct impact on the measured current. This means the values shown in [Fig 3.] are to be considered for a new installation, with typically one joint per 500 m.
For aged installations, the condition must be considered in the evaluation of the current.
Requirement for a sheath test is a continuous insulation of the shield through the sheath against the surrounding soil. Earth contacting joints and armatures are not permitted, since these will conduct the test voltage to earth.
The insulation condition or the electric strength of a shield resp. sheath against earth is easily determined and requires no extensive test instruments. Depending on the insulation material of the cable, but also according to the above described factory rules, DC voltages from 3 to 5 kV (partially 10 kV and more) are connected between the metallic shield and operational earth and the measured leakage current or the insulation resistance is evaluated
In many international applications, voltages up to 10 kV are already standard.
This value depends also on the construction of the cable sheath, where in some cases, for example in HV Cables with a thick sheath, the common 5 kV are insufficient to bridge the thick outer sheath of high voltage cables.

2.4 Conducting the test

The test voltage is connected in such a way, that the negative potential is connected to the shield, and the positive will be connected to earth. Even if polarisation effects are rather rare it is recommended, to maintain this polarity to enable the reproducibility of the measurements. An exception is the bipolar measurement of the new MFM 10.
The typical recommended test duration is 10 minutes. Are the measured current values above the described values, and resulting, the insulation resistance values below the permitted limits, the cable should be investigated more detailed or at lest tested in sorter, regular intervals to check for changes.
After the connection oft he sheath test set, the test voltage is slowly (maximum 1 kV per second) increased to the typical test end value of 3 resp. 5 kV.
During the increase, it is very important to observe the charging current of the shield. Sudden changes or just one single fast increase of the current are a clear indication of a sheath fault
After reaching the nominal test voltage level, single flashovers during the 10 minutes test duration are not always detected, since the observation of an analogue measuring instrument requires a lot of concentration
Some of the flashovers happen only once, due to the fact that one single flashover will already interrupt the fault or will dry it up, causing it to appear like an intact cable sheath. This will happen especially in long cables where the charged cable capacity contains sufficient energy, to dry up the fault during the flashover.
Here sheath test systems are preferable, which indicate a single flashover also in the case, where the unit discharges the shield and switches off after the preset test duration.
For this purpose, the new MFM 10 will automatically record and indicate all these events in the test protocol

2.5 Safety

The discharge and grounding of the sheath test system and the connected shield should receive special attention.
The shield capacity, fully charged, contains a dangerous energy and can provide a high personal hazard.
A shield capacity of app. 1200 pF / m results for a cable lengths of 1000 m in a complete shield capacity of 1.2 µF. This is a charge of 15 Joules, an energy amount that has to be considered as highly dangerous when touched.

[1] $$P = U^2 \frac{C}{2}$$ J or Ws

On the other side, this charge is too small to cause further damages at the fault position.

Also for operation within these specific applications, there is the same potential danger and resulting the same safety rules as for any operation will apply.

For the sheath testing, prelocation or pinpointing of sheath faults it is required to disconnect the cable shield on all ends of the cable. Since a cable shield may carry a dangerous voltage potential, it is important to perform the connection (As well as the disconnection) only on a discharged and grounded shield.
The sheath tester must be only powered up, after all connections have been performed!

Like for any other operation in high voltage environment the 5 safety rules apply!

1. Disconnect power
2. Secure against reconnection
3. Check that there is no voltage
4. Make an earth connection and a short circuit
5. Cover or block access to adjacent components which are energised

3. Sheath fault prelocation

To avoid a long time duration for the pinpoint location procedure, especially on longer cables and solid surfaces, it is always recommended to do a prelocation. Without prelocation the time for the location can consume quite some time, thus also extending the thermal load by on the fault which includes the risk of drying it op, before it has been located.

For the prelocation of sheath faults on cables, high voltage measuring bridges of different type in varying connections can be used. But these measuring bridges and their methods require voltage proof technologies, because the measurement can go up to 10 kV.
Usual bridges operate with voltages up to a maximum of some 100 Volts, a voltage level, which is for the location of sheath faults only seldom sufficient. Another method is the comparison of the ratio measurement, which evaluates the current, voltage and resistance before and after the fault position and converts this ratio to the cable length

For this method, the voltage drop of both cable parts and its according partial test current is measured.
Due to the very high resistive Measurement, the measuring current can be comparatively low, which makes the complete measurement almost independent from resistances in the measuring path. Due to this low current, the risk of changing the fault or drying it up is negligible.
The following described Voltage-Drop-Method in a specific circuit version proved its performance in many thousands of measurements during the past years.
This method does not require any complex measuring instruments or technologies and characterises itself by a most simple calculation process. A modern version determines the fault distance already automatically as soon as the cable length is entered.

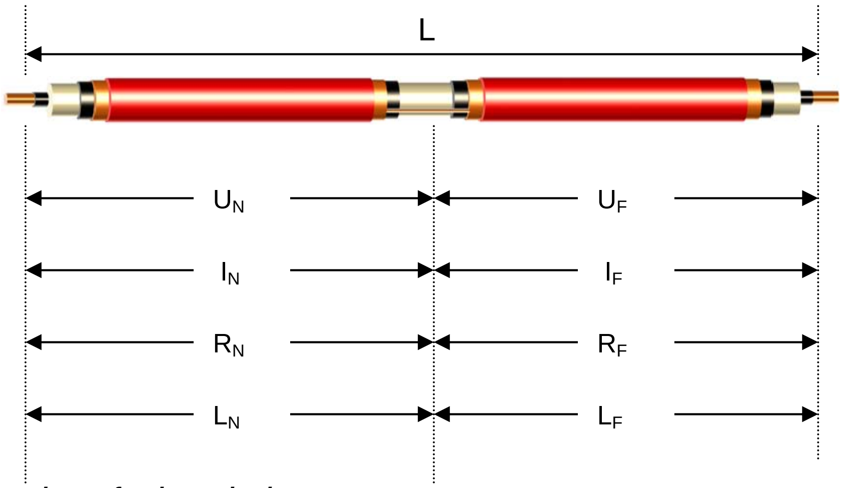


Fig. 4: Comparison of ratio method

Definition of details as shown in the above Fig. 4.
Characters like L describe the according value in respect to the complete length, while the appendix N stands for the distance from near end to the fault position and F represents values in the section from the fault position to the far end.

3.1 *Prelocation with the comparison or voltage drop method*

According to Figure 5, a constant current source **G** is connected between shield and ground. For this procedure, the shield at both ends of the cable to be tested must be disconnected! The current flow is though the fault resistance $\mathbf{R_{fault}}$ via the surrounding soil back to the generator ground.
The current flowing in the route part $\mathbf{L_N}$ (Cable begin to Fault position) results in a voltage $\mathbf{U_N}$ in the size of some millivolts on the shield resistance.
For "test leads" it is possible to use the core of the "faulty" cable and/or core and shield of a second cable of the same system.

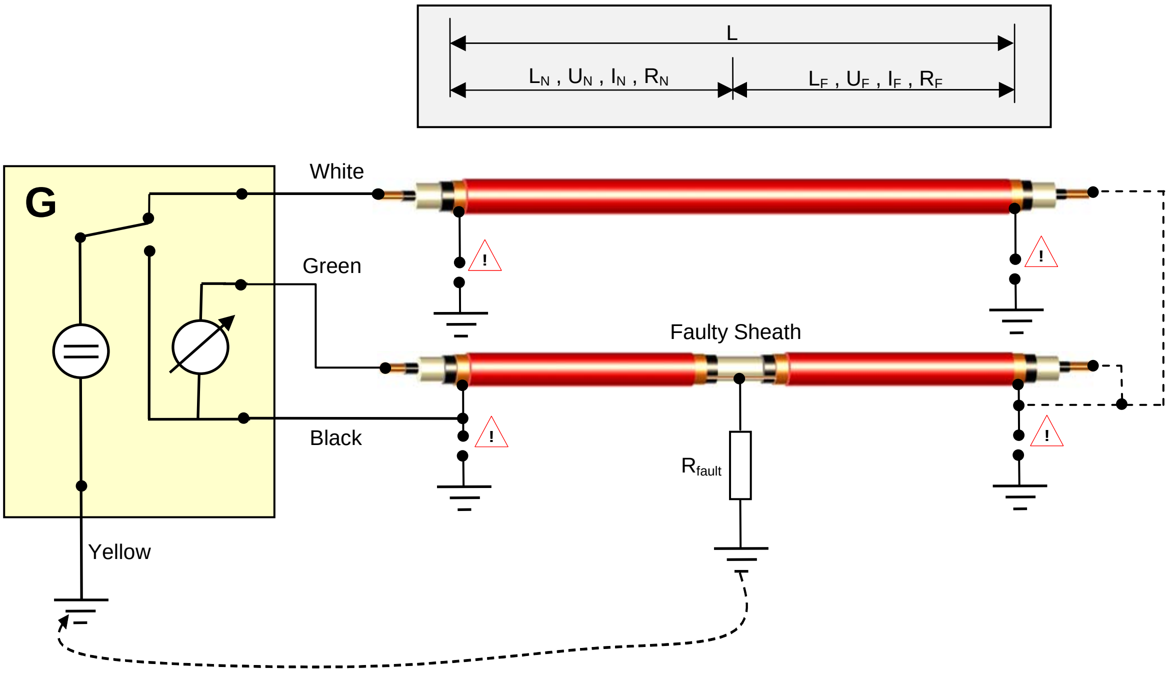


Fig. 5: Principle of prelocation

The voltage drops on the resistance of these" test leads" and the contact resistances of the connection points are negligible, since the measurement system has a high resistive measuring input, and do not need to be included into the calculation of the fault distance.
This one of the major advantages of the voltage drop method in comparison with bridge based procedures.
In a second measurement, the constant current source is now connected though one of the auxiliary lines through the shield at the far end and the fault resistance $\mathbf{R_{fault}}$ via the surrounding soil back to the generator ground. The voltage $\mathbf{U_F}$ is now measured at the shield resistance of the route part $\mathbf{L_F}$. The two partial voltages have the same ratio as the two distances L_N to L_F.
According to the following equation [2] the fault distance L_N can be calculated as follows.

$$[2]...L_N = L\frac{U_N}{U_N + U_F}$$

The only requirement of the voltage drop method is a constant, identical current for both measurements. Small deviations between the two test currents will reduce the accuracy
For this there are two solutions available.
The first is solved with the state of the art electronic supply, which provides an accuracy of the regulated constant currents, much higher than required for the stated accuracy.
The second additional solution is the use of calculated resistance values instead of the voltage drop only. By converting the voltage drop into resistance by simultaneous measuring of current and voltage at the shield of the cable, the resistances of the partial sections can be calculated.
The equation for this process is as follows.

$$[3]...L_N = \frac{R_N}{R_N + R_F}$$

A requirement for small measuring deviations are low resistive connection at the cable ends, since contact resistances will add to the line resistances and may cause deviations in the measuring results.
In case of several sheath faults at the same cable, error measurements are likely, but field test have shown that a careful increase of the test voltage locates the fault with the lowest breakdown voltage first. After the location of this fault the further increase of the voltage will then allow a second sheath fault location. In this case the result will show the distance between the two faults, which very often is an average of the complete cable length.
Therefore, special attention is required if the measured fault distance is similar to 50% of the complete cable length.

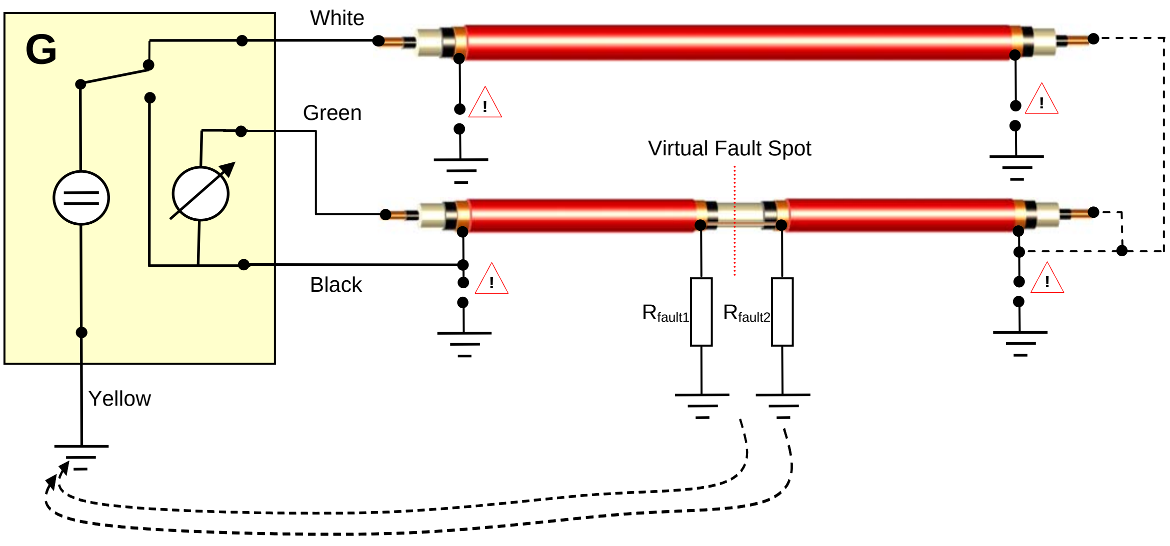


Fig. 6: Multiple faults

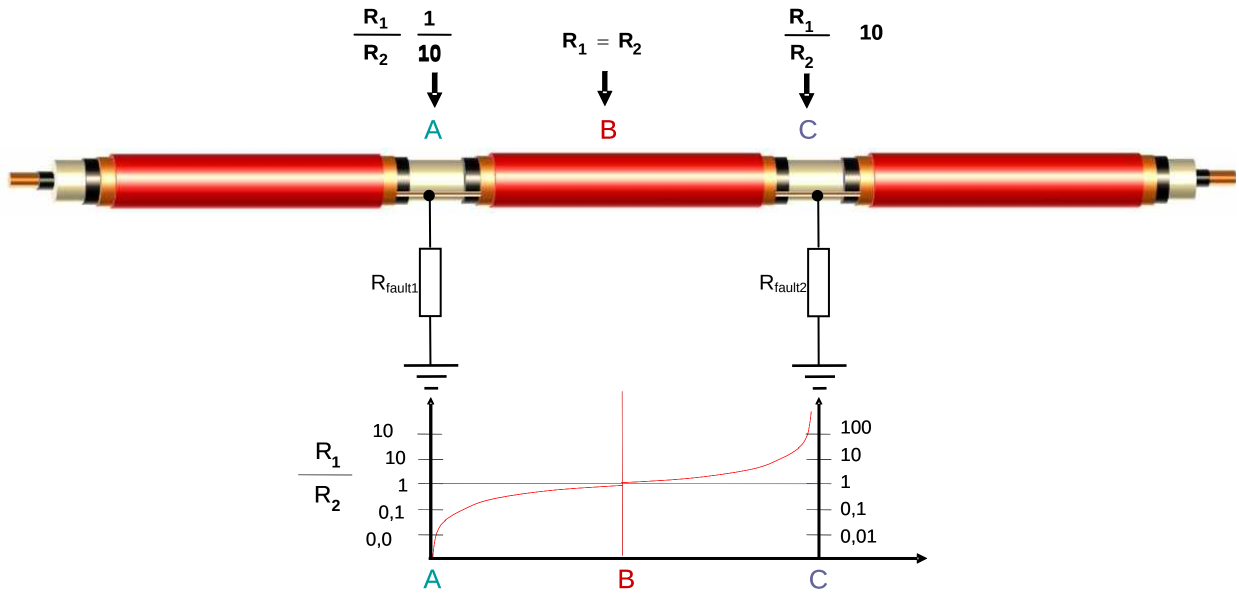


Fig. 7: Multiple Faults – Trend of the display to low resistive faults

3.1.1 Bipolar Measurement of the voltage drop

To increase the accuracy of the voltage drop method, the MFM 10 provides the possibility of a bi-polar measurement. This bi-polar measurement is used to eliminate thermo-electrical and galvanic effects

Thermo-electrical effects are a result of temperature differences in the conductor and will result in a polarised offset voltage on top of the real measured voltage and may falsify the test results. Galvanic effects appear by chemical elements, which are included as metallic ore or as salt in the soil that functions as return for the current. In combination with humidity and the flowing current, they will also generate a voltage which may have an influence on the measured results

With the bi-polar measurement, these effects can be detected and then eliminated by an according correction of the results.

3.1.2 Advantages and disadvantages of the voltage drop method

Advantages of the voltage drop method are:

- Much less error-sensitivity compared to the bridge-based methods resulting in significantly higher accuracy of the prelocation results.
- High sensitivity
- Independency from the resistance of the supplementary wires.
- Independency from the difference in sheath and core conductor resistance.
- No need for manual and tedious corrections using equations and a pocket calculator.
- Fast measurements – no moving parts. No need for time-consuming bridge balancing adjustment using a high precision and motor-driven potentiometer and corresponding readout facilities, which cause significant efforts.
- No sensitivity to contact resistance of the test leads

Disadvantages:

- No direct detection of multiple faults

3.2 *Prelocation with a measuring bridge*

3.2.1 Prelocation

In opposition to the voltage drop method, in bridge measurements the resistance value is used for the evaluation.
For plain resistance measurements it is required to eliminate any external influence. Important is a very good contact between measuring bridge and test object. The contacts points have to be carefully cleaned and the contact itself should be done with screw clamps, and not with clips.
The bridge technology requires a very homogenous line resistance, meaning that the resistance per length unit has to be a constant parameter. For older cables, water ingress and the resulting changes of the cross section due to corrosion of the cable shield may result in resistance in-homogenities.
Similar problems appear, if the cable shields of several segments are jointed inside the joint by a wire with a smaller cross section. Here it has to be as well expected, that the measuring result is of lower accuracy.
In the case of cables with graphitized outer sheath, (semiconduction sheath) the fault resistance is typically lower. The return current flow happens primarily via this layer, and not through the soil.

3.2.2 Prelocation with MVG 5

The prelocation of sheath faults can also be done with a HV Fault location bridge. In this case a good shield of the system is used for the bridge circuit. The according circuit setup is shown in the following fig. 8.
In this case the supply for the high voltage can be delivered from any suitable external high voltage supply.

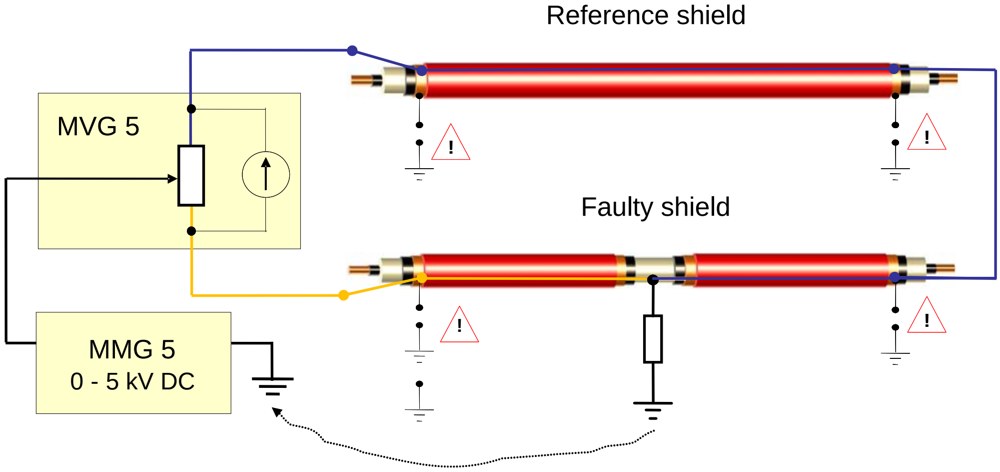


Fig. 8: Principle of a measuring bridge

After the bridge adjustment, the distance is evaluated from the percentage according to the equation [4].

$$l_x = 2 l_g \frac{M[\%]}{100} \qquad [4]$$

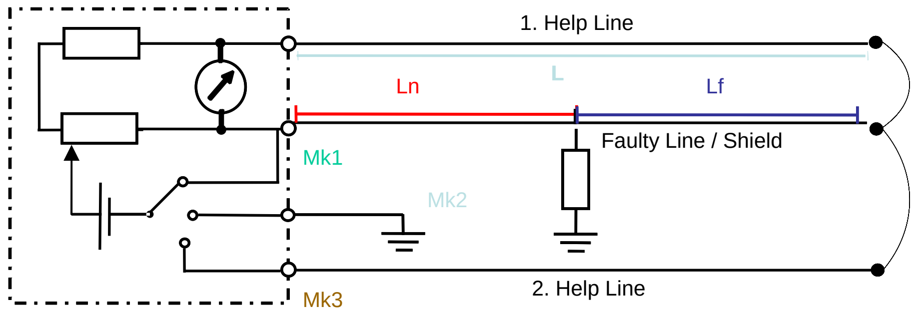
3.2.3 Two wire measurement according to Murray

For longer three phased, single core cables in the kilometre range, the two wire measurement according to Murray can be used. Strict requirement is, that the specific resistance of the “good” shield is equal to the on of the fault shield. And the good shield must undamaged without any sheath faults, which due to practical experience rather seldom.

$$L_X = L \frac{M\,[\%]}{100\%}$$

3.2.4 Three wire measurement according to Graaf

If no good shield is available or if the prelocation is done on three cored cables, the three wire measurement according to Graf has to be used. In this case the insulation resistance of the good wire (Help Line) has to 1000 times higher than the faulty line resp. sheath.



$$L_X = L \cdot \frac{M_{K2} - M_{K1}}{M_{K3} - M_{K1}}$$

Fig 9: Principle of a Graaf bridge

A difference of diameter or resistance parameters between good and faulty line is permitted.

In case of short cables, the test leads will influence the measurement

Three measurements have to be done with:

Earth at the begin of the faulty sheath	Mk1
Earth to ground:	Mk2
Earth at the begin of a good line:	Mk3

$$L_X = L \cdot \frac{M_{K2} - M_{K1}}{M_{K3} - M_{K1}}$$

If no zero adjustment is possible, the result can be corrected by switching the connections for Measurement M_{k2} or M_{K3}.

M_{k2} = 200 - $M_{k2'}$ (connection white lead – red lead switched)

M_{k3} = 200 - $M_{k3'}$ (connection black lead – red lead - 2. help line switched)

In this case the following equation is valid:

$$L_X = L \cdot \frac{200 - M_{K2} - M_{K1}}{200 - M_{K3} - M_{K1}}$$

3.2.5 Advantages and disadvantages of bridge methods

Advantages are:

Disadvantages are:

Bridge measurements are directly influenced by:

- The amount of the current flowing in the bridge circuit
  - a. The accuracy of the measurement depends on the size of the measuring current.
  - b. Sheath faults require some voltage and current to overcome the insulation and galvanic and resistive influences of the soil.
- The loop resistance
- The matching for power transfer of the internal impedance of the galvanometer to the bridge resistance
- The sensitivity of the galvanometer
- Linearity of measuring potentiometer
- The contact resistance of all test leads will influence the measurement accuracy.
- No detection of multiple faults

4. Sheath fault pinpointing

4.1 The different methods

For the exact pinpointing, there are four different technologies available

- DC Impulse-Method
- Surge Impulse Method
- Audio Frequency method with direct or capacitive coupling
- Audio Frequency method with modulated frequency 4.8 Hz

All methods are based on the evaluation of the voltage gradients within the fault position, which can be measured with these different methods and their probes. The different methods have specific advantages as well as disadvantages, which are not so much a question of quality and accuracy, but more related to the fault area situation, as underground and surface condition, and the thermal stability of the fault itself and resulting the ability to manage these influences

4.2 Voltage gradients

The voltage gradients in the area around the fault consist basically of concentric circles. The correct interpretation of there gradients is the base of a successful location of the earth fault.

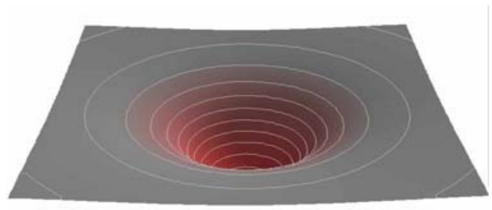


Fig 10: Voltage gradients around the fault

The circles indicate areas of equal potential, and are called equipotental lines. The closer to the fault, the higher is the measured step voltage potential. If an earth fault probe is inserted into the ground in a way, that both earth electrodes (earth spikes) are on the same equipotental line, the probe will not see any potential difference. As result, the indication will be zero. This happens also, if the fault is directly between the electrodes. But it will also happen if the electrodes are above the centre of the fault, or half way between fault and ground connection. Similar effects can also be observed around the earth rod which is used to provide the ground connection at the connection point of the transmitter. There the return signal produces the voltage gradients.
If the earth fault probe is moved away from this earthing point towards the fault, the displayed signal will decrease until the midpoint between earth rod and fault is reached.
At this point the signal amplitude will have the absolute minimum.

Continuing to move further towards the fault will increase the signal.
70% of the signal are measured at the last third of the distance.
The measured signal strength is proportional to the amount of voltage gradients between the earth spikes. The maximum signal is displayed, when the spike is directly on to of the fault.

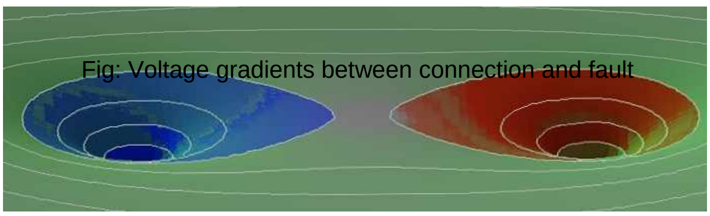


Fig 11: Voltage gradients between the two earth contacts

4.3 The DC Method

The DC source in this case is like for the sheath fault prelocation, a small DC burner down unit with adjustable current limitation. The maximum output voltage range can be set to1, 2, 5 or 10 kV, depending on the required or allowed test parameters.
The fault location is done as follows
The sheath test device is connected to the screen of the faulty cable and to the operational earth / ground.

Fig. 12: Principle of the pinpointing with voltage gradients

As described in the Fig 13, the output voltage of the sheath tester forces a current through the shield via the fault and back through the ground to the ground connection of the tester.
The resulting voltage gradients at the earth contact of the fault resistance R_{Fault} are then detected and measured with two earth rods, which measure the value of the voltage as well as its polarity.
For the localisation of the voltage gradients, the earth rod a stuck into the soil, and the voltage is measured.

For a higher sensitivity, the distance between the two earth rods can be multiples of 10 m at the start of the location. Close to the fault the step voltage increases to a maximum with a defined polarity. Here the distance can be reduced to some decimetres or centimetres. If both earth rods are inserted in the same distance to the fault, the different polarities of the voltages compensate each other, resulting in a zero Volte display, indicating, that the fault is exactly in the centre between the two rods. Then the procedure is repeated in a 90°angle to the cable route, and by the same procedure a second zero point is measured. The crossing point of these two measurements is directly on top of the fault. The accuracy of this method is in the centimetre range, and no other technology can reach this accuracy.

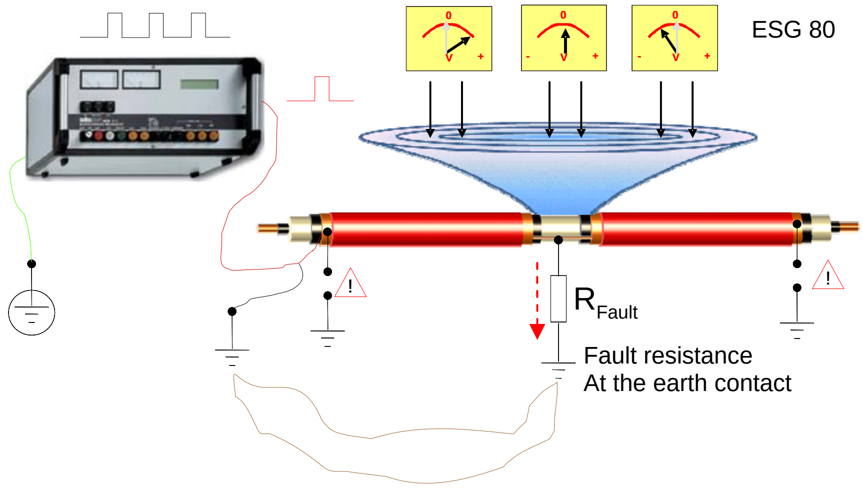


Fig. 13: Pinpointing

There is not always the possibility to measure directly on top of the cable route, since the road surface is often insulating, and the earth rods cannot provide a solid earth contact.
(The drilling of holes to make contact is not always permitted and will increase the time for the locating process).
In this case it is also possible to shift the whole measurement sideways to the unpaved area of the road, due to the fact, that the significant voltage gradients have range some ten metres.
At the side of the road, there is always chance to use the free accessible soil, gaps between stones or between plates to determine the centre of the voltage gradients. The longitudinal coordinate can then be determined by normal tracing with audio frequency locators.

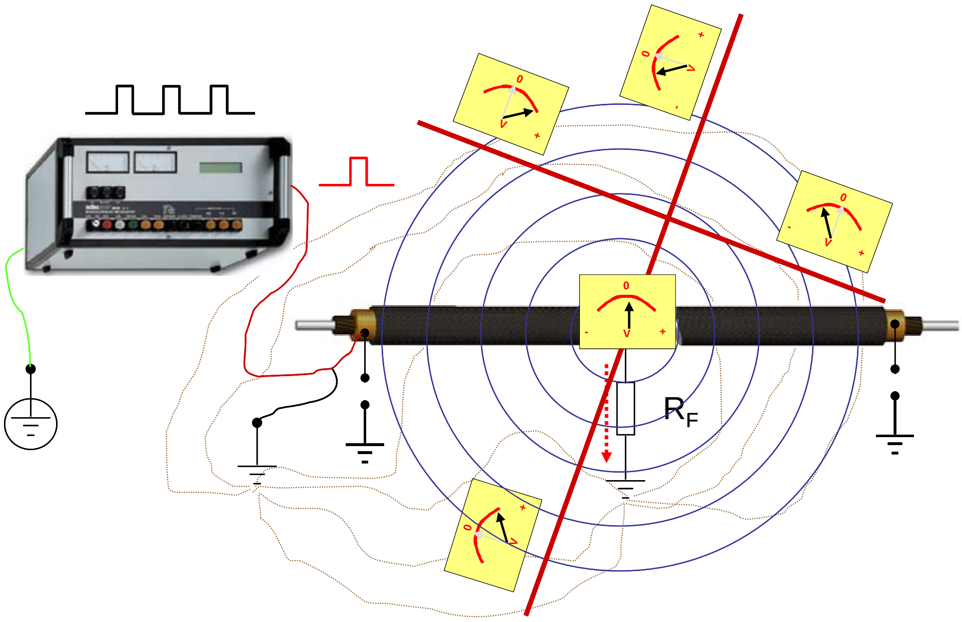


Fig. 14: Determination of the crossing point

4.3.1 Pulsed DC and current limits

When using the DC Method, a periodical interrupt of the current flow has a very positive effect on the location procedure. External influences of currents in the underground, e.g. resulting from railway, tram, cathodic protection systems or similar sources will influence the operation with a straight DC. With a pulsed Signal however, the pointer of the earth fault probe will show only the capacitive decoupled change of the pulsed signal as a short but clear directional deflection.
Instead of a zero point, the real fault position will be shown by a change of the polarity. The pointer can be at any value of the display scale.
The pulsing or duty cycle of the signal, is typically 3 seconds on and 1 second off.
The duty cycle can also be used for receivers without capacitive decoupling, to compensate for the stray currents and for possible electrolytic effects, which may build up at the probe tips.
For the pinpointing of sheath faults the rule "less is more" applies as well. Large currents will logically produce larger, better detectable voltage gradients, but the current for the location of sheath faults performs better between 10 and 100 milliamps. The sheath tester should also provide the possibility of an automatic current limitation. Both of these limitations have the purpose to avoid a drying up of the sheath fault due to thermal effects, and will protect other cable system in the vicinity of the fault. Lower currents will also limit the damage of the sheath fault which will then allow an easier repair since the inner conductors remain undamaged.
A current limited location procedure has the advantage, that the full power of the sheath tester is only applied during a short moment, during the change of the fault from high to a low resistance.

4.3.2 Power

The actual sheath fault location happens only with a low power of some 10 watts. Exact Details can be taken from the table below. A further reduction of the thermal stress is caused by the pulsing, which also reduces the duration and following the thermal stress effect of the current flow through the fault.

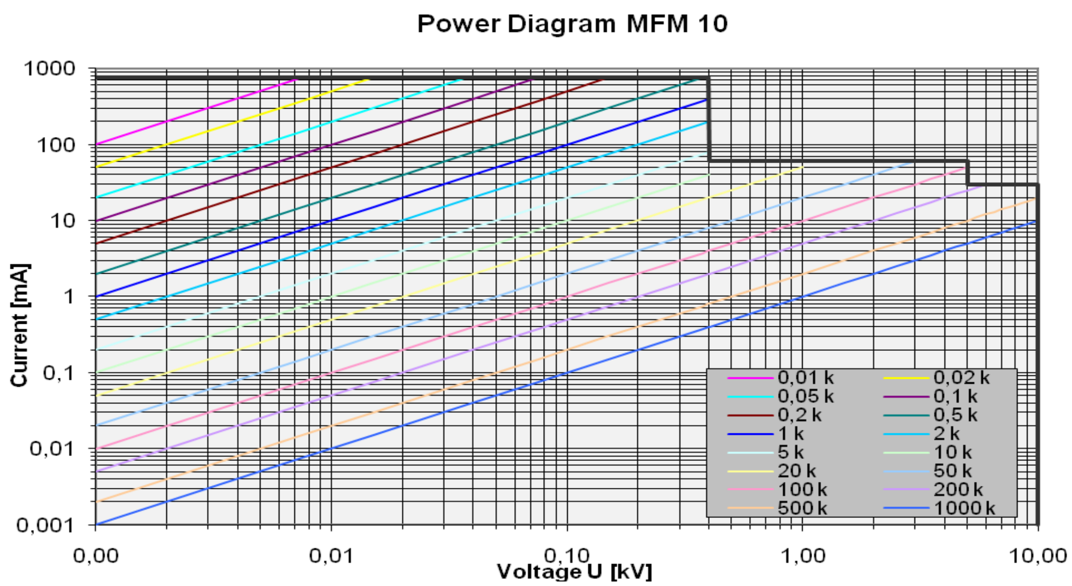


Fig. 15: Power diagram MFM 10

4.3.3 Specialties of the DC - Method

For multiple sheath faults, each conductive fault will generate its own voltage gradients. This will result in so called phantom faults, which cause false measurements
The following Fig. 16 shows such a situation. The correct observation of the polarity changes during the pinpointing procedure will easily reveal phantom faults by wrong polarity indications and behaviour.

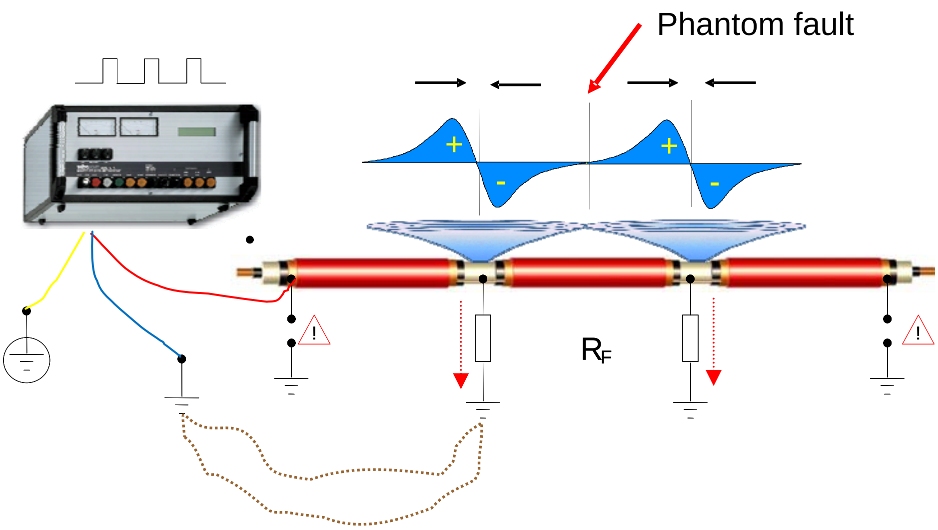


Fig. 16: Phantom fault

4.3.4 Influences

DC currents in the underground, e.g. resulting from railway, tram, cathodic protection systems or similar sources will influence the operation with a straight DC. By a capacitor in series with the input, the DC influence will be blocked, the input signal is differentiated and the display shows the correct information. An important point is, that always the according first deflection only indicates the correct direction towards the fault.

4.3.5 Advantages and disadvantages of the DC - Method

Advantages of the DC method are
- Prelocation of the fault position
- No Error measurements by capacitive coupling
- No distortion by 50 Hz or by short switching impulses
- No influence to the fault by the location process
- Low distorting by external DC
- High resistive fault break down
- Small loss of sensitivity in case of multiple faults

Disadvantages are:
- Low sensitivity
- Low sensitivity in case of multiple faults and in some case no breakdown
- Difficult location on solid surfaces

4.4 Surge Method

The application of this method is identical to the DC Method, but is based on the discharge of a surge generator. The output of a surge generator delivers a signal, which is virtually identical to a pulsed DC.

Warning!

When using this method, highest caution is required. When using the surge method the current can reach much higher values even with small pulse widths than for the DC method. A step voltage of 60 V must not be exceeded. The surge energy should be limited to a maximum of 100 J.

Advantages of the surge method are

- Higher sensitivity
- Low distortion by external DC
- Break down of high resistive fault
- Relatively low loss of sensitivity in case of multiple faults

Disadvantages are:

- Error measurements by capacitive coupling
- Changes to the fault spot by high energy (drying)
- High safety requirements

4.5 Localisation of earth contacting faults in LV plastic insulated MV systems

Short circuits (0 Ohms) between core and shield cannot be localised by means of an acoustic pinpointing method. Sometimes it is possible to locate the fault because the magnetic pick-up for the Digiphone sees the magnetic signal rapidly reduce on cables with armoured shields. But 95 % of short circuit faults inside cables with no steel armour are also earth contacting. By disconnecting the shield on both ends, these faults can be pinpoint located by the DC step voltage method. This method in combination with reflectometer or voltage drop prelocation has also performed very well for the fault location on very long cables, for example wind farm feeders.

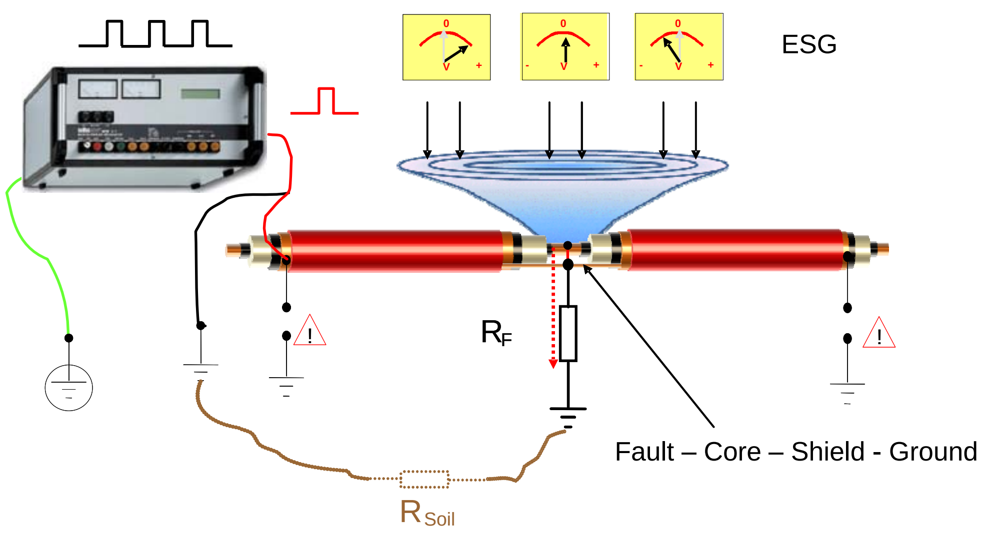


Fig 22: Combined earth faults

4.6 *Audio frequency methods*

Instead of a DC generator, a powerful audio frequency transmitter is connected between the faulty cable shield and earth. Audio frequency units are typically used for cable location, tracing and for the location of low resistive faults and are therefore in most situations available.

The use of the audio frequency method instead of the DC method has some advantages despite the limited distance.
Audio Frequency can be selectively amplified by the receiver, which permits a very efficient suppression or filtering of many types of distortions, for example as a result of electrolytic voltage sources or from stray currents. Additionally the Audio frequency technology allows the use of a capacitive voltage measurement. The capacitive voltage measurement provides the possibility to locate sheath faults in case of solid, poor conducting or insulating surfaces which prevent the use of a conventional step voltage measurement with earth rods, which have to be inserted into the ground.
Due to the high capacity of the shield towards earth, the supplying audio frequency generator has a capacitive load. This may result in a low output voltage in the case of an automatic impedance matching. In this case it is likely that flash over faults may not ignite and the fault remains undetectable. The capacitive resistance of the shield and the resulting output voltage of the generator can be calculated by the following equation.

$$[5] \quad R_C = \frac{1}{\omega C}$$

$$[6] \quad U = \sqrt{PR_C}$$

The following table shows the output voltages in respect to different generator power ratings and frequencies.

50 Watt @ 480 Hz	117 V
50Watt@ 1450 Hz	68 V
50 Watt @ 9820 Hz	26 V
500 Watt @ 480 Hz	370 V
500 Watt@ 1450 Hz	213 V
500 Watt @ 9820 Hz	82 V

Fig 17: Power dependent on Frequency

To reduce the effect of the capacitive resistance of the shield and to have the voltage at the sheath fault position as high as possible, it is strongly recommended to keep the frequency for the capacitive step voltage measurements as low as possible.

An according step voltage probe, for example DEB 3-10, consists of a light frame that carries two capacitive plates in approximately 0.8 m distance and is easily handled by one person. Due to its construction it can be used with capacitive plates or with earth spikes for direct galvanic applications. Like for the DC Method, the location is done along the cable route and the voltage gradients around the sheath fault are evaluated.

Fig18: Capacitive Probe

4.7 Equipment combination FL 50 with Step voltage Probe DEB 3-10

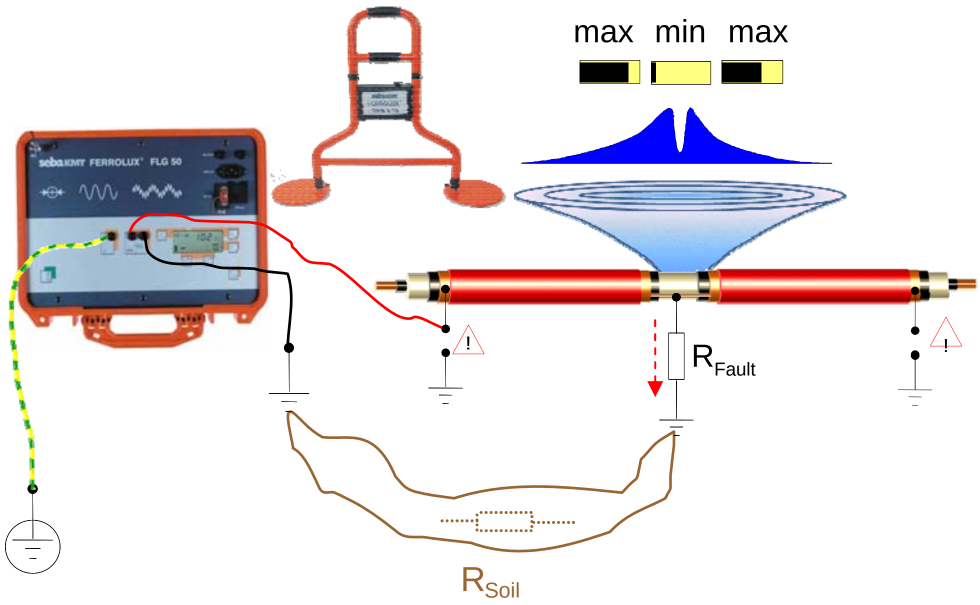
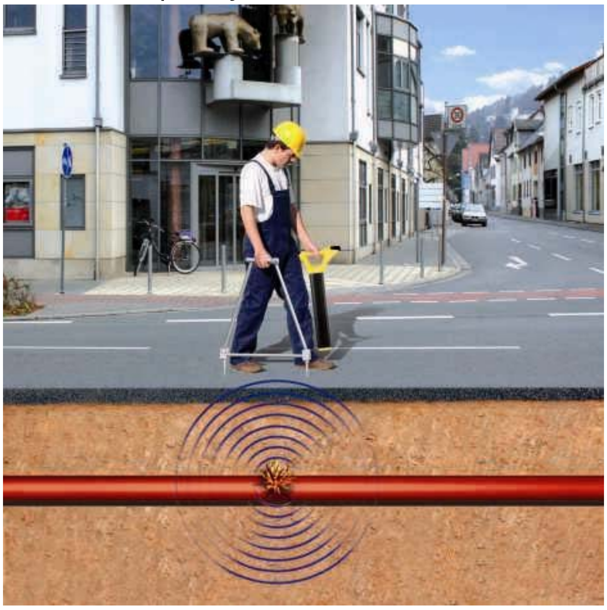


Fig. 19: Audio Frequency – Step voltage

To increase the sensitivity, the capacitive plates can be exchanged by earth spikes. In this case, the sensitivity of the receiver has to be adapted.
Capacitive plates allow fault location over all ground surfaces. Spikes require good ground contact so are best on soft ground, and not hard surfaces unless the condition is improved by wetting the spike contact areas.

4.8 Audio Frequency Method with 4,8 Hz and A-Frame

The SFL2 A frame is a stand alone unit and can be used alongside a locator to follow the cable route. The Locator transmitter is connected between the isolated conductor and the earthing point. The signal generator transmits a low frequency AC 4.8Hz signal and also a location frequency of 9.82 or 83kHz which is used to locate and trace the conductor.



This causes voltage gradients in the area of the earth fault which are then detected by the earth spikes of the A-Frame. The A-Frame display guides the operator direct to the correct fault position.
The A frame displays voltage gradient by a bargraph. At the start of the survey the voltage gradient is checked and then the reference is noted. Then tests are made at regular intervals along the cable.
Where there is no fault, hence no voltage gradient across the spikes, the active display shows 0 or low values. When a fault is detected, the direction to fault is indicated by blinking arrows, active numbers and bargraph signal strength increase.

Fig. 20: Audio Frequency with earth spikes (vLoc Pro with A-frame)

Beyond the fault the direction blinking arrow is reversed and active numbers and bargraph signal strength decreases.
The exact point of the fault is determined by blinking arrows changing direction and minimum active value, as the voltage between spikes is minimum. The fault is directly under the centre of the A frame.
Very close to the fault the active number will be almost the same as the reference value. If it is substantially less, then more than one fault exists.
If this is the case, the best approach is to dig up and clear the fault and resurvey using shorter interval between measurements.

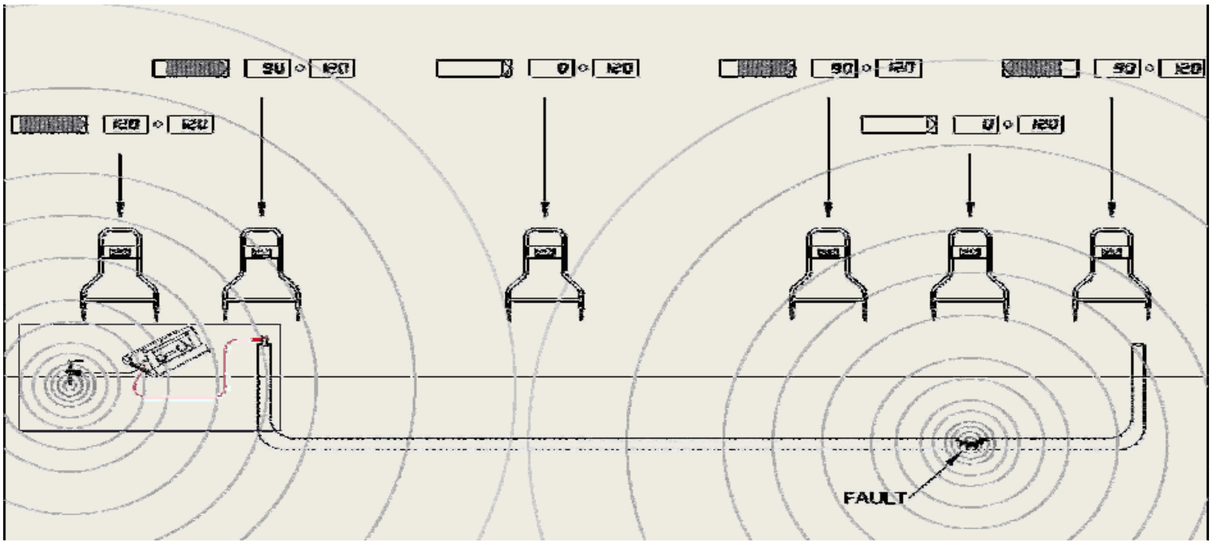


Fig. 21: Audio Frequency – Step Voltage with frequency modulation using SFL

The Metrotech SFL and i5000 transmitters are ideal for high resistance faults where a higher current is needed to pass current to ground. Low resistance sheath faults are better located with the Vloc Pro system.

Bargraph: The arrow indicates the direction toward the fault and the bargraph shows the signal strength.

Active: Shows the numerical value of the potential difference along the cable route. (Maximum on top of the largest fault)

Reference: Shows the maximum potential difference that was measured during synchronisation.

Like for the DC Method, the principle is the same. The display indicates the direction towards the sheath fault, by measuring the voltage gradients. Also the crossing measurement to determine the exact location is done the same way.

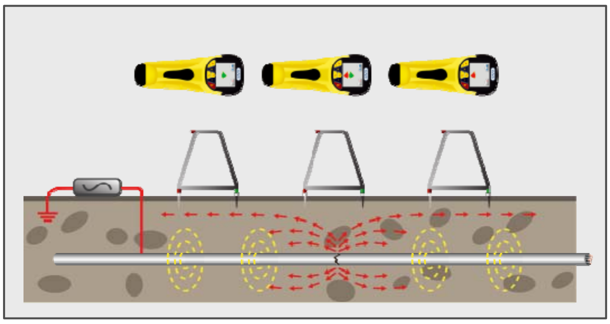


Fig. 21: Audio Frequency with earth spikes (vLoc Pro with A-frame)

The fault location technique using the Vloc system is similar to SFL system above. The transmitter is connected across the isolated cable and a grounding point. The transmitter signal transmits a 4.8Hz low frequency AC and 8 kHz location signal. The Vloc A frame has no display, so is connected by a cable to the Vloc pro locator, and automatically sets the locator display to the faultfinding display.
The contact spikes of the A frame are provided with green and red markings, and green and red arrows on the locator display indicate direction to fault and signal strength dB numbers.
The locator also provides left/right arrows to indicate the cable route.
The fault pinpointing procedure is similar to SFL2 A frame operation.

4.9 Localisation of earth contacting faults in LV and illumination systems

The pinpointing of earth contacting faults in LV and street illumination systems is a low cost alternative measuring principle and has spread fast after the introduction of plastic insulated LV cables. It is made easy and effective using audio frequency A frame types. The requirement is a plain plastic insulated network without earthing contacts. Old streetlight systems using T connections to streetlight and armoured cables are not applicable. The protective earth must be disconnected from the common ground at the feeding point, in the distributions and as well in the house connection. If the common earth connections and earthing in house connections cannot be disconnected then the method is not applicable
Especially in the so called secondaries, as the are used in the US Typical LV distributions, the used cables are mostly single, unshielded conductors.
Due to the short lengths, and the single cores, a TDR based fault location method is almost impossible.
But especially here, any fault has also earth contact, which permits the easy use of an A-Frame for the fault location

Final comments
The regular and early testing, detection and location of sheath faults will reduce the amount of faults, especially in medium voltage cables with extruded outer insulation.
Cable faults can also be located indirectly, since external damages of a cable will often lead consequentially to real cable faults.

5. Wording

Due to the fact, that especially the area of sheath fault location deals with a huge amount of different terms, also partially based on local use, we would like to list these words to avoid confusion among the readers

PILC, Paper Insulated Lead Cable	The outer lead sheath will prevent the typical Sheath fault location due to its continous earth contact.
XLPE, Crosslinked polyethylene	Insulation material, also used for the sheath
PVC, Poly vinyl chloride	Insulation material, also used for the sheath
Sheath, Jacket, Sleeve	Outer cable insulation
Shield, Screen	Outer conductor can be of copper, aluminium, lead Sometimes made of steel as armour
Semicon	Semiconducting filling material between conductors
Insulation, Dielectric	The insulating material that insulates the different conductors from each other
URD	Underground Residential Distribution
Secondaries	LV Distribution
Primaries	MV Distribution