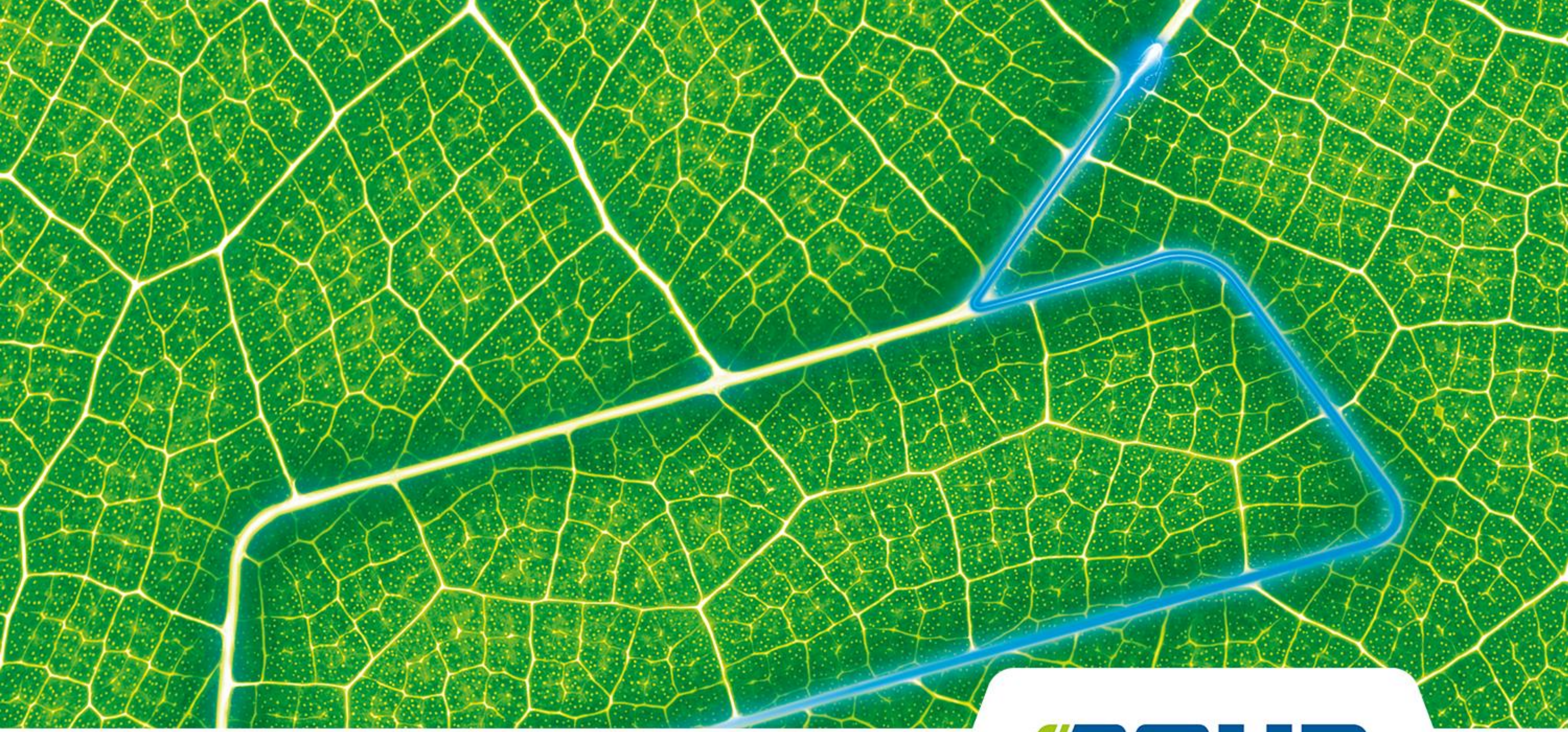


Introduction into Cable Fault Location

training

07-2018

Fault prelocation can be confusing and misleading if general rules are not observed.
Another discussion point are the possible varieties that can be used for fault pre-location.

This presentation is intended to bring some light into the questions

Basics of cables and cable fault location

There are always discussions about the understanding of different types of cable materials and constructions.
We want to address this now in detail.

Cable types

wet

Oil filled cables

PILC
- lead coating
- plastic coating

dry

PE
- graphited outer semi conductive layer

XLPE
- extruded outer semi conductive layer
- peel able outer semi conductive layer
- graphited outer semi conductive layer (1st Generation)
- open sheath (mostly used forUS types)

TR-XLPE
- Tree retardant XLPE

EPR
- Rubber cables

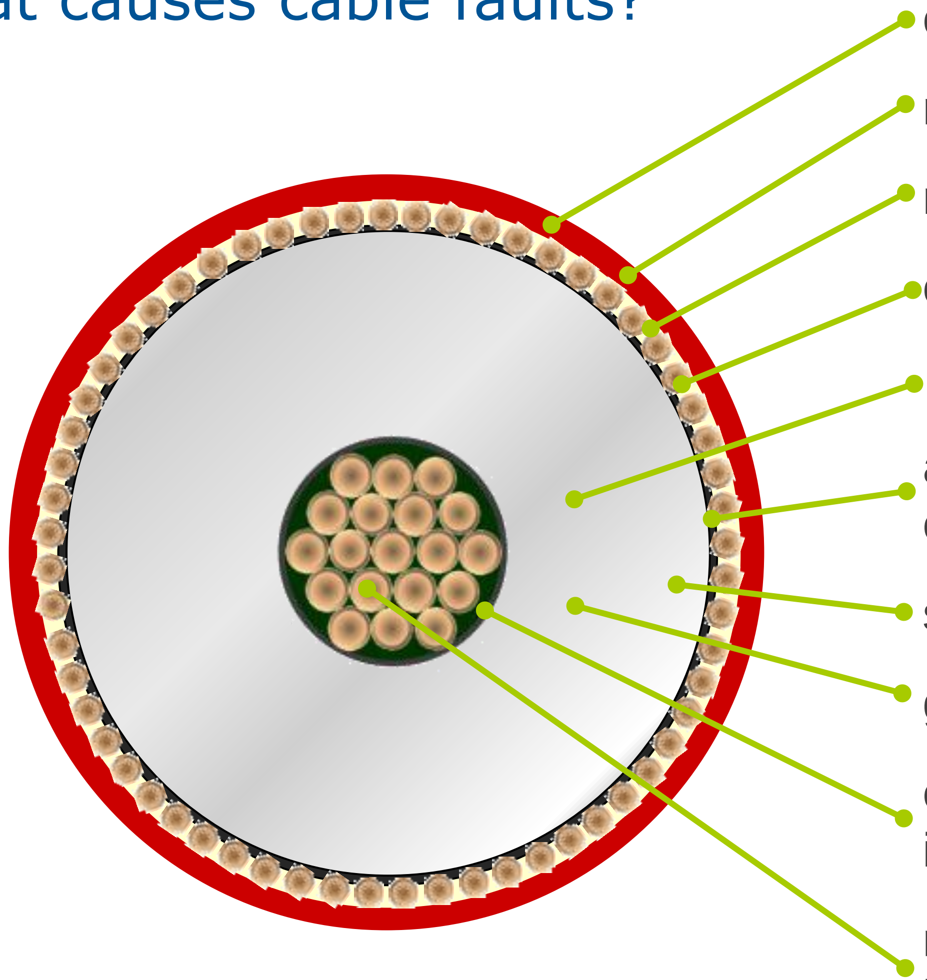
PVC
- Polyvinyl chloride cables (MV) mostly used in power stations

Basics

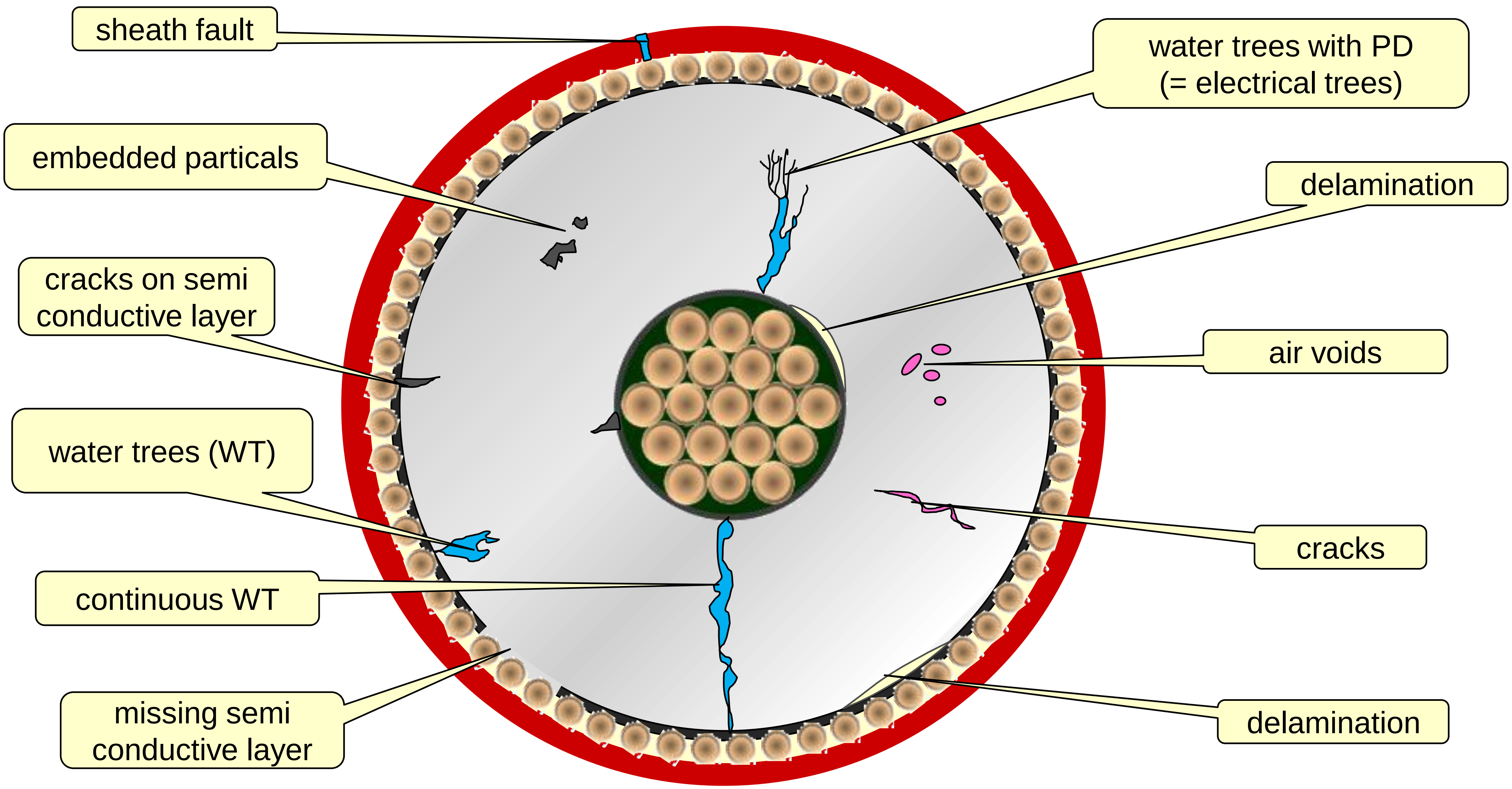
Despite the partially complete physical and chemical differences of the materials used for cable isolations, the ones occurring phenomena and reactions to tests are very similar. Exceptions such as the DC test are detailed described, but the majority of the problems respond comparably to the available testing and diagnostic procedures.

EPR aging is similar to that of XLPE. But XLPE is the most difficult to test and diagnose dielectric material. Although the methods described here are characterizing the aging phenomena and damage to XLPE cables, the other materials react very similar.

What causes cable faults?



Causes for cable faults in XLPE cables



Further reasons for cable faults

- damage from the outside (e.g. excavator)
- temperature fluctuations and overheating
- strong bending
- aging effects
- electrical changes, e.g. higher current, voltage or load
- bad workmanship of joints and terminations
- delamination, especially on PILC cables and joints
- strong mechanical forces during short circuits
- environmental effects on exposed cables
- landslides

Shielding

- concentric copper wires
- flat band shielding
- wavy shielding
- longitudinally welded screen
- lead coated sheath (PILC)
- without coating (open sheath - Bare Concentric)
  - only used in older US types

Benefits of a sealed sheath (e.g. EDF 20 kV cable)

- reduced, and / or delayed aging
- improved electrical characteristics (EMC)
- barrier agains water ingress

Material

Corrosion of a lead coated PILC

- Paper isolated PILC
- First technology for massive production of cables
- High amount of experiences
- Still in use for HV cables
- Environmental issues with expiring oil
- Low sensitivity to problems

600-kilovolt HVDC PILC submarine cable

Material

PILC Disadvantages

- Environmental issues (oil & lead)
- Difficult installation (joints)
- Regular service required (oil)
- higher cost of production
- Temporarily self-healing

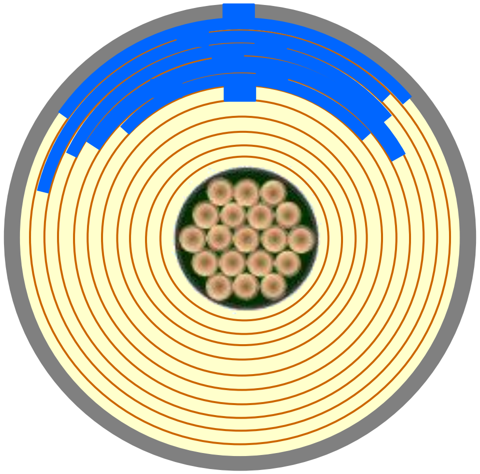
PD tracks on a dried PILC

PILC Problems	Approach
corrosion of lead coating	TAN δ
Water / moisture	TAN δ
Drying out of oil impregnation	PD
Sagging of the oil on slopes	PD
Joint issues	PD
Polymerisation – resinified oil	TAN δ / PD

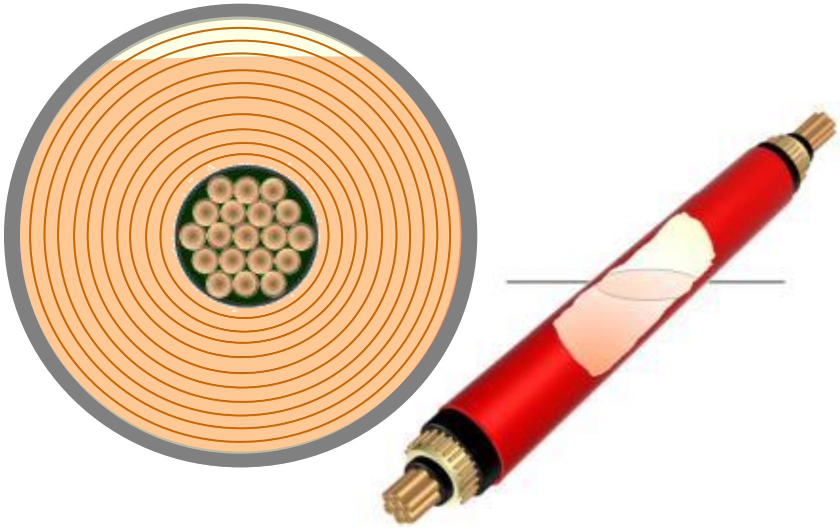
+ VLF

Partial Discharges in PILC

Water ingress



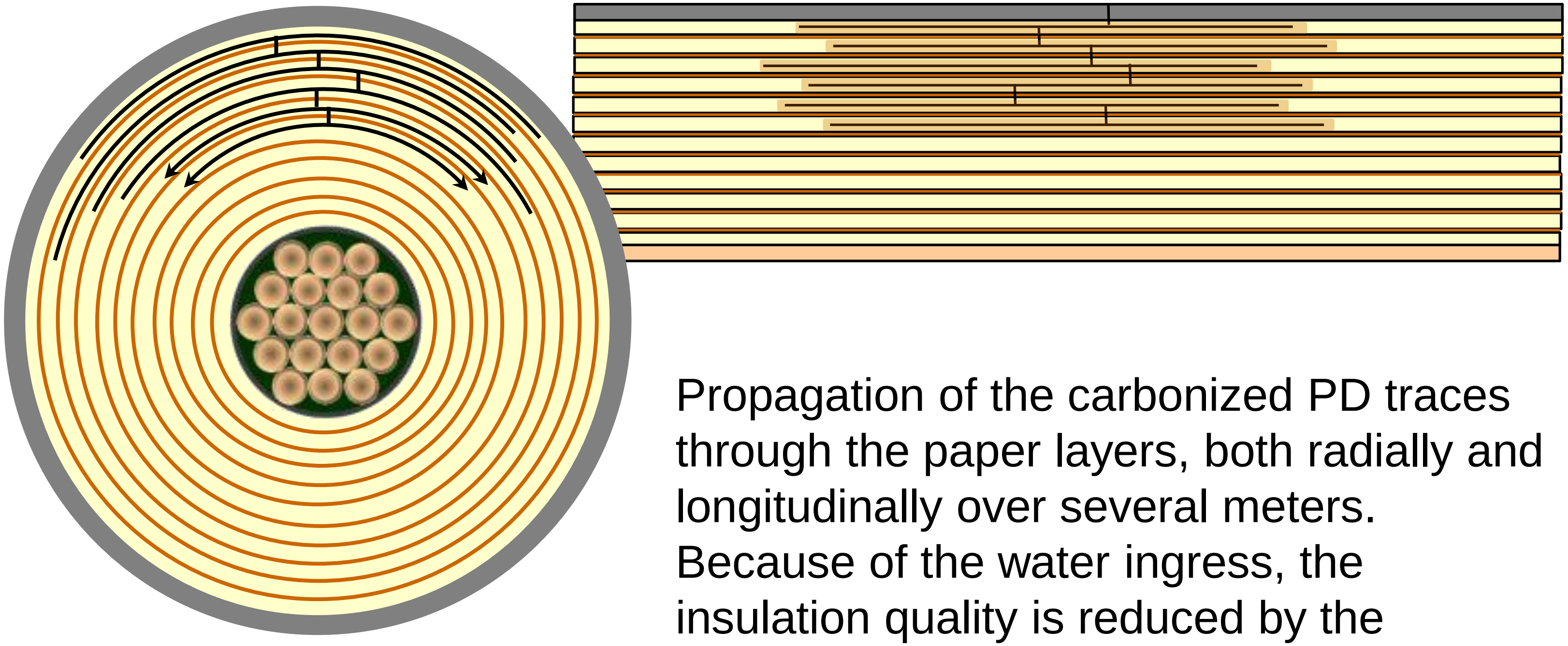
Sagging of oil because of oil losses



The ingress of water reduces the effective insulation thickness.
The field strength and the stress in the residual insulation increases, the voltage strength decreases.

By the slightly "disappearance" of the oil, the cable dries out. Therefore the insulation quality drops, partial discharges (PD) are occurring and breakdowns are the result. Self-healing effects are possible. Hereby oil with lower viscosity (heated oil) flows to the faulty spot and increases the voltage strength.

Electrical Treeing

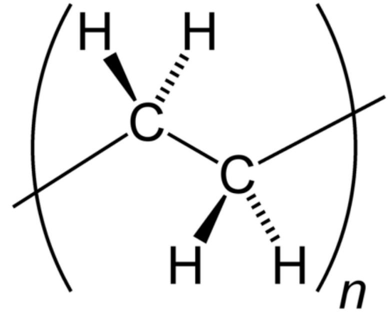


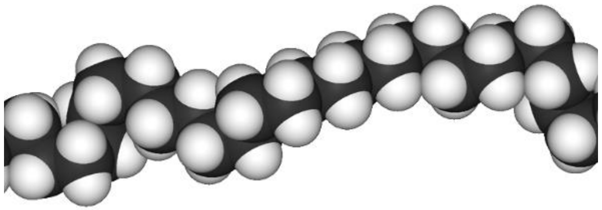
Propagation of the carbonized PD traces through the paper layers, both radially and longitudinally over several meters. Because of the water ingress, the insulation quality is reduced by the carbonized layers. This happens for a longer periods of time until the cable fails.

Material

Cross linked polyethylen XLPE / PE

- Very high dielectric strength
- Low transmission losses
- Excellent dielectric properties
- Theoretical life expectancy > 50 years
- Reduction of the cable thickness
- Quite easy to install
- Higher mechanical strength
- Higher operating temperature
- Easy and cheap to manufacture
- Easy to process





Material

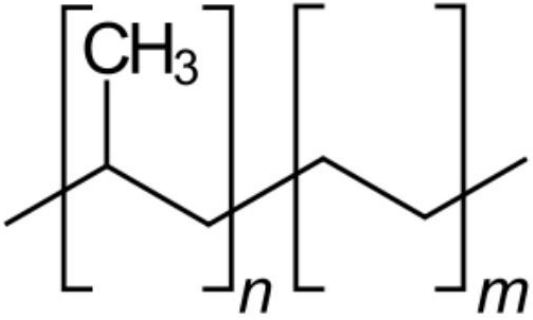
XLPE disadvantages

- Moisture supports tree growth
- Sensitive to HF / HV transients
- Requires proper handling
- 1st generation PE just managed 20 years
- Testing with DC is useless and damaging

XLPE Problems	Approach
sheath fault / water ingress	TAN δ
aging / water trees	TAN δ
contamination during production	PD
mechanical damages	PD
joint issues	PD

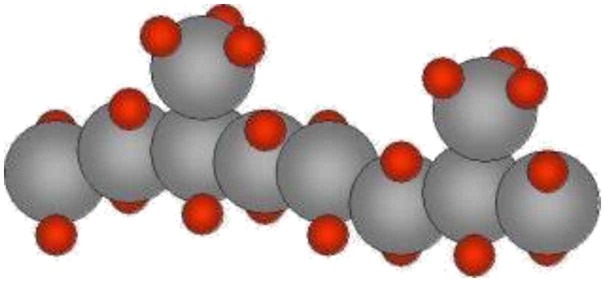
+ VLF

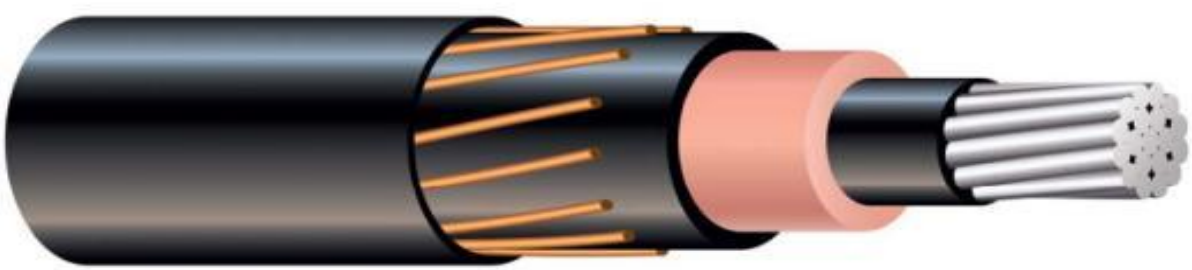
Material



EPR ethylen propylene rubber

- high life time expectation
- very flexible
- little expansion by heating
- standard material
- better properties at high temperatures





Material

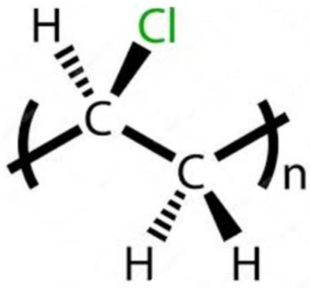
EPR disadvantages

- Is attacked by fuels and oil
- High tan delta value (higher dielectric losses)
- Lower dielectric strength
- Dielectric properties dependent on temperature

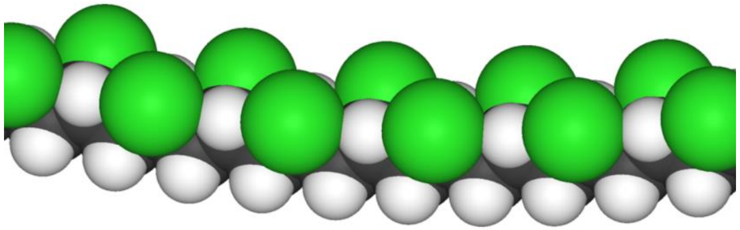
EPR problems	Approach	
cracks	TAN δ	+ VLF
aging / water trees	TAN δ	
contamination during production	PD	
problems with stuffing	PD	
mechanical damages	PD	
joint issues	PD	

Material

PVC cable



- Low costs
- Flexible
- Tolerates high temperatures
- High life expectancy
- Electric treeing is not critical
- Use primarily in LV installations
- Partial use also in MV plants
- High dielectric losses



Material

PVC
Color sensitive (alternating electrical parameters on different colors / V2 / εr)
High PD values are not critical
Bad dielectric constant
Dielectric strength <1/3 of XLPE
Environmental problems during manufacturing

Flammable:
Example: airport fire in Düsseldorf
- PVC of cables produced dense black smoke
- PVC generated hydrochloric acid and chlorine-containing emissions.
- PVC has supported the spread of fire
- PVC produced a dioxin contamination of 120 µg / kg in the deposits

Material properties

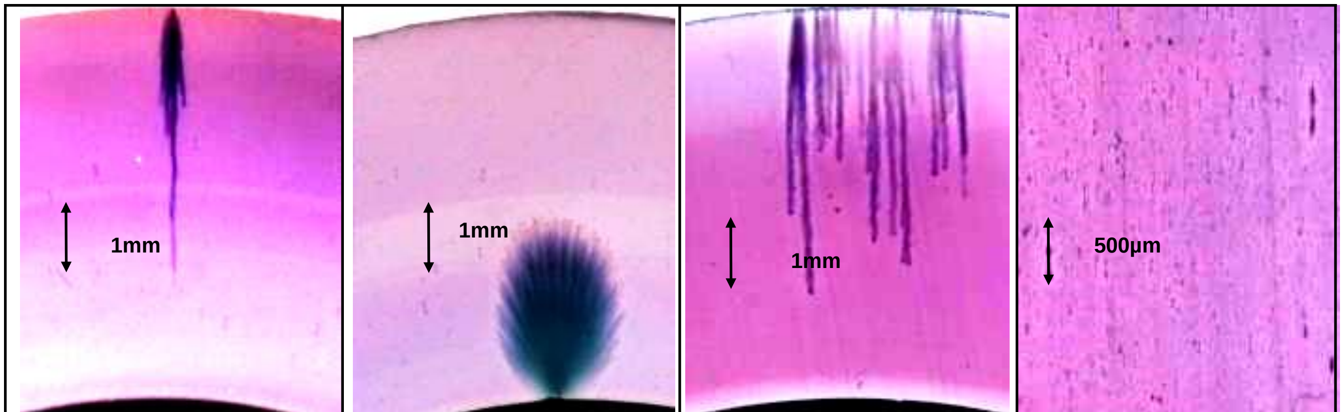
material	acronym	VDE symbol	dielectr. index (800Hz)	electrical strengh in kV/mm	dense g/cm³	water absorption %	tan delta @ 50 Hz x 10^{-4}
Polyvinylchlorid	PVC	Y	4.0	10	1.35	0.4	<1000
heat-proof Polyvinylchlorid	PVC	Y	3.5	20	1.35	0.4	<1000
Polyethylen LD	LDPE	2Y	2.3	75	0,9	0.03	<10
Polyethylen HD	HDPE	2Y	2.3	100	0,9	0.03	<10
Ethylen-Propylen-Gummi	EPR/ EPDM	3G	3.5	20	1.45	0.2	<40
cross linked Polyethylen	XLPE	2X	2.4	50	0,92	0.03	<10
Blei-Papier	PILC	K	3.3	12	0,9		<30

New cable with fabrication defect

missing semi-conductive layer
problems with the extruder

water trees / WT

water tree growth in XLPE isolation



A) Kabel S6, 21 Jahre alt	B) Kabel S6, 21 Jahre alt	C) Kabel S1, 17 Jahre alt	D) Kabel S10, 11 Jahre alt

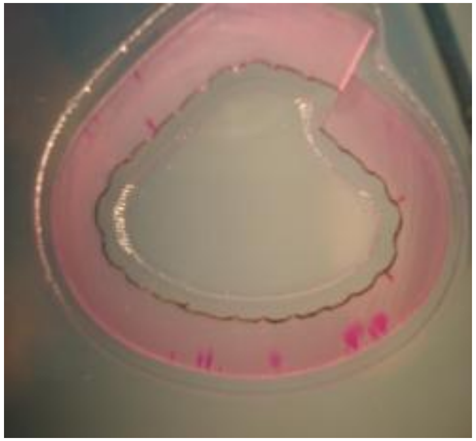
water trees / WT

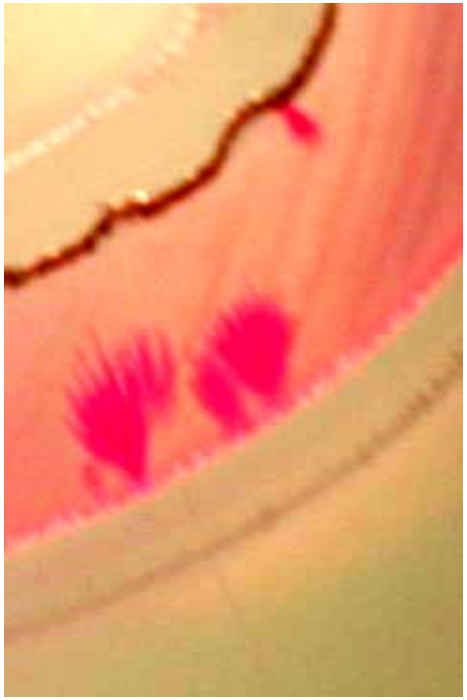
growth even at low electrical field strengths
(< 1 kV/mm)

very slow groth rate
(6 - 15 years)

no partial discharges (PD)

water trees are not visible



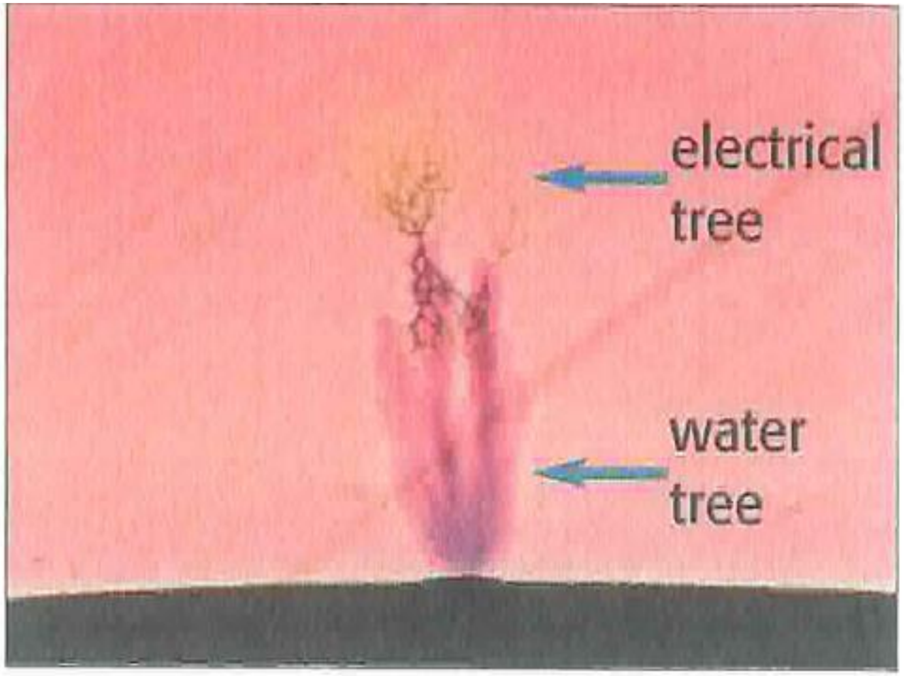


water trees / WT

- high probability in aged cables
- only effects of WT are measurable, the WT themselves can‘t be measured / located
- affecting the operation of the cable
  - Full-grown WT don‘t have to lead to a cable failure, as the water in the WT is not allways conductive.
  - The cable isolation is still intact only the value of ε_r is worser.
- Faulty conditions or applied DC voltage are able to bring the “isolating“ WT to failure.

electrical trees / ET

The final stage of a water tree.
The water tree turns into an electric tree.



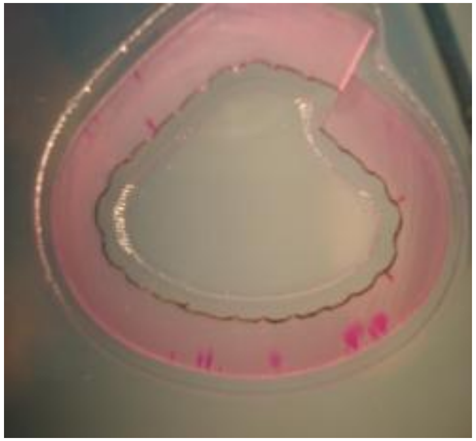
electrical trees :

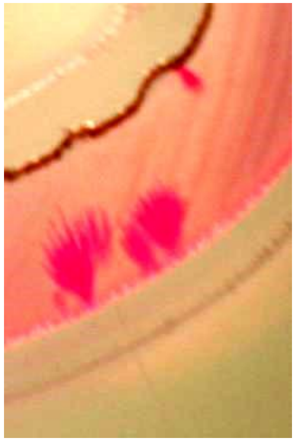
- partial discharges
- final stage bevore flash over

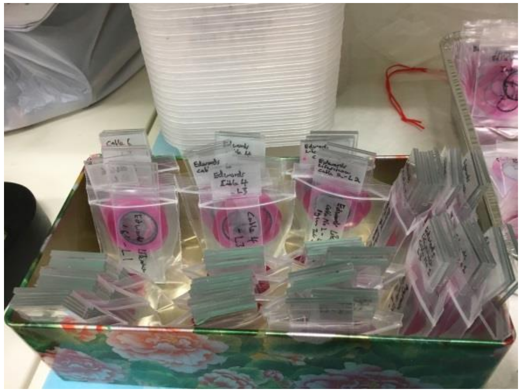
water trees :

- no partial discharges
- leackage current

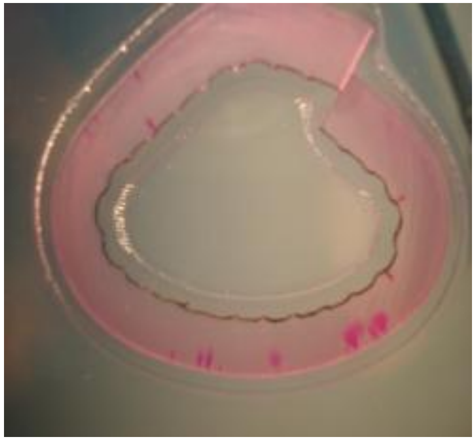
Cable dyeing – make water trees visible

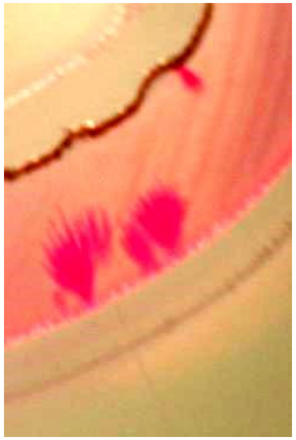


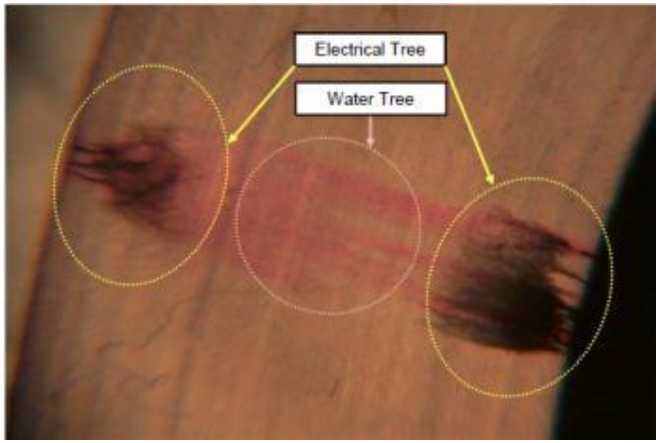


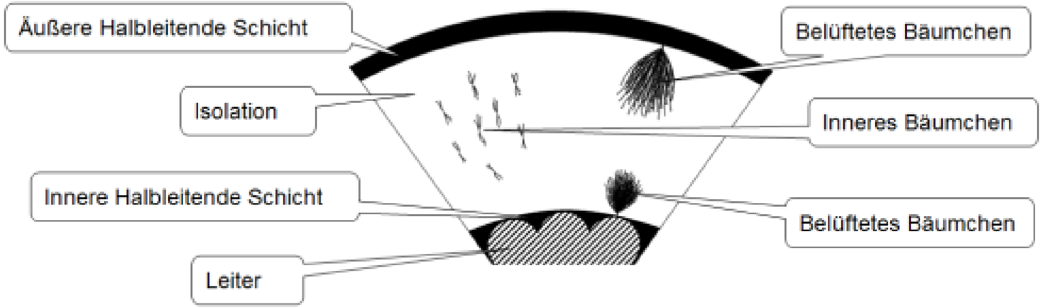


water trees / WT and other phenomena

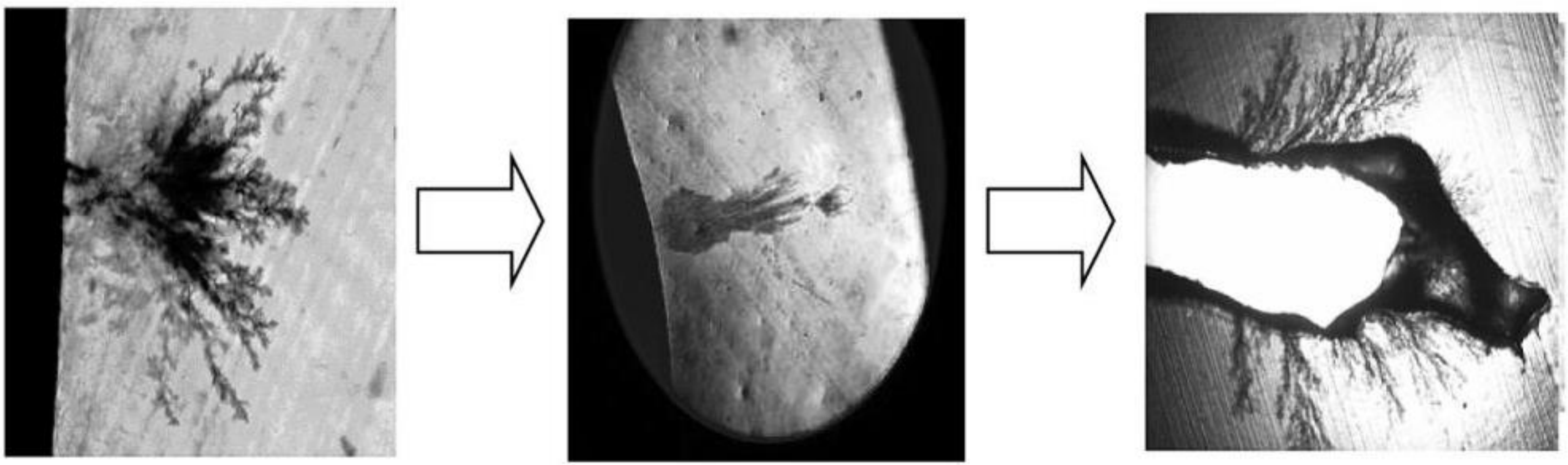








Developement of a cable failure beginning with a water tree



water tree　　electrical tree　　flash over

partial discharge (PD)

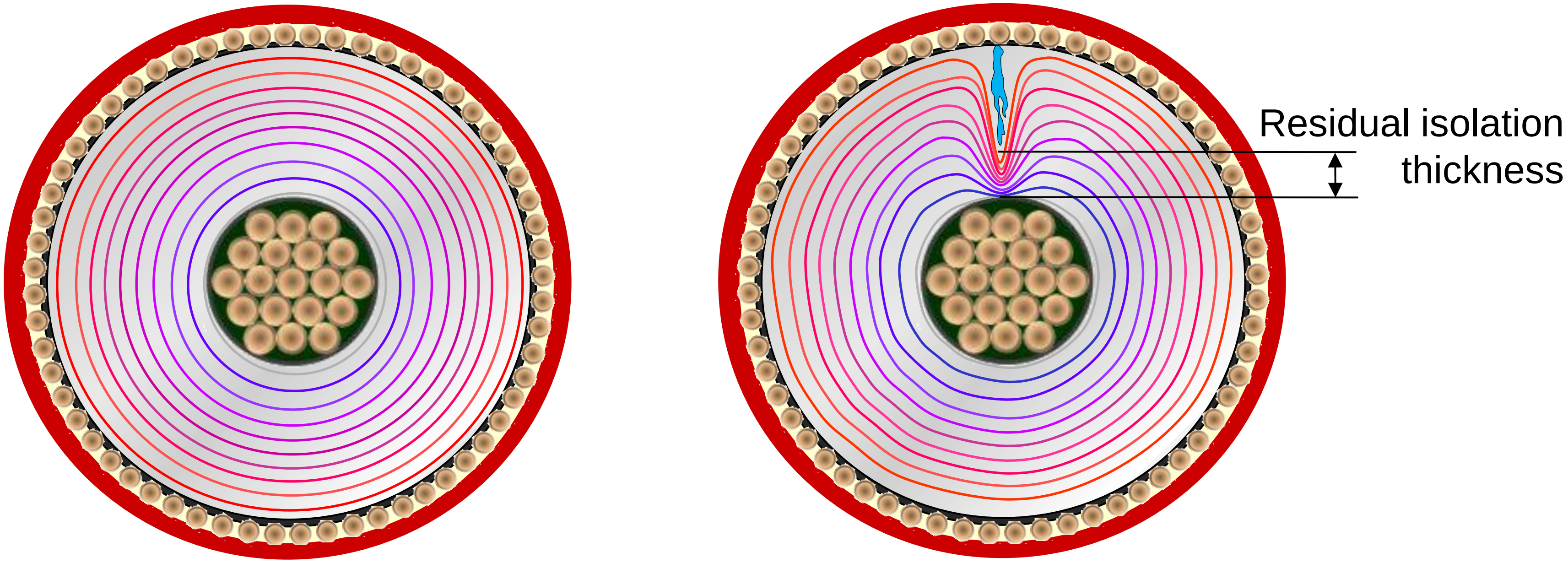
- Micro discharges (pC – nC)
- Signals of the order of µ and mV and pA
- Frequency in the MHz range
- Measurable with different approaches
- High attenuation of the signals, depending on length, no. of joints, …

IEC 60270 Section 3.1 states

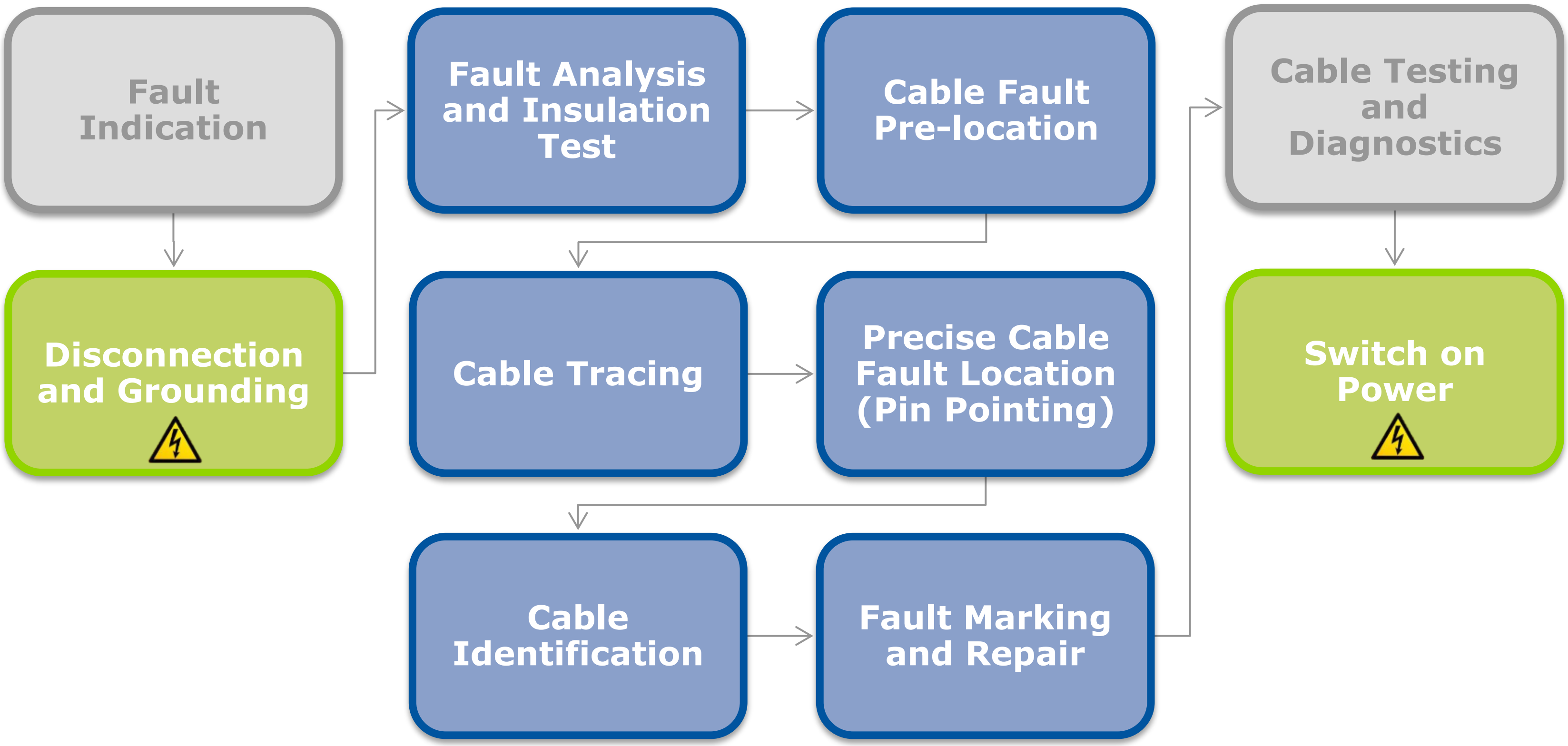
- “Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation…”
- “Corona is a form of partial discharge that occurs in gaseous media around conductors which are remote from solid or liquid insulation…”
- “Partial discharges are often accompanied by emission of sound, light, heat, and chemical reactions…”

Distribution of the electrical field

The electrical field of an healhy cable is characterized by homogeneously running field lines of the same field strength (equipotential lines). This results in a slight degradation of the field between the conductor and sheath. The field is distorted around faulty spots like WT, cracks, voids. The electric field is “compressed” to significantly reduced thickness, the applied field strength in kV / mm is increased and therefore the strain is much higher.



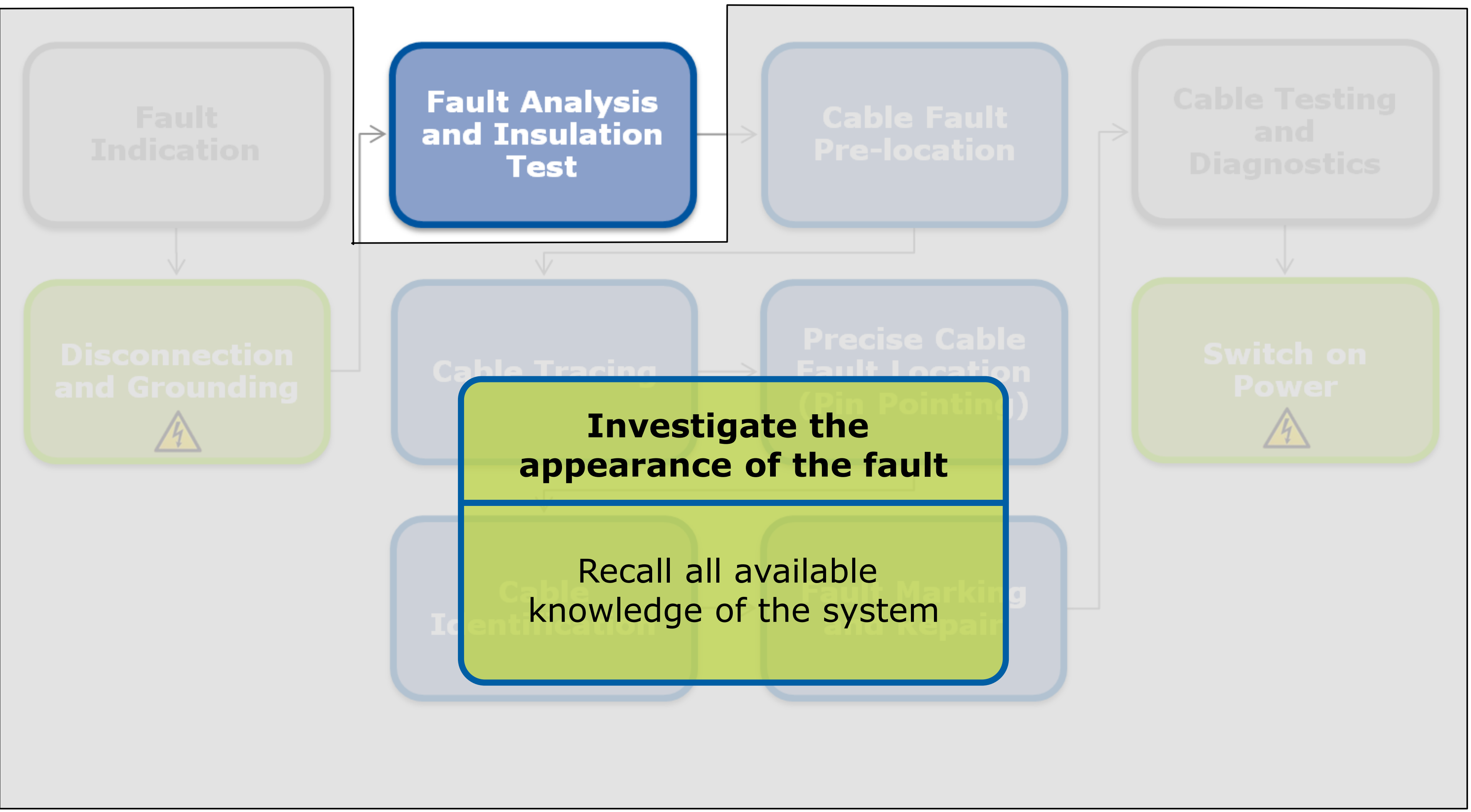
Cable fault location procedure



= sub process

= safety procedure (according to local standards and safety regulations)

= process for cable fault location



Investigate the appearance of the fault

Recall all available knowledge of the system

BAUR
ensuring the flow

Fault Indication

Fault Analysis and Insulation Test

Low resistance < 10 – 100 Ω continuity, cable length, interrupt

"IRG TDR"
"Cable Radar"
"Impulse Echo"
"Reflectometer"

Identify affected phase, fault resistance and breakdown voltage

Which phases are affected?

- Phase – to – Phase
- Phase – to – Sheath
- Phase – to – Soil
- Sheath – to – Soil

High resistance > 10 – 100 Ω

Isolation Tester
0 … 10 kV
DC Test / Breakdown recognition
VLF Tester

Sheath to soil (0 … 5 kV)

Isolation Tester
DC Tester

BAUR
ensuring the flow

Low resistance
<10 … 100 Ohm

TDR
"IRG"
"Cable Radar"
"Impulse Echo"
"Reflectometer

Cable Fault Pre-location

High resistance, wet fault

Burning,
Conditioning SIM/MIM
permanent fault conversion

High resistance
>10 … ∞ Ohm

SIM Secondary Impulse Method
MIM
Conditioning SIM /MIM
ICM Impulse Current Method
DECAY with HV DC-tester

Fault to earth (soil)

Sheath fault
HV Bridge Methods

Connection

Passive (no transmitter):
50 / 60 Hz,
RF radio frequency
Active:
Direct galvanic,
Inductive Clamp
Inductive Antenna

Cable Tracing

Frequency

RF radio frequency
50 / 60 Hz power frequency
100 – 150 Hz: Subsea applications
400 … 1000 Hz: poor coupling, long range
1 … 10 kHz: good coupling, low interference
10 … 80 kHz: high coupling, water pipes

Method

Minimum (Null)
Maximum (Peak)

Low resistance

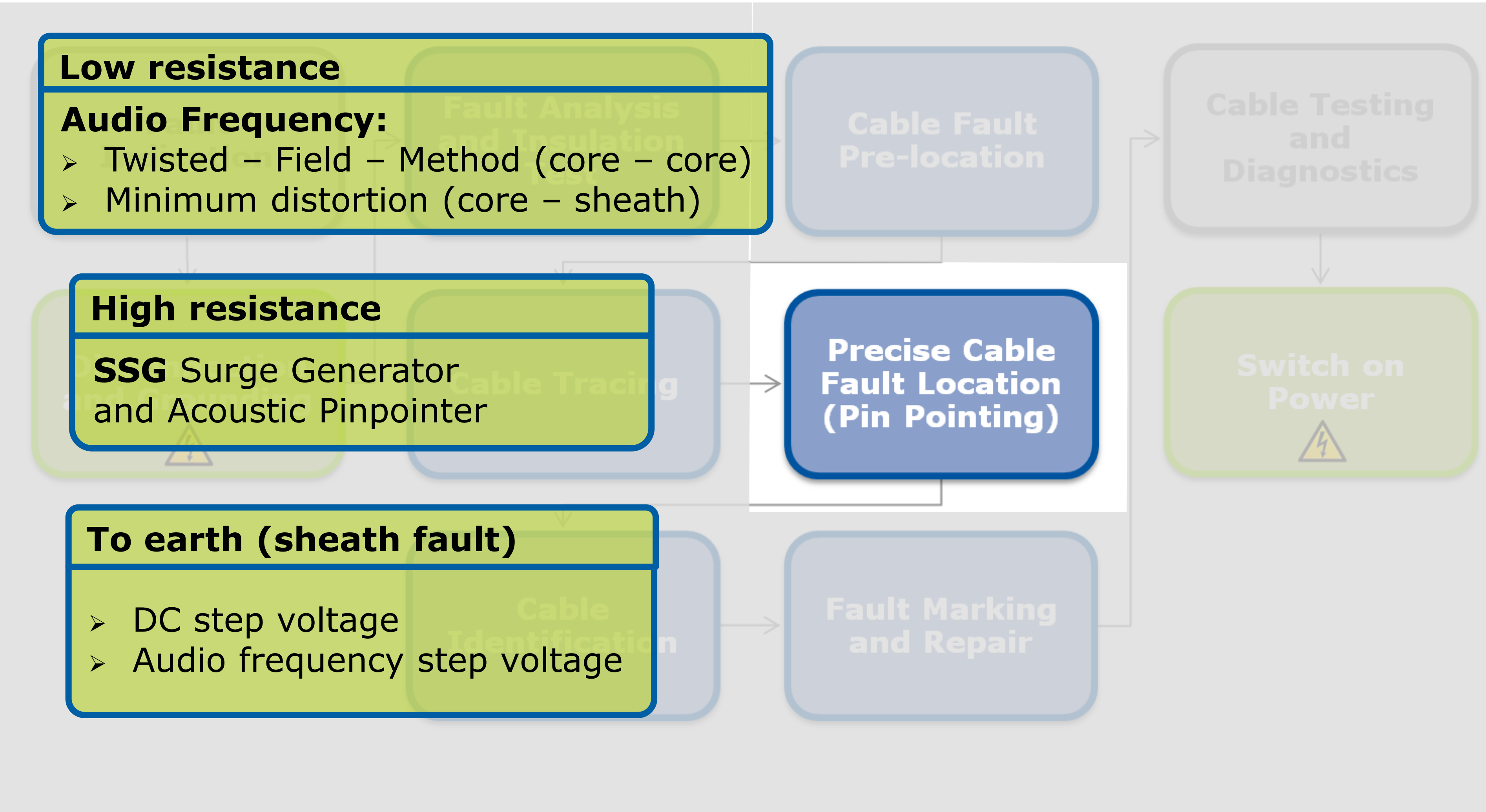
Audio Frequency:
- Twisted – Field – Method (core – core)
- Minimum distortion (core – sheath)

High resistance

SSG Surge Generator and Acoustic Pinpointer

To earth (sheath fault)

- DC step voltage
- Audio frequency step voltage



Single Phase Cable

Pulse Method

Audio frequency signal identification
with inductive clamp connection

Multi Conductor Cable

Pulse Method
- Pulse direction
- Pulse intensity
- Phase synchronisation

Audio Frequency
- Twisted – Field – Method

Energized Cable LV

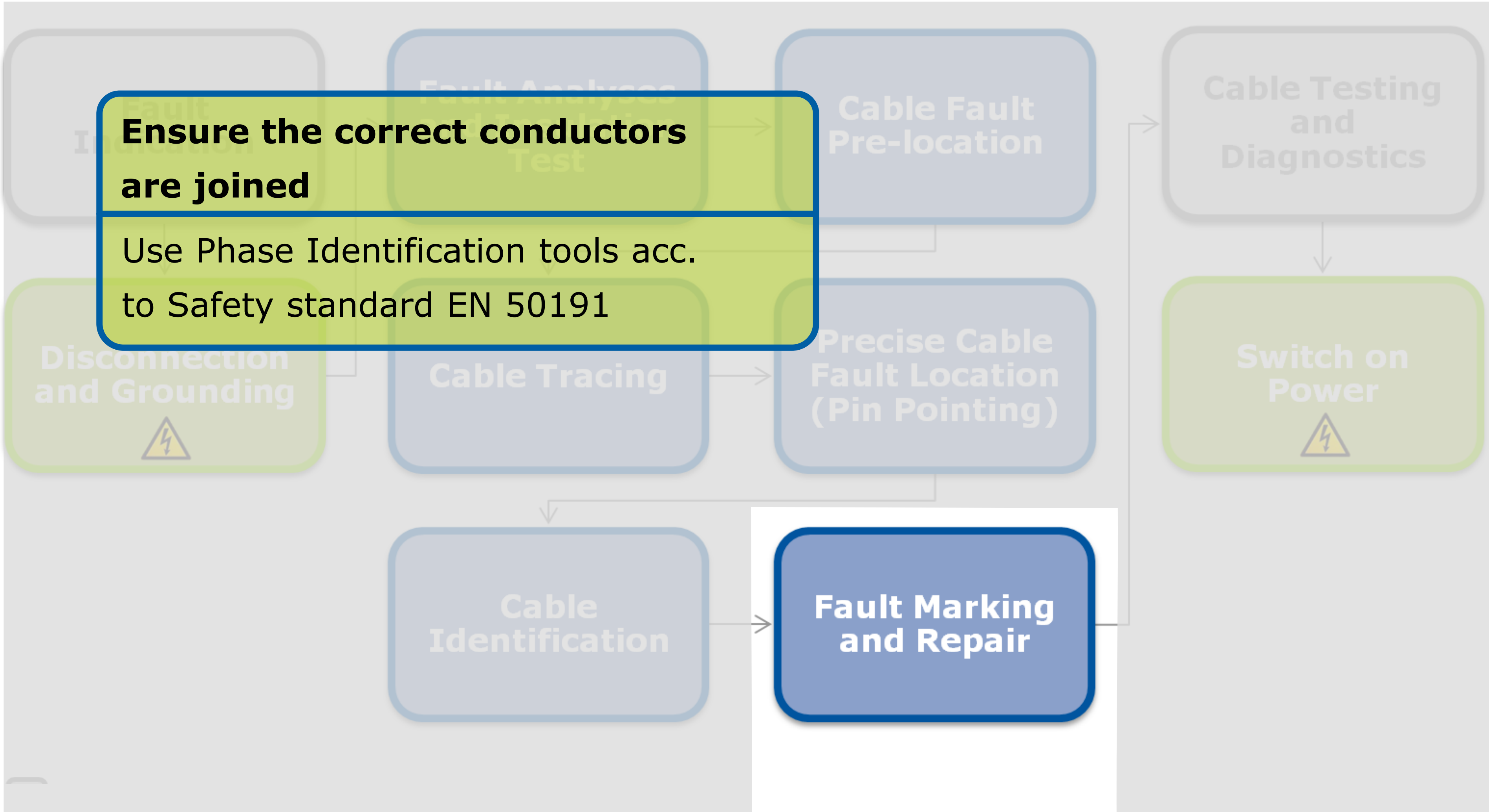
Pulse Method for Life Cables (LV)

Audio frequency signal
with inductive clamp connection

Cable Identification

Ensure the correct conductors are joined

Use Phase Identification tools acc. to Safety standard EN 50191



Laws

Commissioning of elec. installations

German Laws, but also other world wide laws require a norm conform testing of electrical installations before re-energizing!

Acceptance Test

Partial Discharge Test

Isolation test

DC test (PILC)

Short DC Test max. 5 min. (XLPE)

VLF 0.1 Hz (60 min, 1.7 … 3 U_o)

Soak test (24 h energized at U_o)

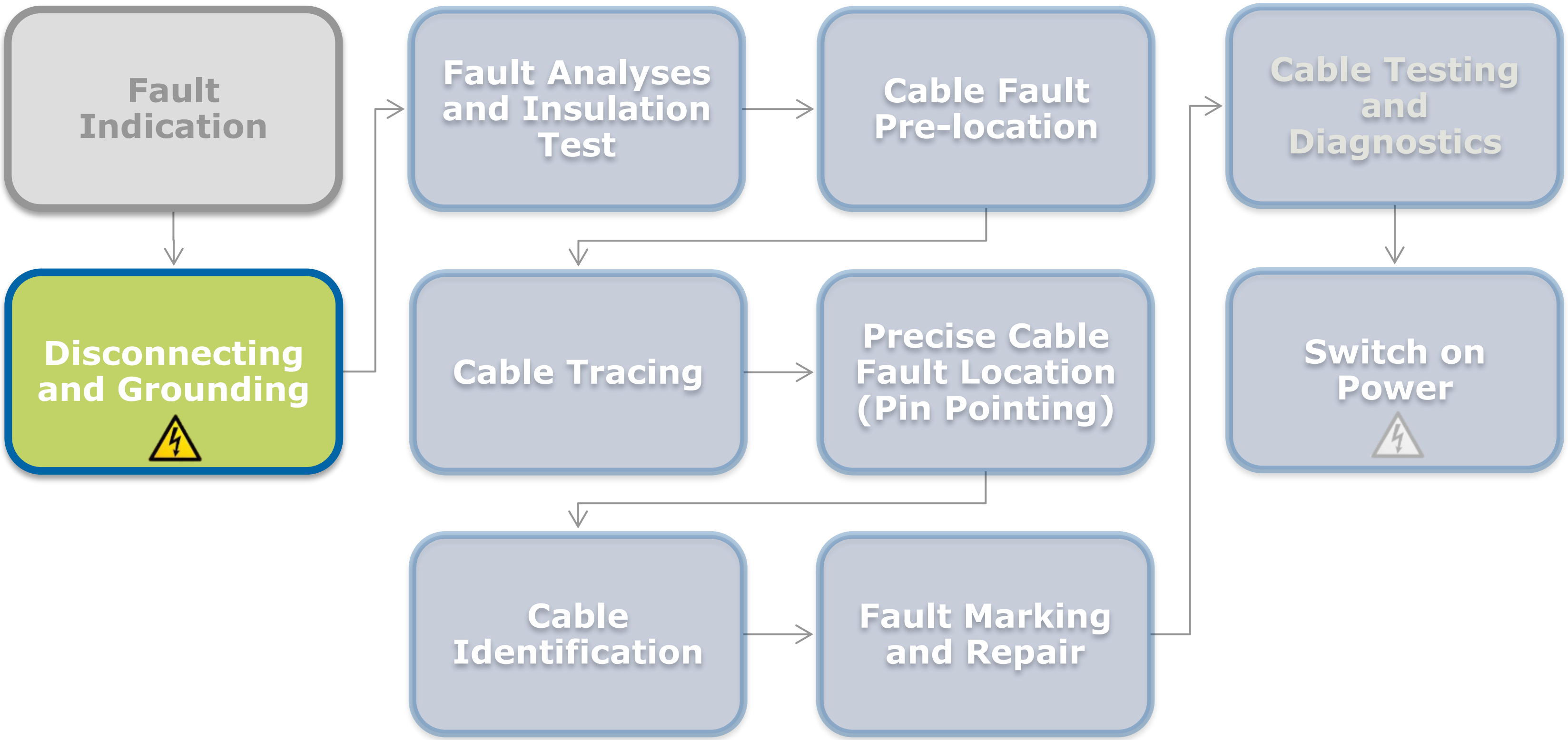
Resonance / 50 Hz test

Sheath test

BAUR ensuring the flow

1st step

Fault indication, disconnecting and grounding



Fault indication

Fault indication

- No power
- Fuse activation
- Flickers
- Other power interrupts (of unknown reasons)
- Your experience?!

*according to local standards and safety regulations

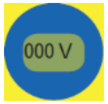
Safety first

Disconnecting and grounding

SAFETY REGULATIONS*


Disconnect the test object


Secure against re-energisation



Ensure the voltage status of the disconnected object.

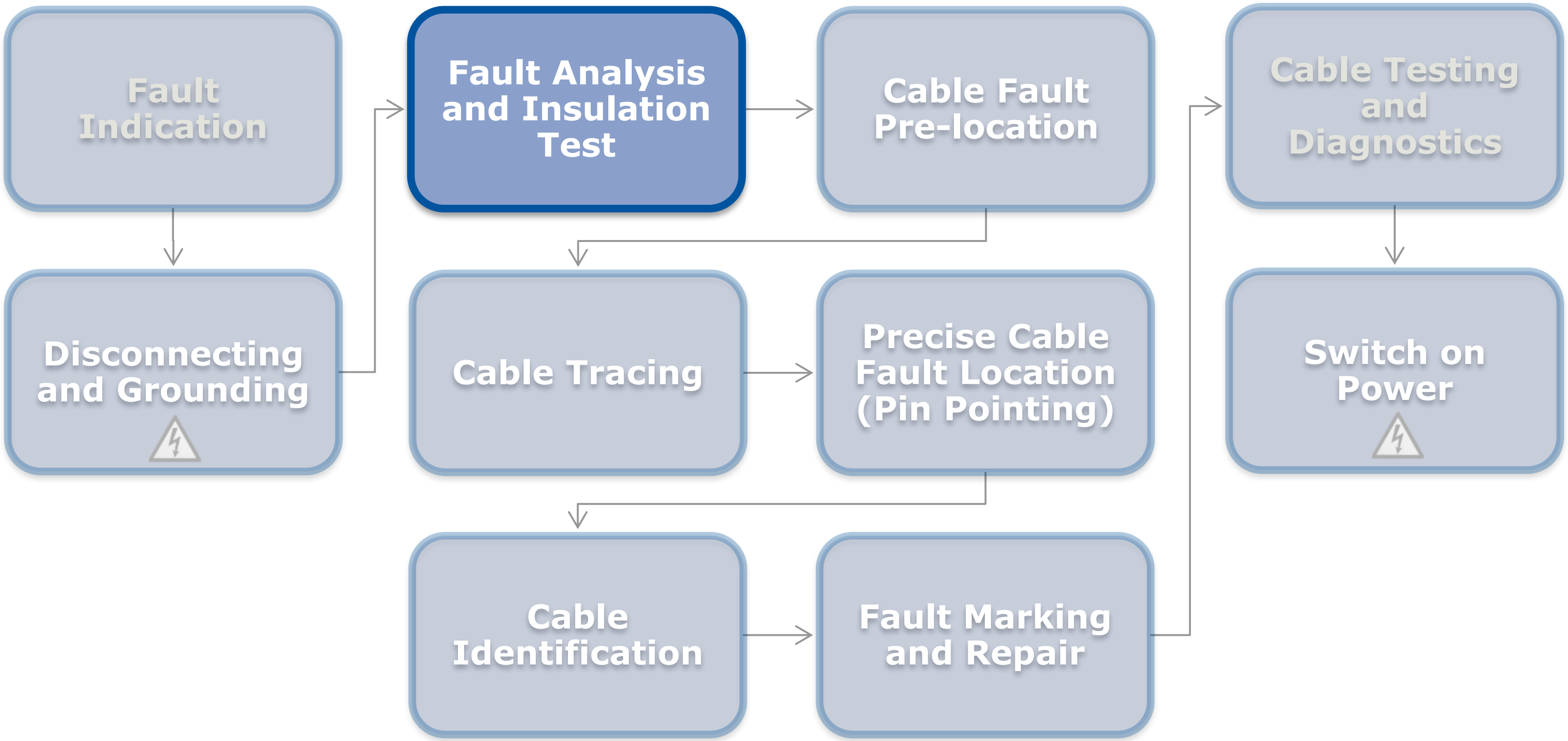

Short-circuit the test object to earth.


Protect or isolate the test object from adjoining live HV parts.

*according to local standards and safety regulations

2nd step

Fault analyses and insulation test



Fault location is the combination of ALL available information

Fault

What happened
Where

History

Age/Date
Previous faults
Faults in the vicinity

Only the Comparison of all details will provide the full picture

Details

P-P / P-N
Sheath
Insulation
Road work on track
Conduit?

Data

Cable Type
Joints
Termination
Material
Manufacturer

Follow the rules and their common sense !

A. Safety first!

B. Unused wires must be grounded!

C. Only believe what you see!

D. Compare all 3 phases!

E. Make sure, that the cable end is visible!

F. The cable is always shorter!

G. Less is more!

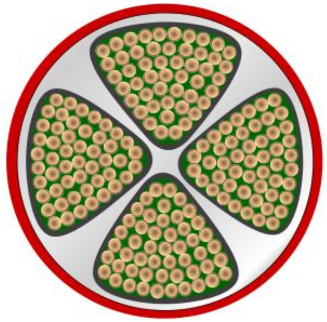
H. Even a fully automatic system does not produce miracles , the " human computer" is always better

Shielded
segmented cable

LV

3 or 4 conductor
plus shield

Faults mostly
internally

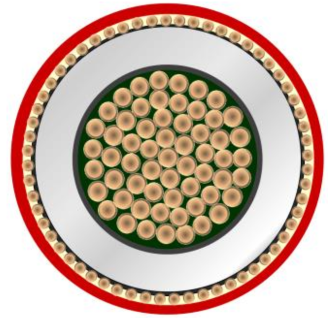


Unshielded
segmented cable

LV

3 to 5
conductors

Faults to ground
and
between cores



Shielded
concentric cable

MV/HV

1 conductor
plus shield

Faults between
Core and shield

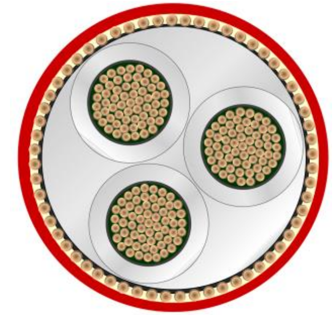
Shielded
concentric

MV/HV

3 conductors
with own shield
ea.

Faults between
Core and shield

Core to core
fault
unlikely except
for extreme
external damage



Belted cable w.
common shield

MV

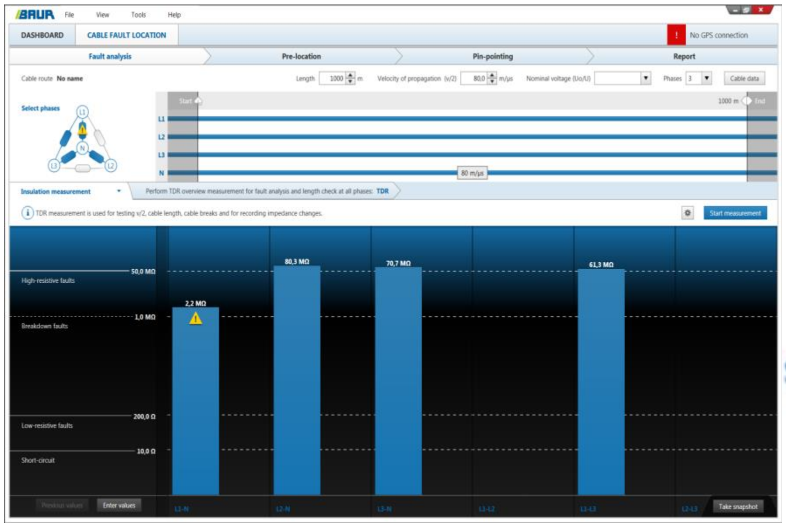
3 conductors

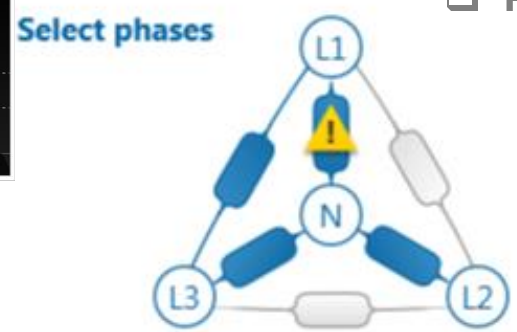
Faults between
Core and core
and shield

Fault location
difficult due to
multiple path
Core - core
likely

2nd step: fault analyses and insulation test

Type of cable fault





- ❑ Phase 1 – Neutral
- ❑ Phase 2 – Neutral
- ❑ Phase 3 – Neutral
- ❑ Phase 1 – Phase 2
- ❑ Phase 2 – Phase 3
- ❑ Phase 3 – Phase 1

Check the Insulations resistance between core / core and core / sheath

2nd step: fault analyses and insulation test

Type of cable fault

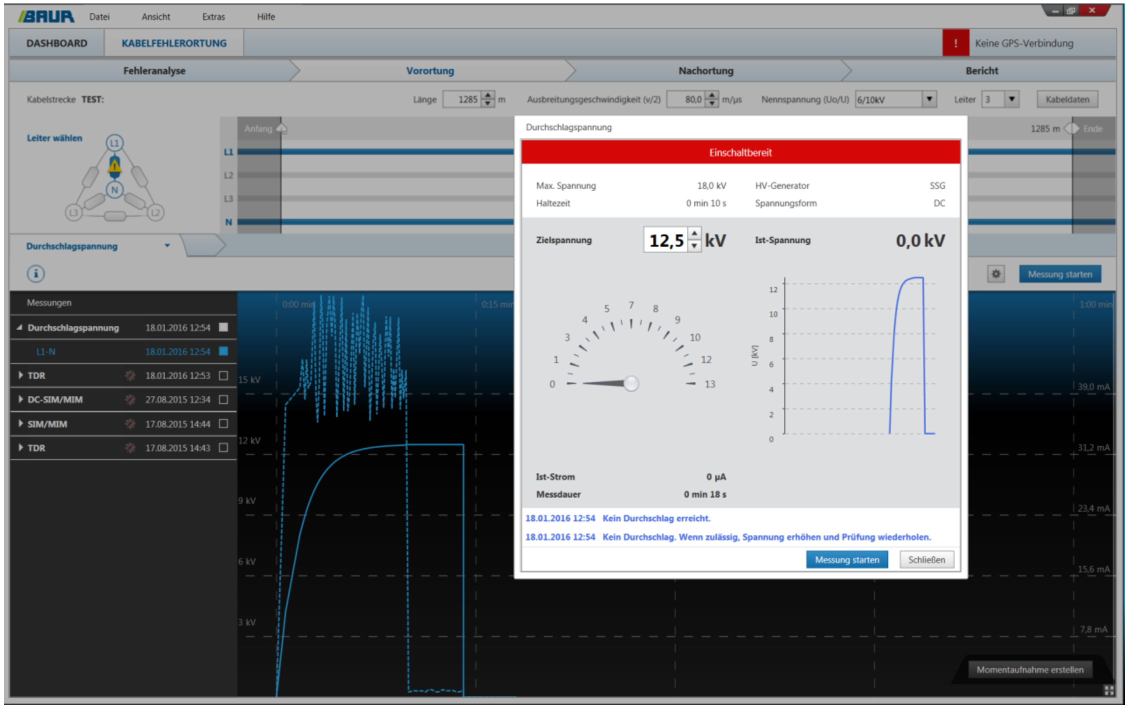
- **Low resistant faults (R < 100 Ω) ISO**
  short circuit (R < 10 Ω)
- **High resistant faults (100 Ω < R < ca. 1M Ω) ISO**
  Restistive fault
- **High resistant faults (R → ∞ Ω) Breakdown voltage**

faults between core-core or/and core-sheath

- **Cable Earth faults Leakage current**
  Sheath faults
  Earth faults

defects on the outer insulating sheath/Jacket (PVC, PE)
Shield or conductor contact to earth

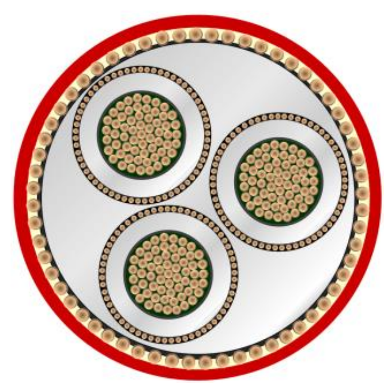
Type of cable fault – Breakdown voltage detection

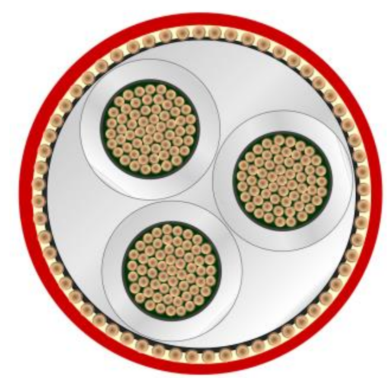


- ❑ Phase 1 – Neutral
- ❑ Phase 2 – Neutral
- ❑ Phase 3 – Neutral
- ❑ Phase 1 – Phase 2
- ❑ Phase 2 – Phase 3
- ❑ Phase 3 – Phase 1

Measurement between Phase and Neutral - Exception: Belted cable

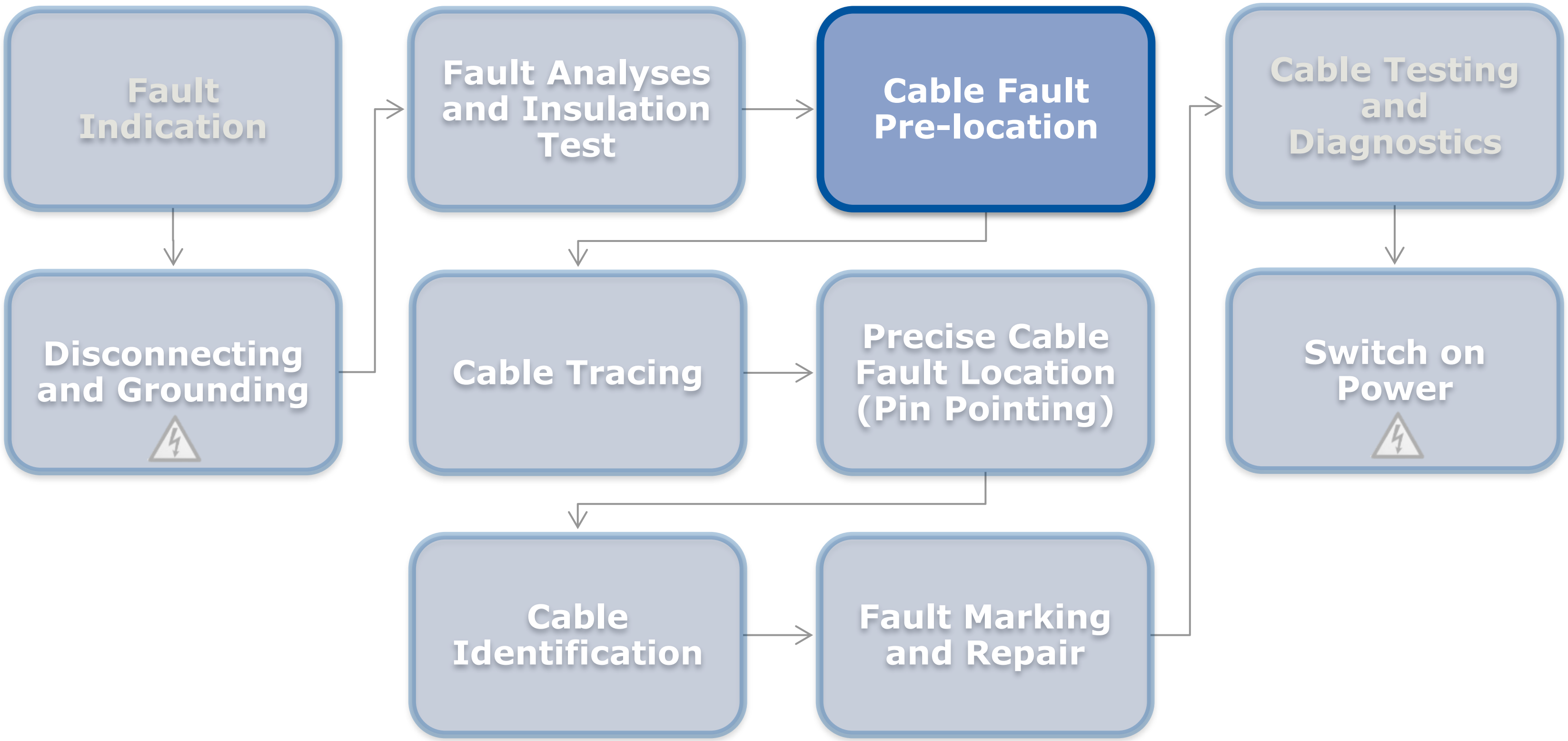
Determination of breakdown voltage between core and shield





3rd step

Cable fault pre-location

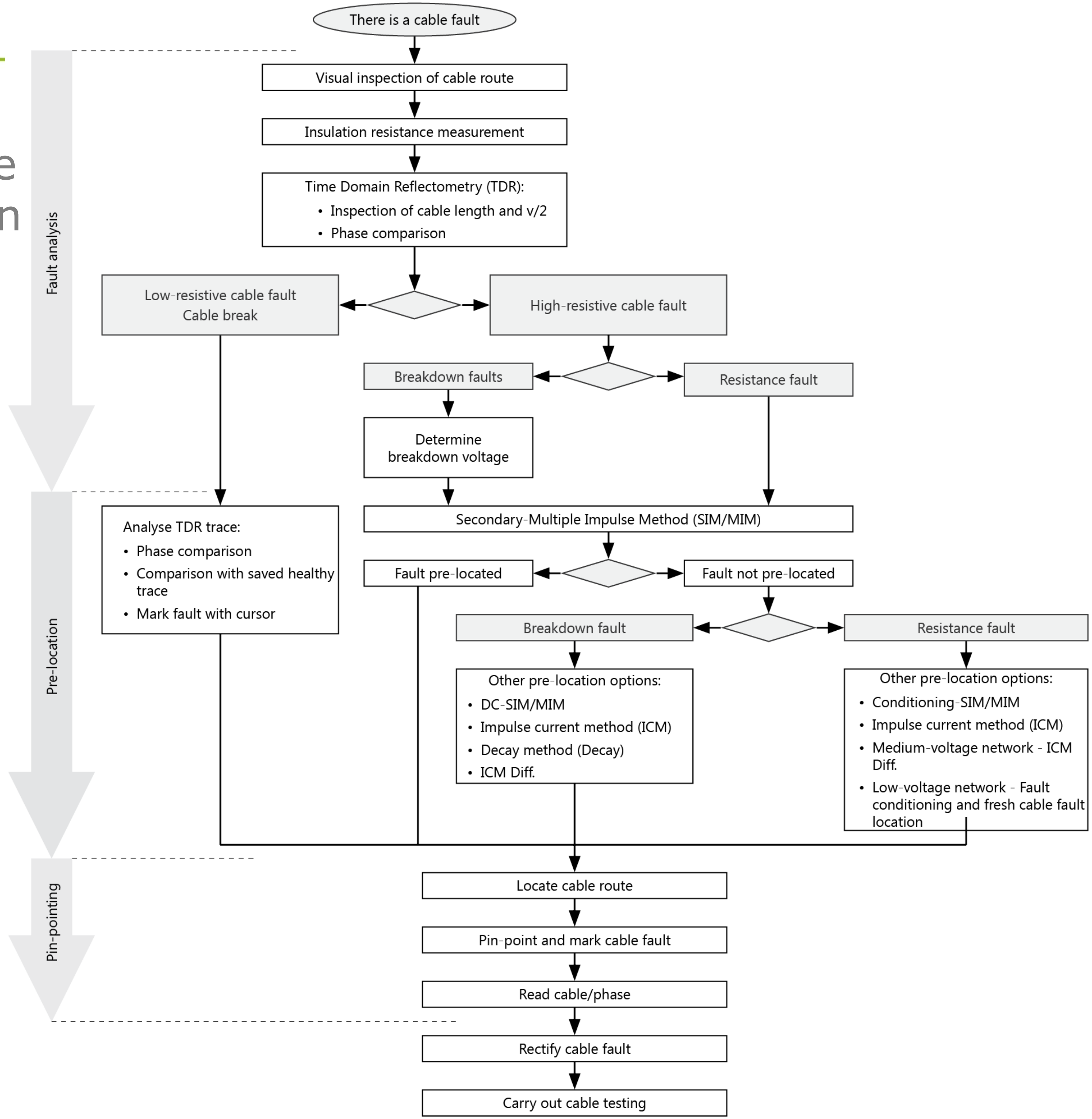


3rd step: cable fault pre-location

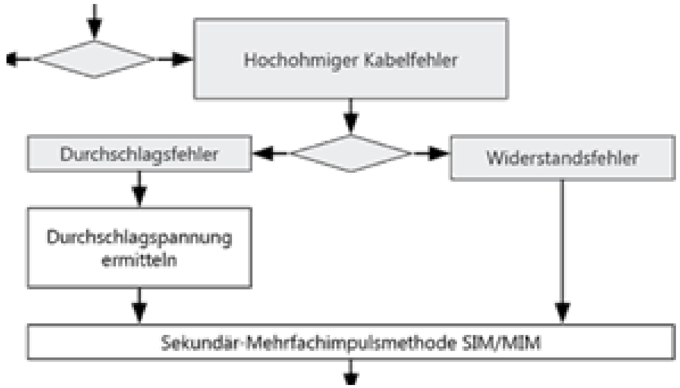
Methods of cable fault pre-location

Method	Fault characteristics
Pulse Reflection Method (**TDR**)	short circuit faults (low Ω), cable cuts
SIM / MIM Secondary / Multiple Impulse Method	high Ω – faults, flashing faults
Conditioning **SIM/MIM**	high Ω – faults , flashing faults, wet faults
Burn Down technique	high Ω – faults, wet Faults
Impulse Current Method - **ICM**	high Ω – faults, flashing faults (preferred for long cables)
Decay Travelling Wave Method	Flashing HV Faults
Differential Method	branched Cable systems faults
Bridge measurement	high & low Ω – faults, cable sheath faults

Methods of cable fault pre-location Flowchart



Types of failures

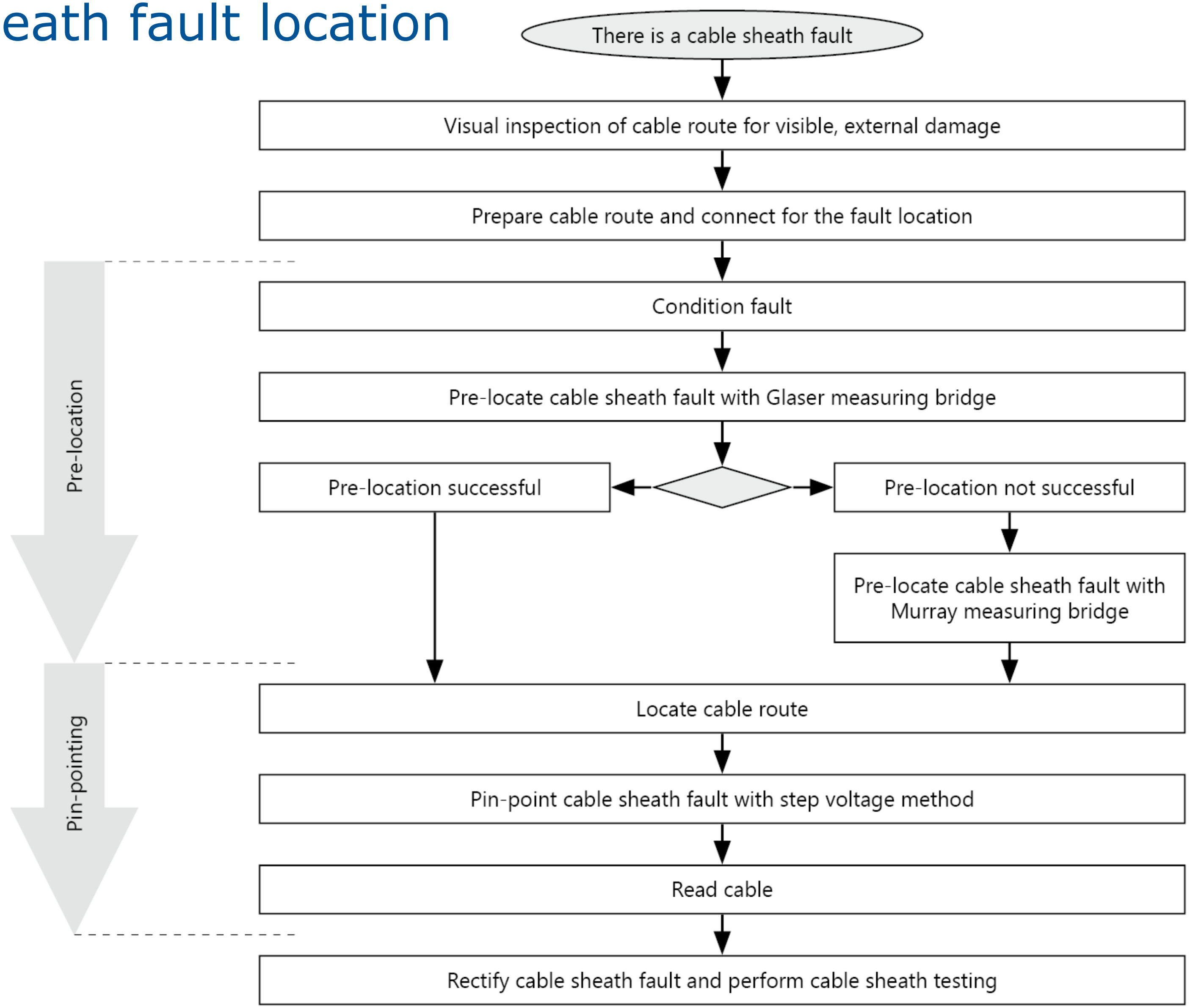


Breakdown faults
The failure has an infinite resistance and will be ignited by increasing the voltage

Resistance faults
The resistance of the failure can be measured.
Typically 2-5kV are enough to ignite the failure

Methods of cable fault pre-location

Flowchart sheath fault location



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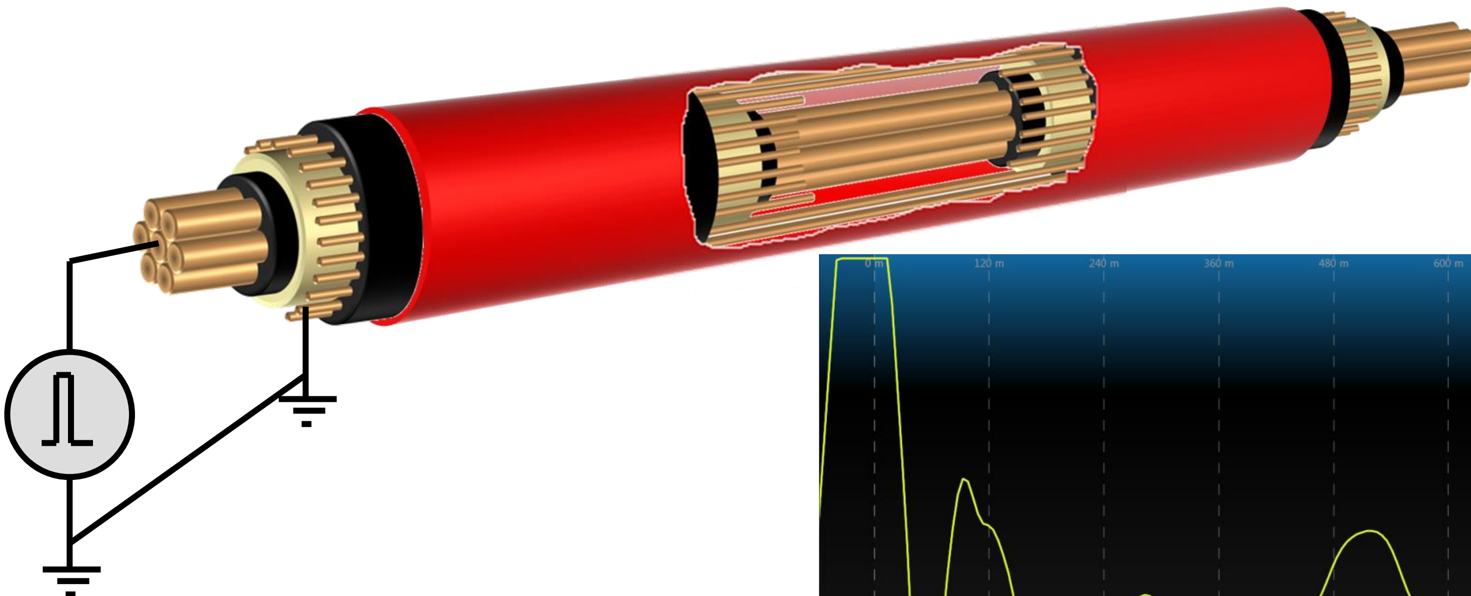
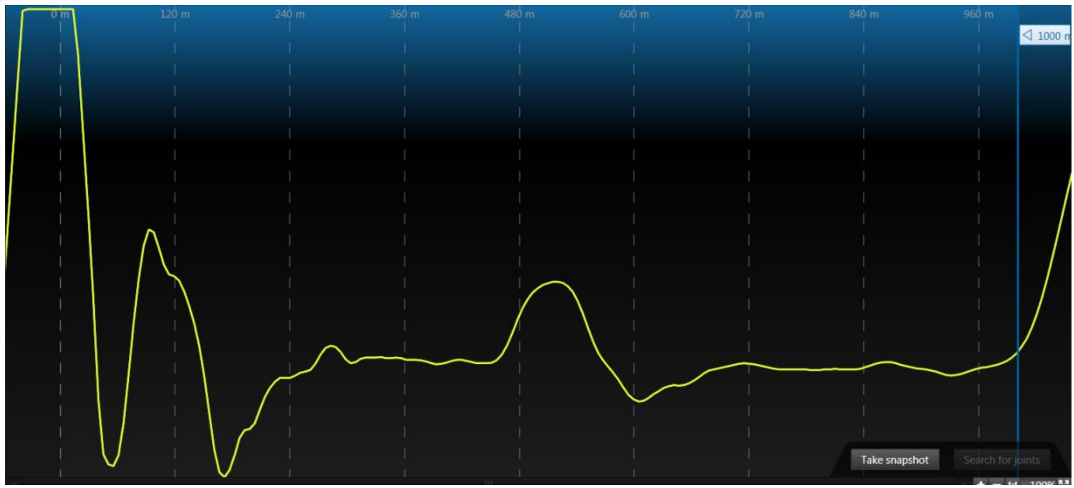
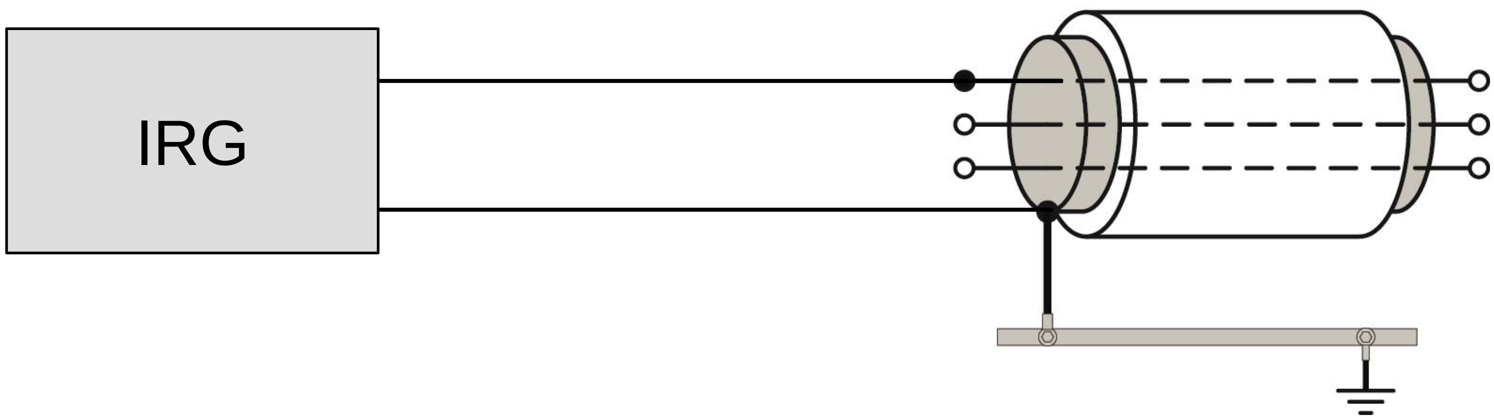
Principles of the reflection technology

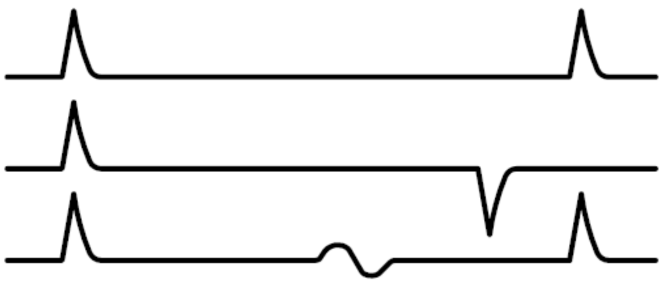




The TDR works on a similar principle as a radar
The transmitted TDR pulse travels along the cable.
Each impedance change reflects portions
of the impulse back to the TDR.
The TDR then converts this time to the distance.

Pulse Reflection Method (TDR)





high Ω, open end

low Ω, short circuit fault

change of impedance, e.g. joint

l = t x v/2

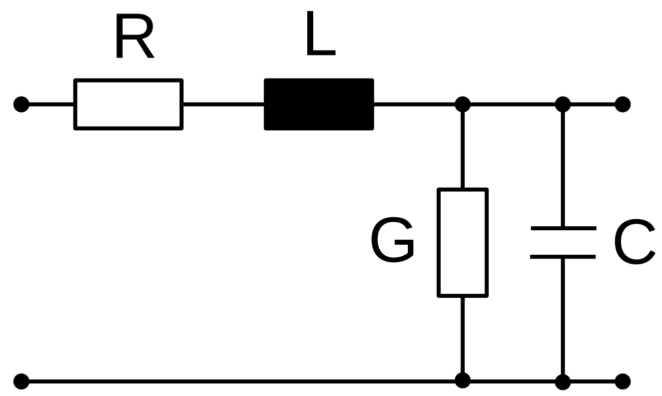
reflection factor $r = \dfrac{Z_2 - Z_1}{Z_2 + Z_1}$

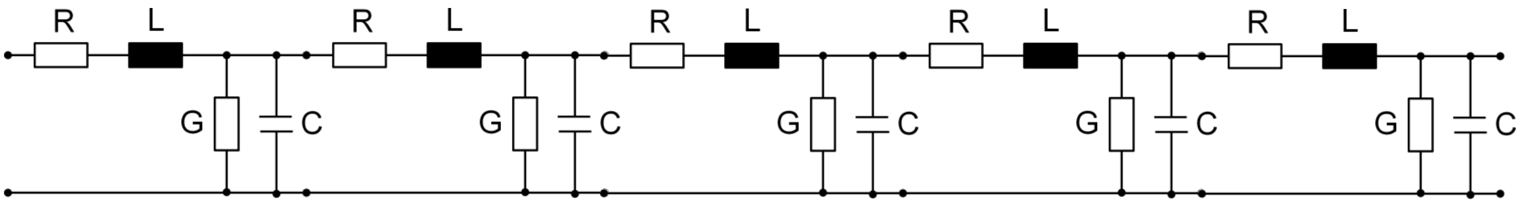
Z1 …. Cable impedance of the cable

Z2 …. Impedance of the failure position

The electrical diagram

The cable is represented by an infinite amount of
R - Serial Resistance
L - Serial Inductivity
G - Parallel Resistance
C - Parallel Capacities





C´ = Capacity value **in nF/km**
G´ = Conductivity value **in Ohm/km**
L´ = Inductivity value in mH/ per km
R` = Resistance value in Ohm/ per km

Impedance

(Frequency depending resistance)

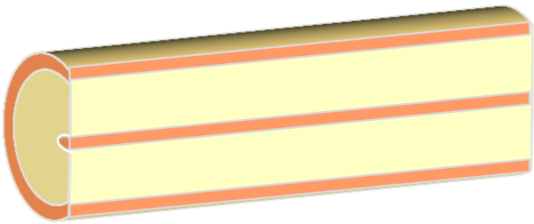
The resistance is determined by R und G
The impedance of the cable is determined by L and C

The equation to calculate the impedance is $\sqrt{\frac{R+J\omega \times L}{G+j\omega \times C}}$

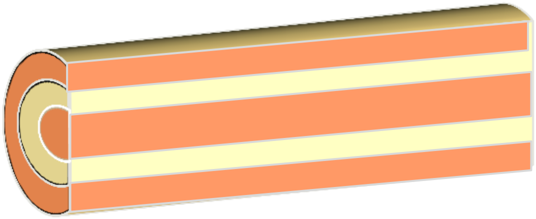
As approximation with high frequencies we can use $\boxed{Z=\sqrt{\frac{L}{C}}}$

General Rules:

Thin conductor – thick insulation
L = high – C = low Z = High

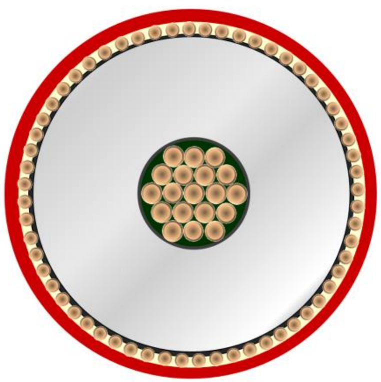


Thick conductor – thin insulation
L = low – C = high Z = low

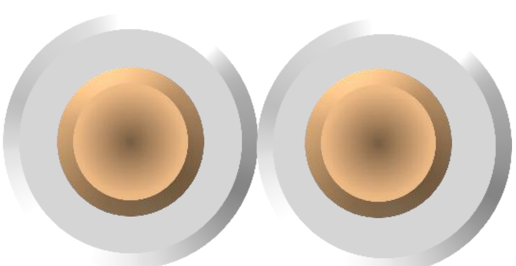


Cable impedance

High impedance
thick insulation in relation
to conductor cross section

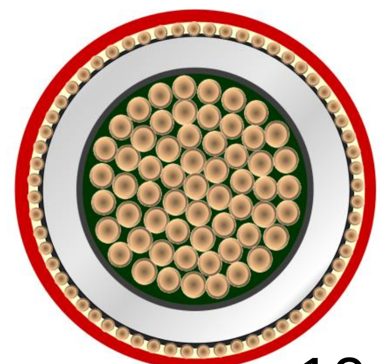


50 – 75 Ω



100 – 120 Ω

Low impedance
thin insulation in relation
to conductor cross section



10 – 50 Ω

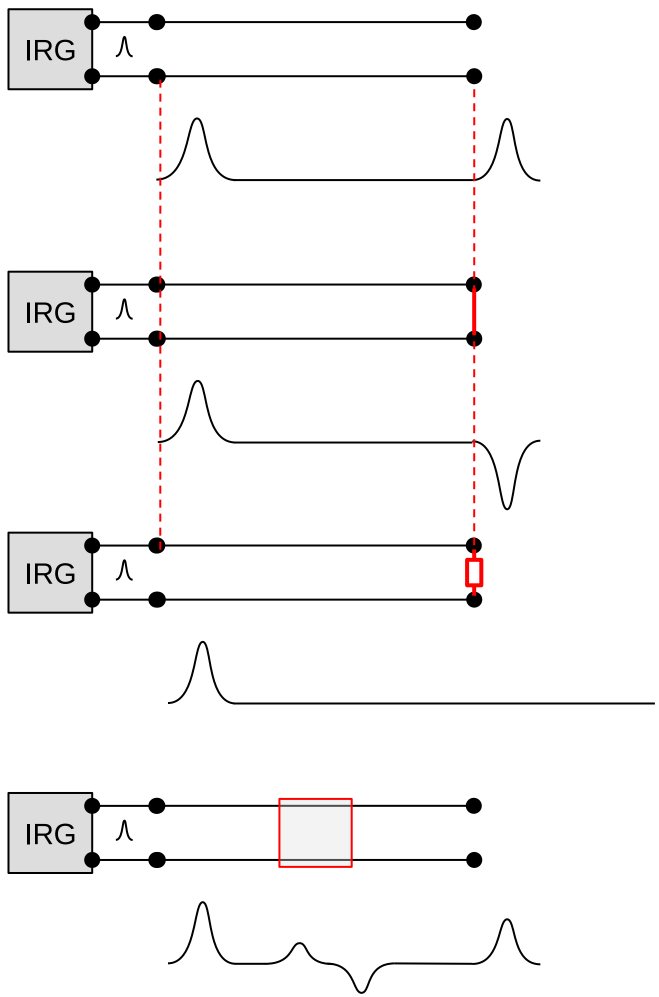
Cable impedance values

Overhead line	> 300 Ω
Telecom cable	app. 135 Ω
Coaxial cable	50 Ω, 75 Ω
Energy cable	app. 20 Ω
Tramway cable	app. 5 -10 Ω

Pulse Reflection Method TDR Basics

$$r = \frac{Z2 - Z1}{Z2 + Z1} = 1$$

$Z1 = \mathit{Cable\ impedance}$ to the point of failure
$Z2 =$ Impedance of the failure



Open End

$$Z2 = \infty$$
$$Z1 = 5 \ldots 150\Omega$$
$$r = \frac{\infty - Z1}{\infty + Z1} = 1$$

Short at the end

$$Z2 = 0$$
$$Z1 = 5 \ldots 150\Omega$$
$$r = \frac{0 - Z1}{0 + Z1} = -1$$

Matched impedance

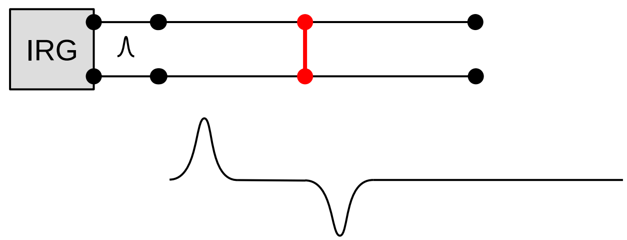
(Telecom)

$$Z2 = Z1$$
$$Z1 = 5 \ldots 150\Omega$$
$$r = \frac{Z1 - Z1}{Z1 + Z1} = 0$$

Joint

Pulse Reflection Method TDR Basics

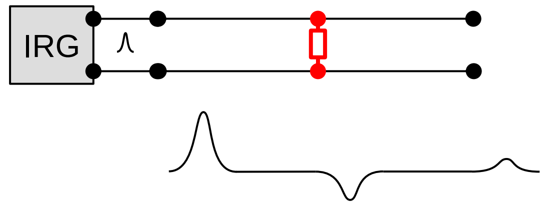
Short Core to Core



$$Z2 = 0$$
$$Z1 = 5 \dots 150\Omega$$

$$r = \frac{0 - Z1}{0 + Z1} = -1$$

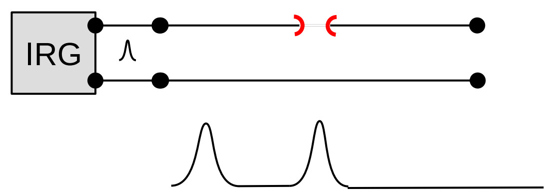
Parallel resistance core to Core



$$e.g.\, Z2 = \frac{1}{2} Z1$$
$$Z1 = 5 \dots 150\Omega$$

$$r = \frac{\frac{1}{2}Z1 - Z1}{\frac{1}{2}Z1 + Z1} = -\frac{1}{3}$$

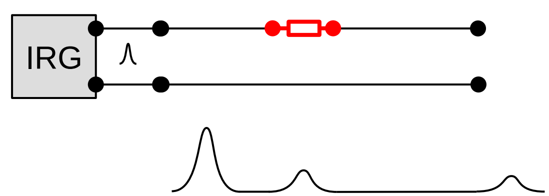
Interrupted cable



$$Z2 = \infty$$
$$Z1 = 5 \dots 150\Omega$$

$$r = \frac{\infty - Z1}{\infty + Z1} = 1$$

Serial Resistance

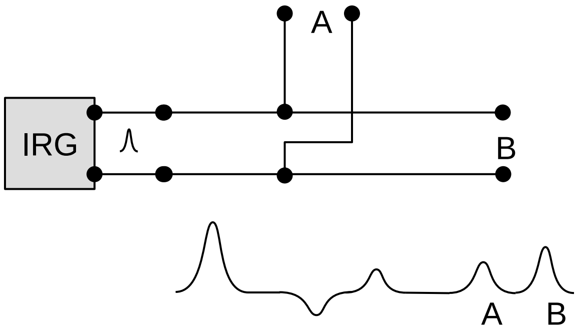


$$\text{e.g. } Z2 = 2 * Z1$$
$$Z1 = 5 \dots 150\Omega$$

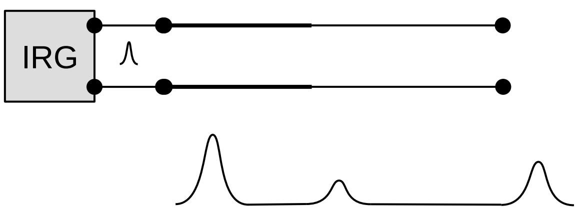
$$r = \frac{2Z1 - Z1}{2Z1 + Z1} = \frac{1}{3}$$

Pulse Reflection Method TDR Basics

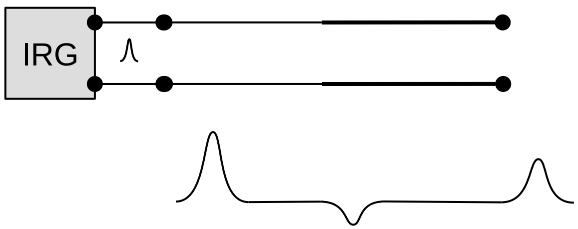
T Joint



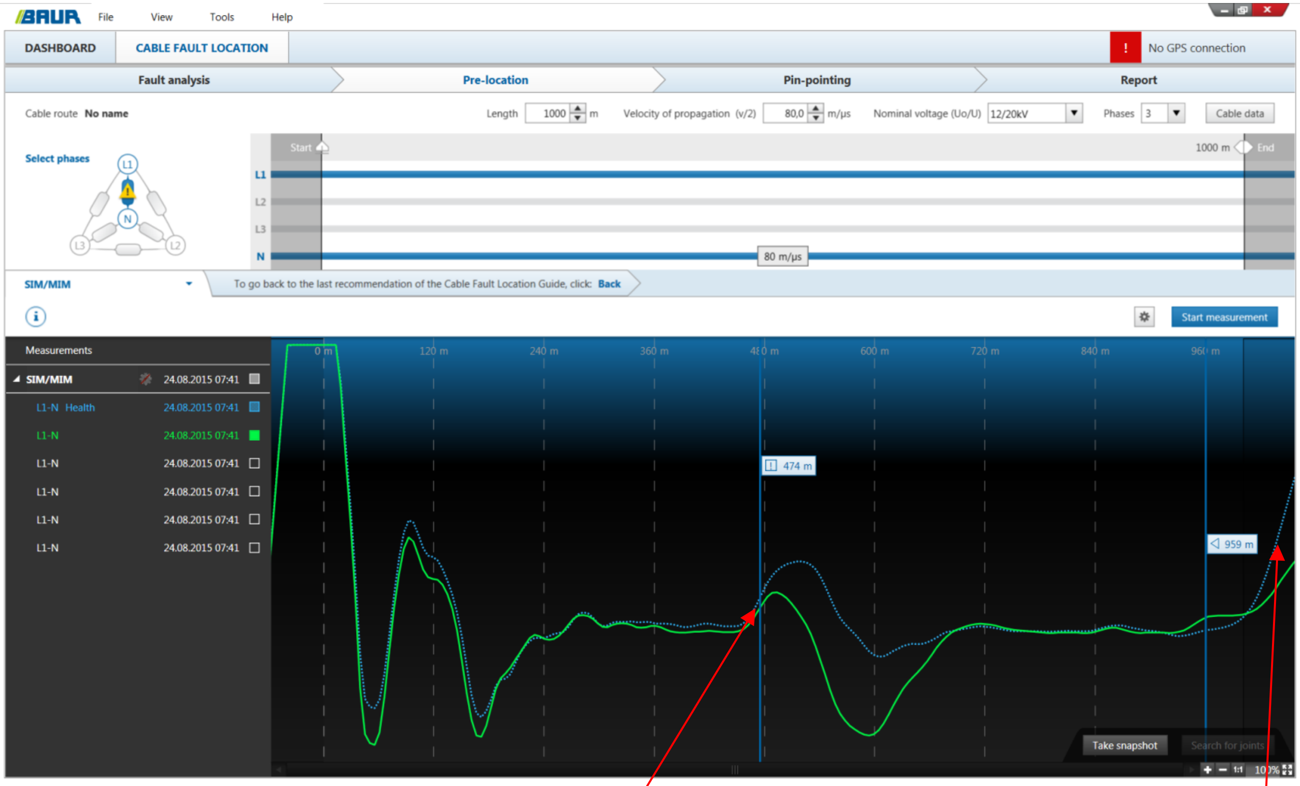
Impedance change Positive



Impedance change negative



Pulse Reflection Method (TDR), comparison

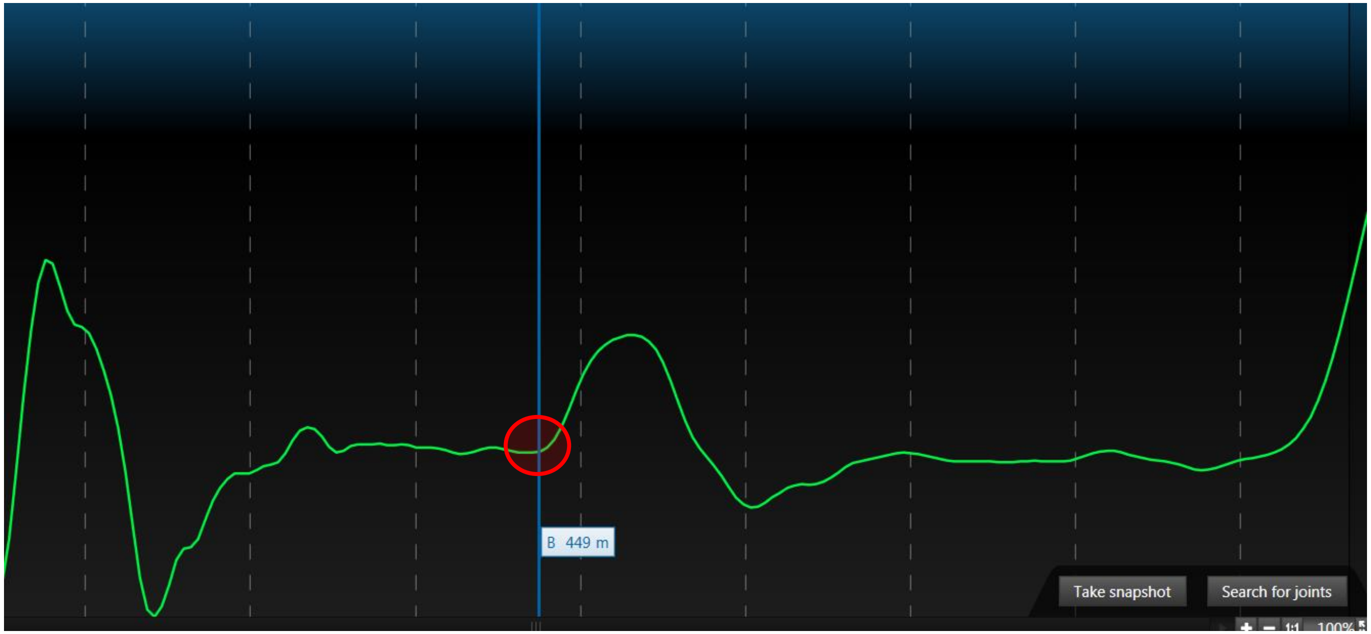


Negative reflection at the fault position (short circuit) of the **faulty core**

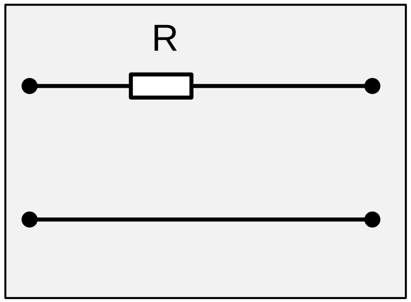
Positive reflection at the cable end of a good **reference core**

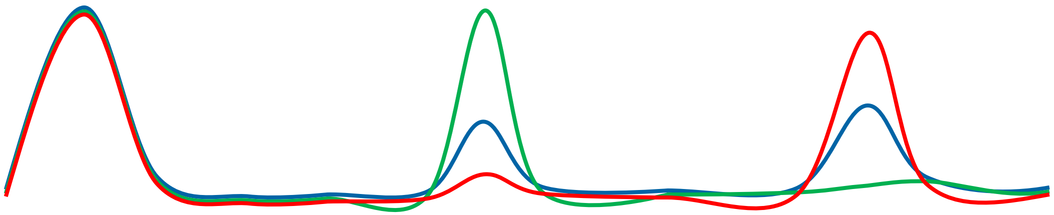
The impulse

The distance measurement is done at the “Foot point” the point of the impulse.
The Foot point “sees” the change of impedance first

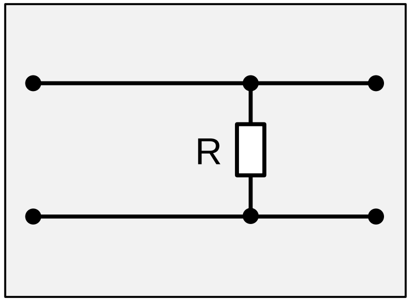


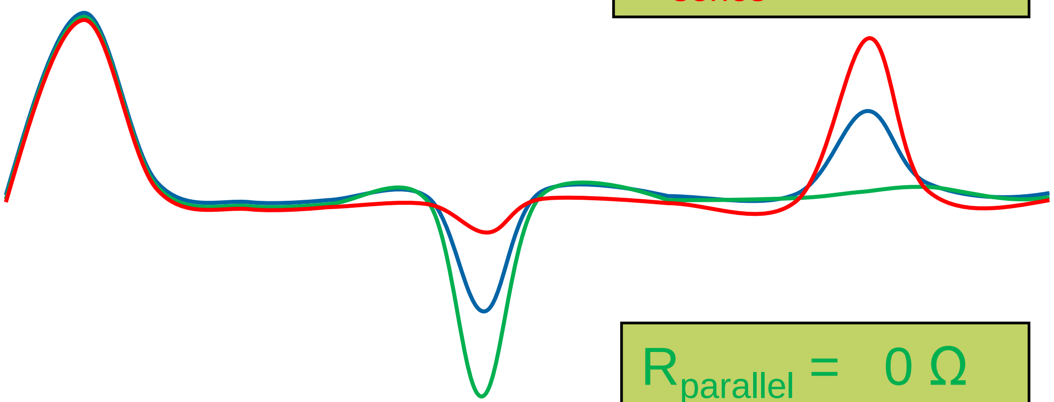
Influence of the fault resistance





$R_{series} = \infty$
$R_{series} = 100\ \Omega$
$R_{series} = 5\ \Omega$

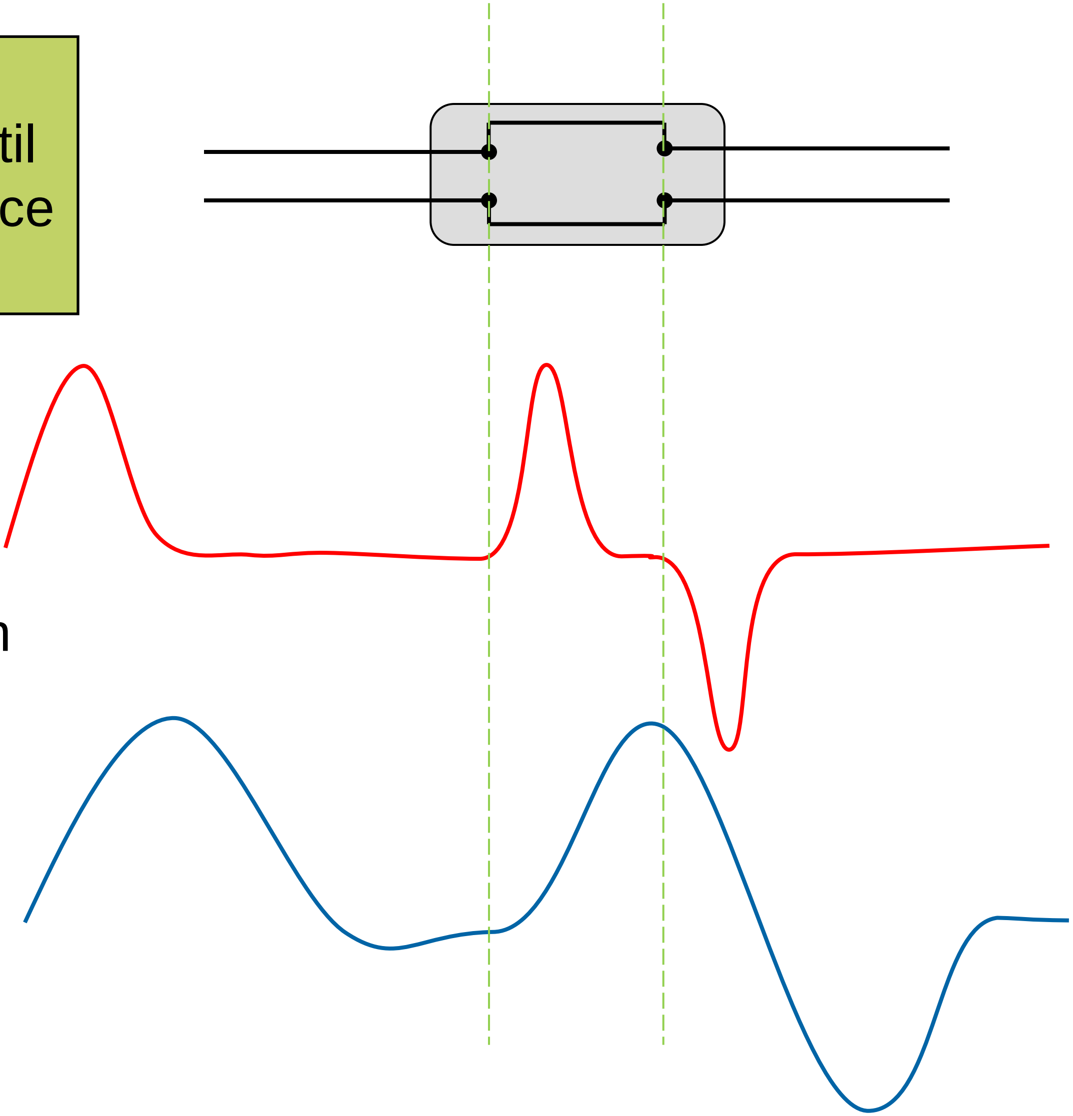




$R_{parallel} = 0\ \Omega$
$R_{parallel} = 100\ \Omega$
$R_{parallel} = 250\ \Omega$

Pulse width

Rule:
Increase the pulse width until the end is visible, then reduce until details become visible



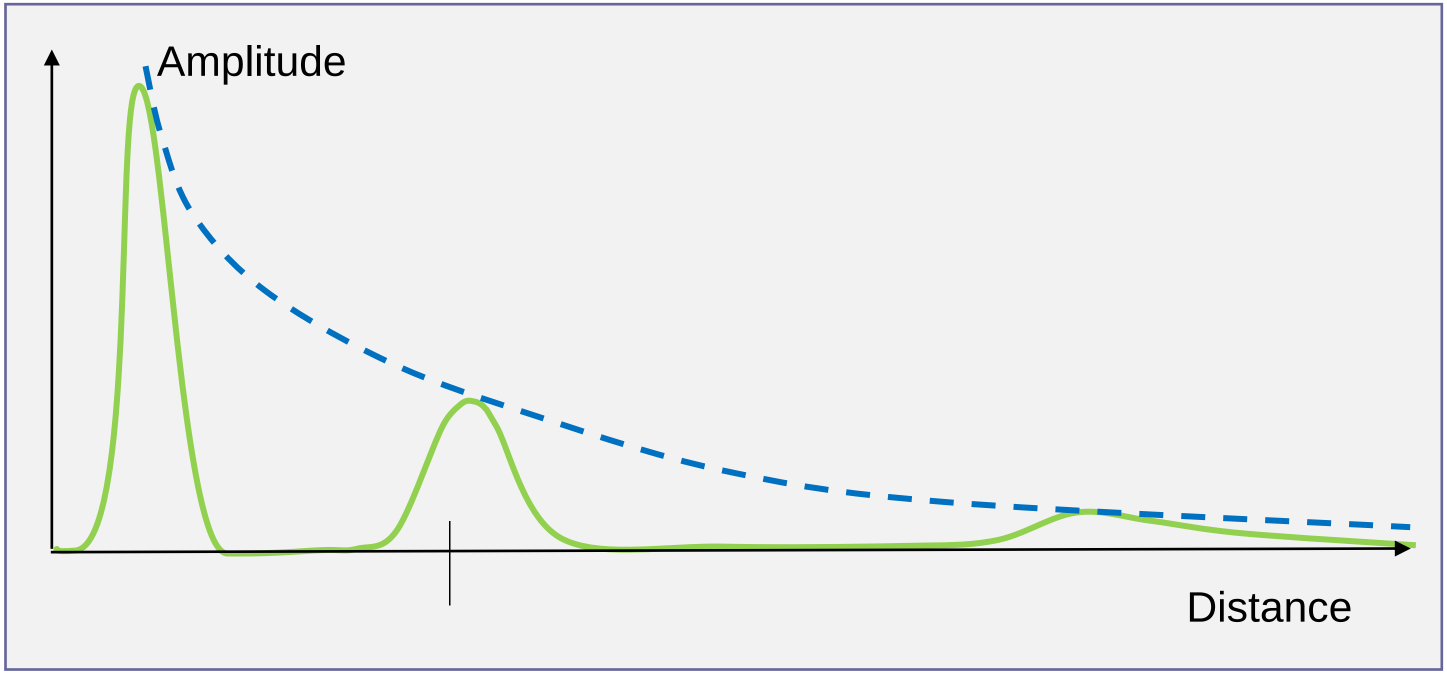
Narrow pulse — short distance, high resolution

Wide pulse — long distance, low resolution

Pulse width

Pulse width	Time	Range ($^{V}/_{2}$ = 80 m/µs or NVP = 0.533)
100 ns	Up to 6.25 µs	Up to 500 m
200 ns	6.25 µs … 31.25 µs	500 m … 2,5 km
500 ns	31.25 µs … 93,75 µs	2,5 km … 7,5 km
1 µs	93,75 µs … 375 µs	7,5 km … 30 km
2 µs	375 µs … 750 µs	30 km … 60 km
5 µs	750 µs … 2 ms	60 km … 200 km

Cable attenuation – Cable dispersion



Attenuation defines the loss of signal amplitude over distance

Dispersion is the loss of higher frequencies over distance

The propagation Velocity v/2

The propagation velocity depends primarily on the dielectric, the insulation material between the conductors.

Dielectric	**Value ε_{rel}**
Vacuum	1
Plastics	2 to 4
Water	81

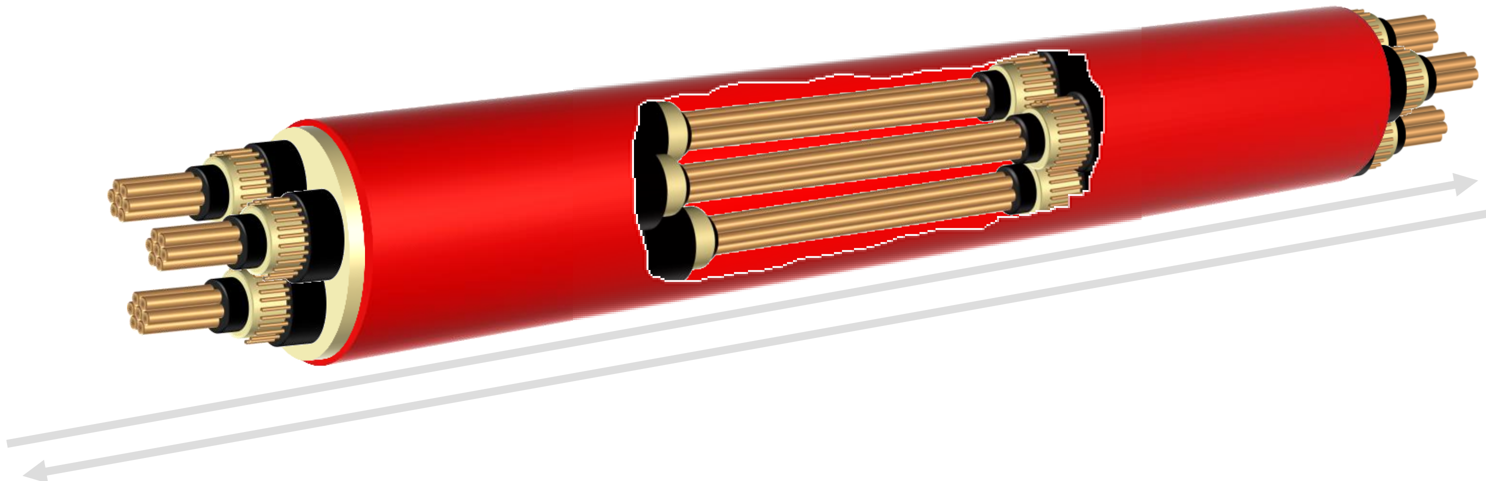
v	Propagation velocity of an electrical impulse
c	Speed of light 300 m/µs)
ε_{rel}	Relative electrical constant

$$V = \frac{c}{\sqrt{\varepsilon_r}} \qquad Z = \sqrt{\frac{L}{C}}$$

$$\varepsilon_{rel} \Uparrow \;\rightarrow\; Z \Downarrow \; + \; v \Downarrow$$

Z	Typical Impedance
L	Cable Inductivity
C	Cable Capacity

Propagation velocity and distance



$l_x = \left(\frac{v}{2}\right) \times t_x$

$\left(\frac{v}{2}\right)$ Half of the measured propagation velocity

v Propagation velocity of the electrical impulse

t_x Time of the electrical impulse to the cable end

lx Length of the conductor

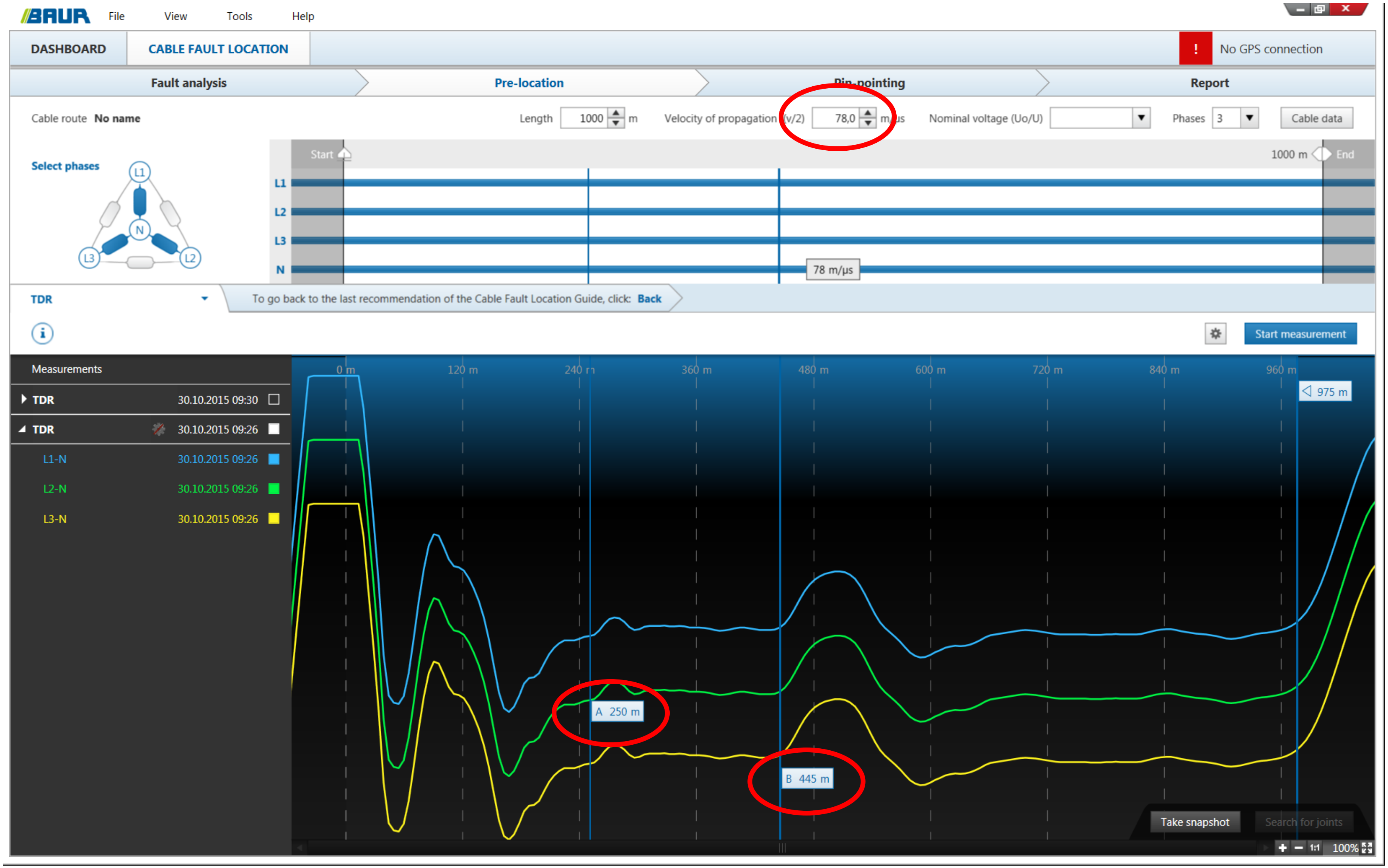
Propagation velocity v/2

In Vacuum 300 m/µs, app 80 m /µs or 250 ft/µs in cables.

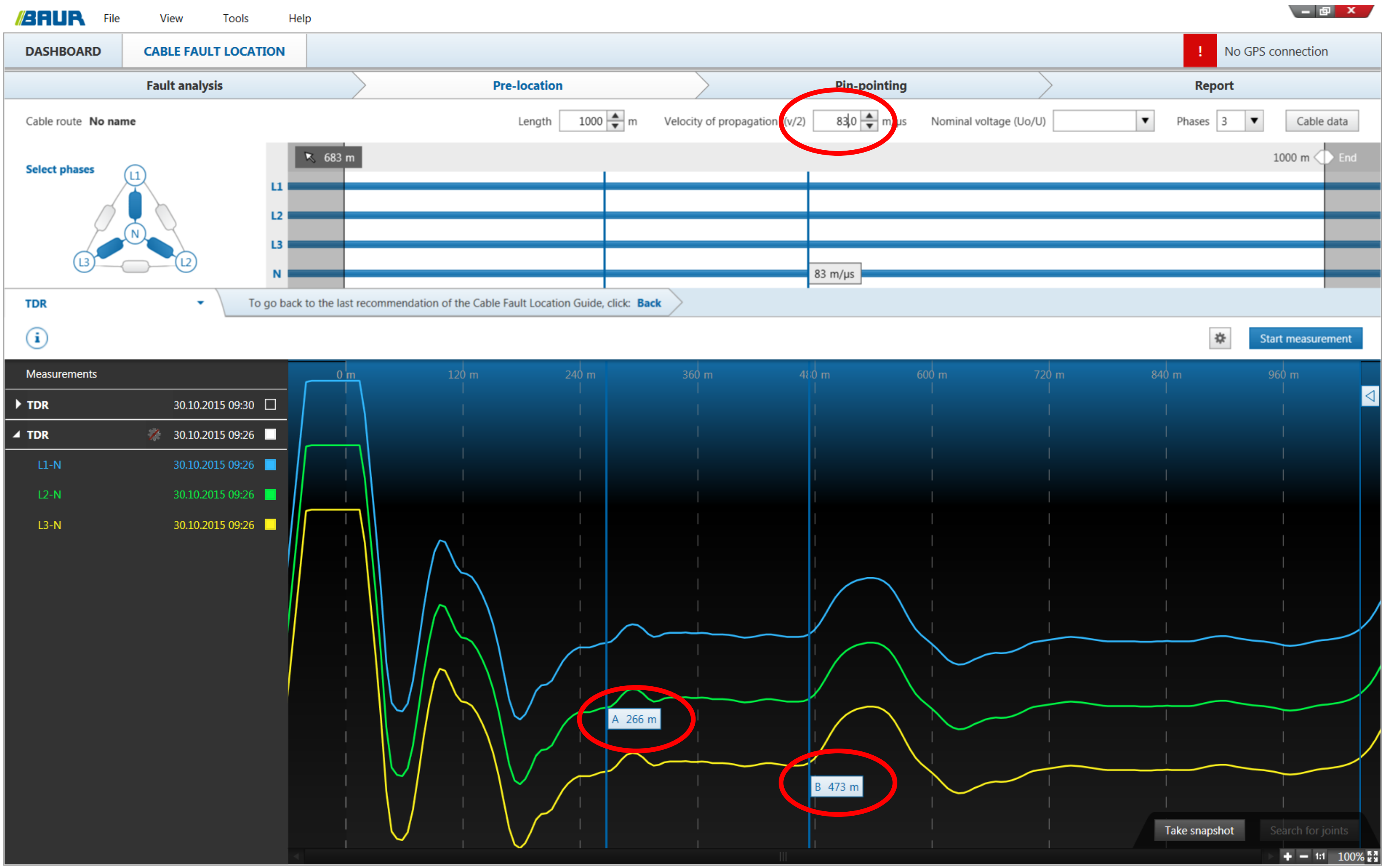
It is also defined as NVP Nominal Propagation velocity as percentage of the speed of light used primarily on telecom cables.

PILC	80 m/µs (77-82 m/µs)
PVC	78 m/µs (70-80 m/µs)
XLPE	85 m/µs (82-86 m/µs)
mixed line	83 m/µs
Telecom cable	95 – 120 m/µs
Overhead line	147,5 m/µs

Propagation velocity determination



Propagation velocity determination



Influences on the Propagation velocity

Impedance

Dielectric (colour (PVC), material of insulation)

Age of the cable

Temperature

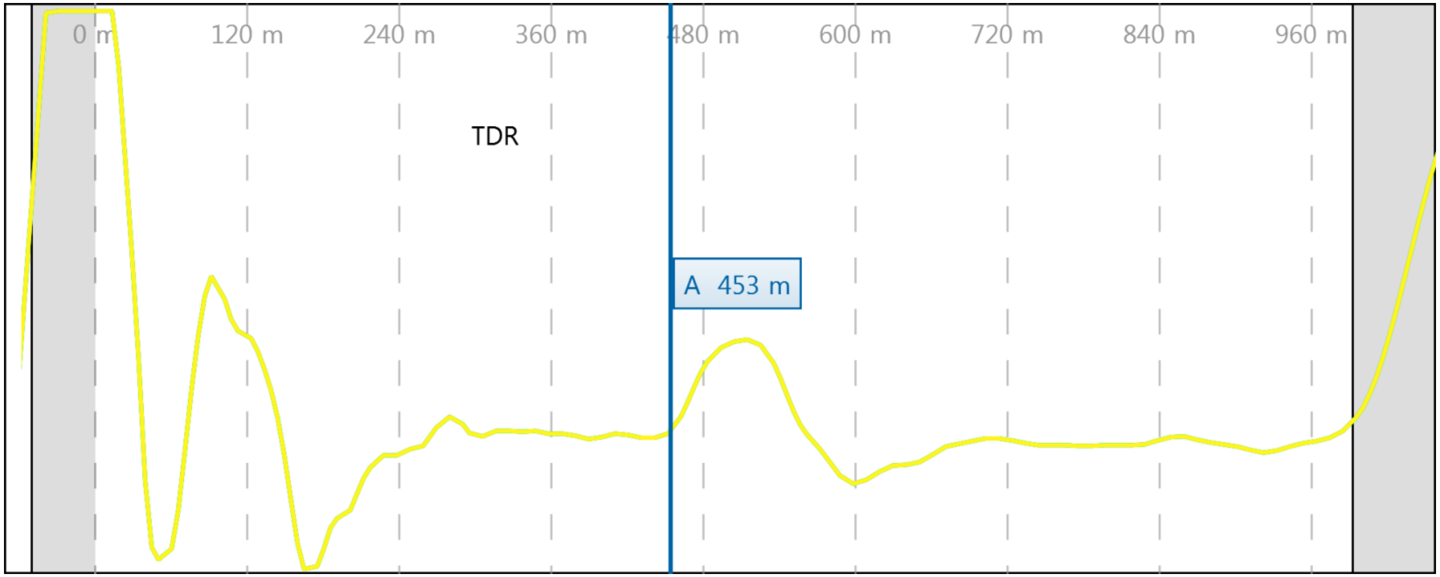
Water v/2 drops to approx. 65 m/µs

Arrangement of the cores inside the cable

High Voltage

A plain TDR Measurement will only show faults with a resistance which is significantly below the cable impedance.
„Visible" resistances are typically below 10 Ohms, higher resistances are may be visible, but are hardly recognisable.

Since most Faults have higher resistances or are so called flashing faults with infinitive resistance they need to be made visible by the support of specific HV applications.



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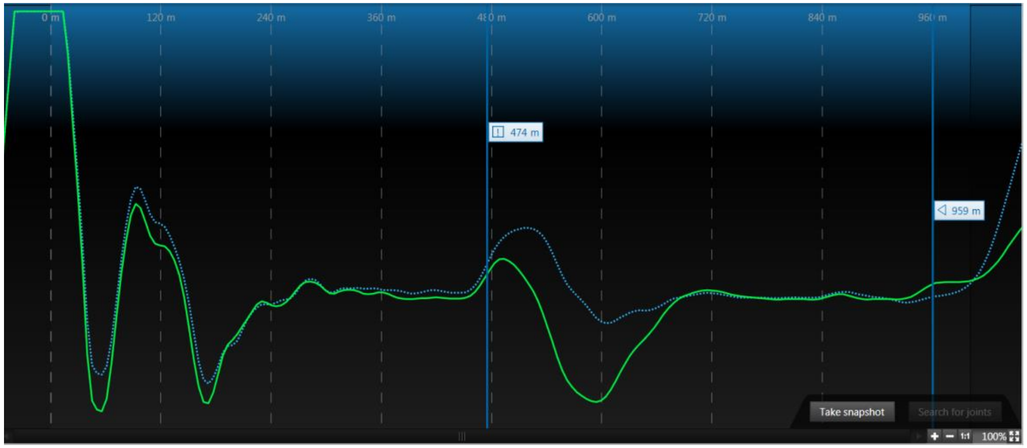
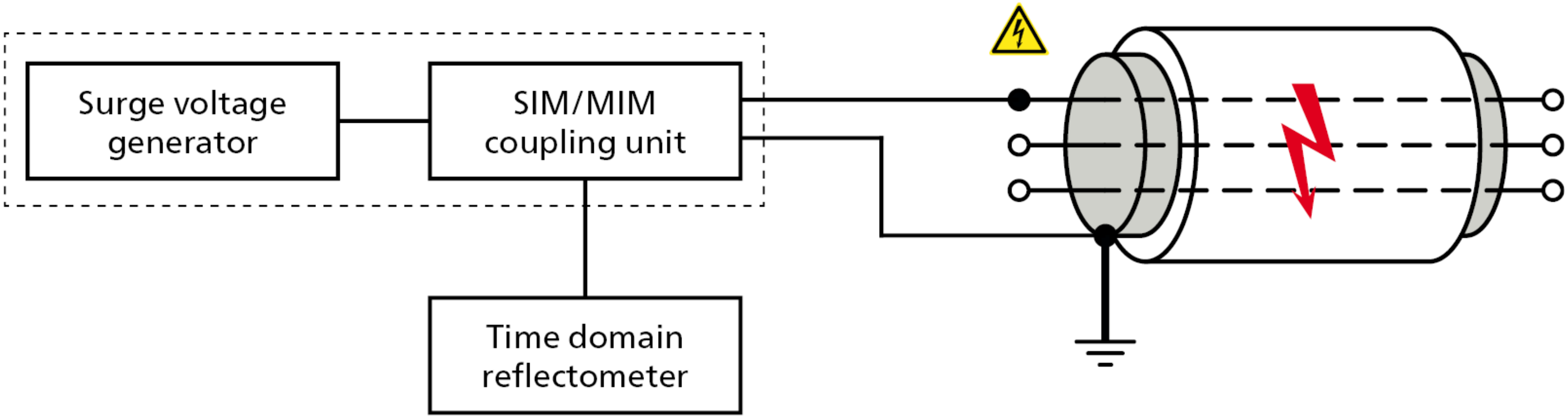
SIM – Secondary Impulse Methode

The general idea is a temporary short circuit triggered by a HV Flash over. While this flashover or arc is burning, the fault position is low resistive and appears to the IRG as negative reflection.
For these HV applications, the IRG requires special protective filters, which allow the operation of the IRG, while the HV is existent.

The principle is as a first step the recording of a good reference trace and following the comparison of this reference trace with the recording, obtained during the HV flashover, which shows the fault position as clear negative reflection .

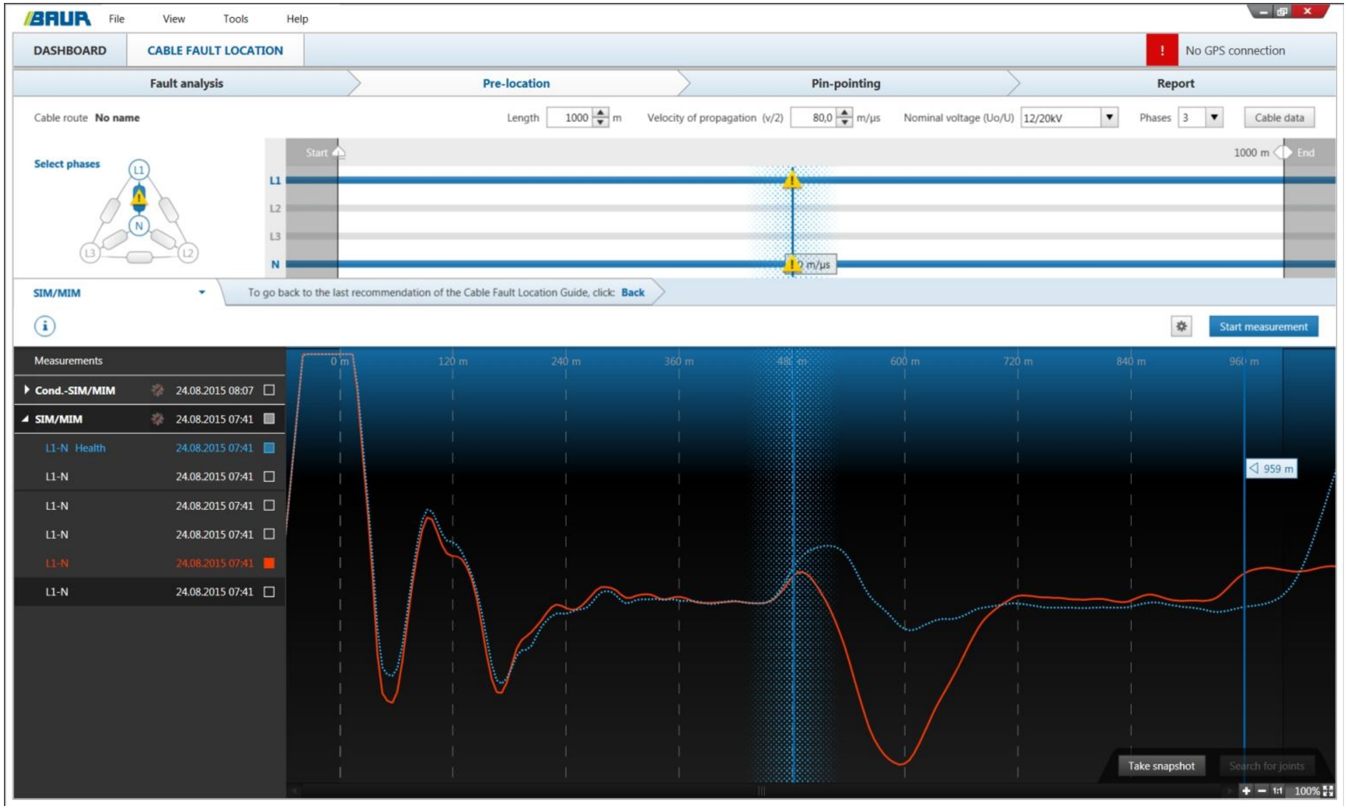


Secondary Impulse Method – SIM



l = t x v/2

Secondary Impulse Method - SIM



First measurement: positive reflection of the cable end

Second measurement: negative reflection from the arcing fault

(with high voltage impulse)

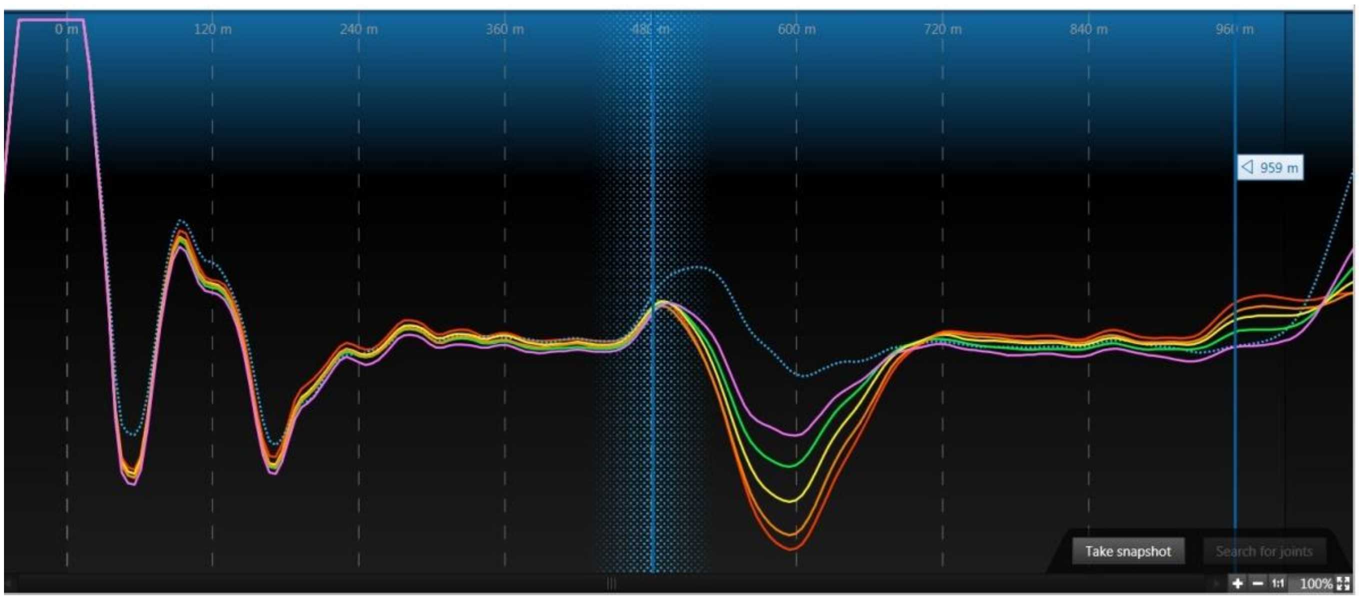
MIM – Multiple Impulse Method

The timing response of an fault is unpredictable

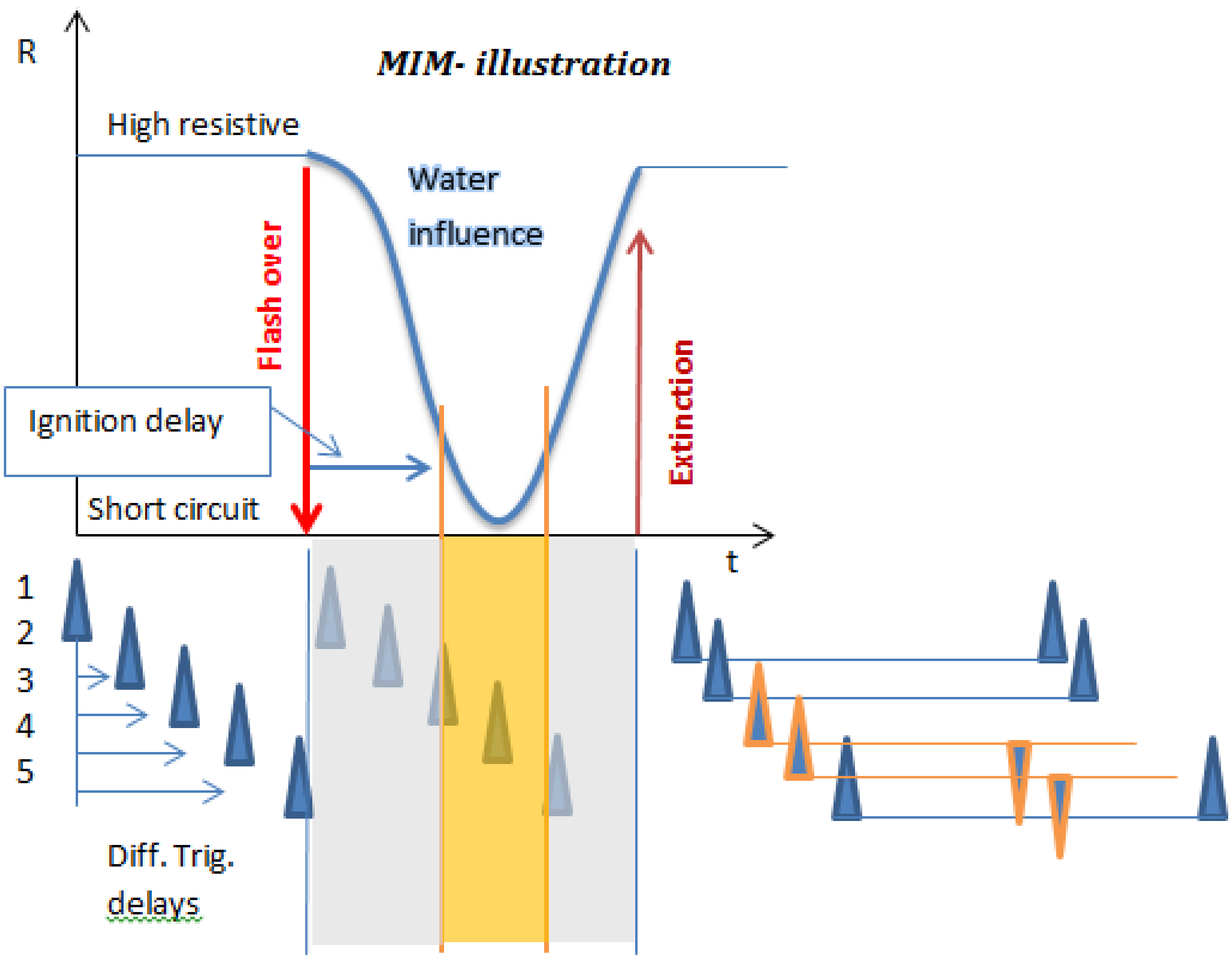
Depending on the cable length and its condition, it becomes sometimes difficult to trigger the breakdown in the right moment.

A simple and reliable solution is the automatic collection of several measurement to increase the possibility of having the one and correct trace.

By doing multiple SIM measurements, the MIM does 5 SIM measurements in a sequence and displays them.



Multiple Impulse Method – MIM, advanced SIM



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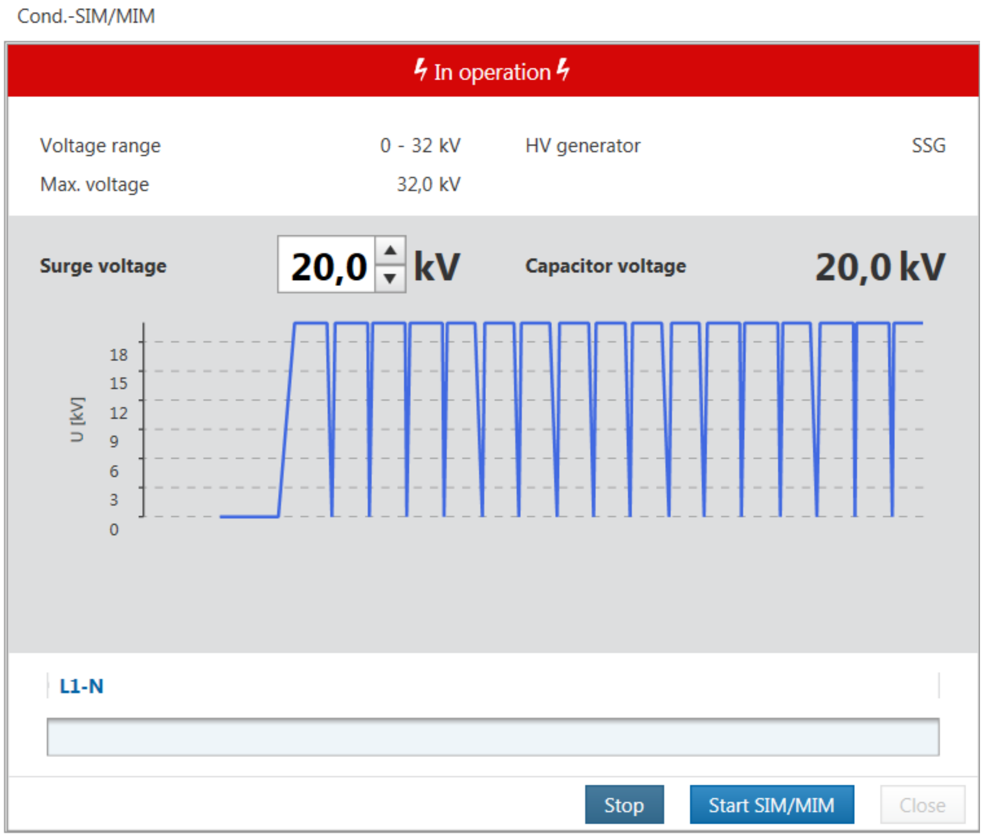
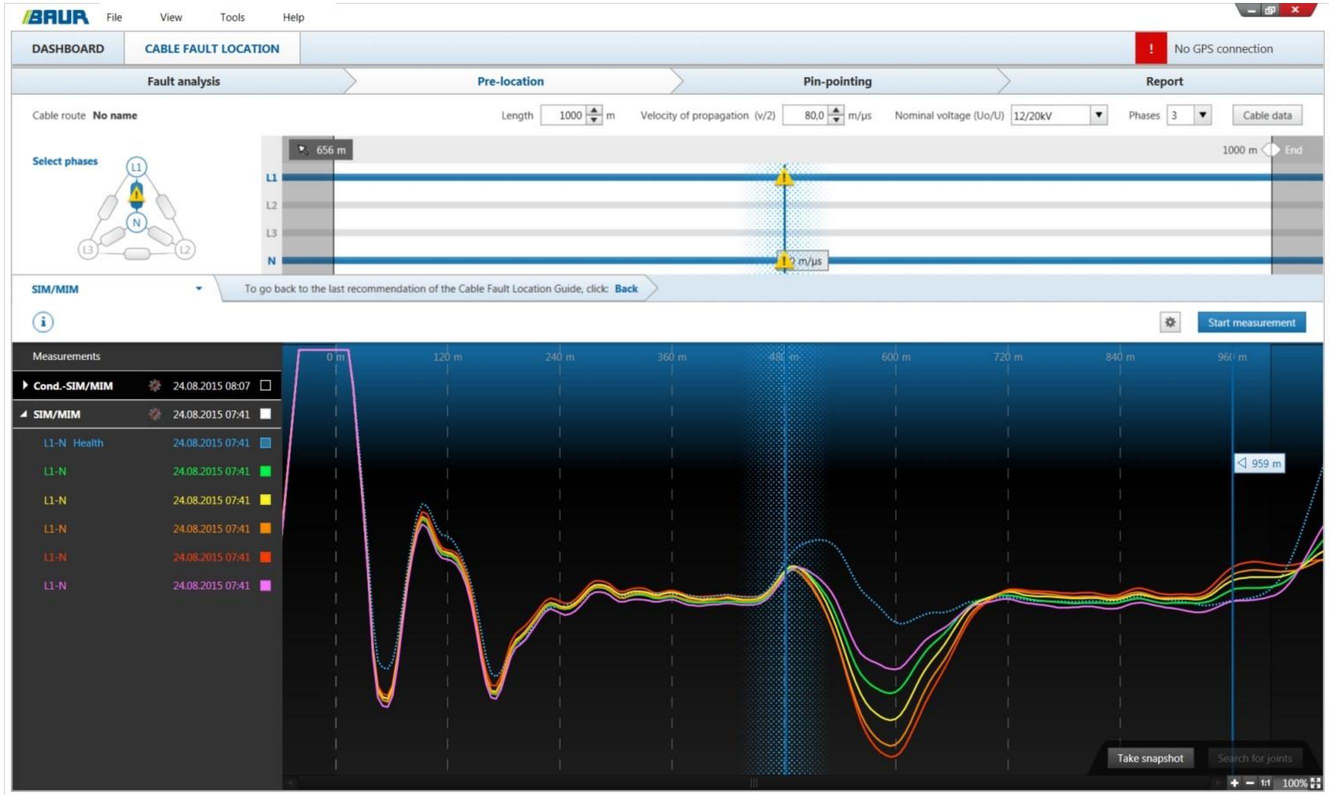
Conditioning SIM/MIM



Conditioning SIM/MIM Technique:

1. High Resistive / Wet Cable Fault
2. Continuous Surge discharging into the Cable Fault
3. Carbonizing of the Fault
4. The high resistive fault becomes low resistive
5. Cable Fault location with TDR & SIM Method

Conditioning SIM/MIM



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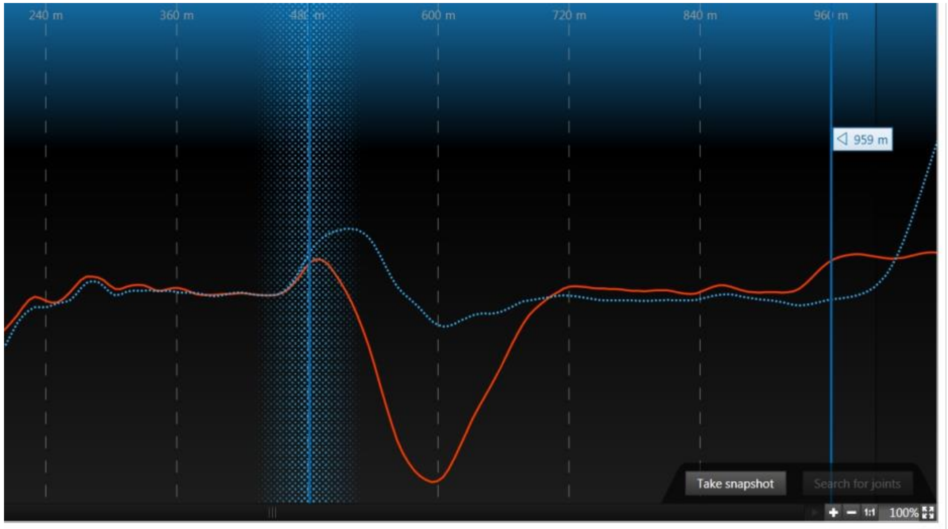
Bridge measurement	high & low Ω – faults, cable sheath faults

Burn Down Technique



Burn Down Process:

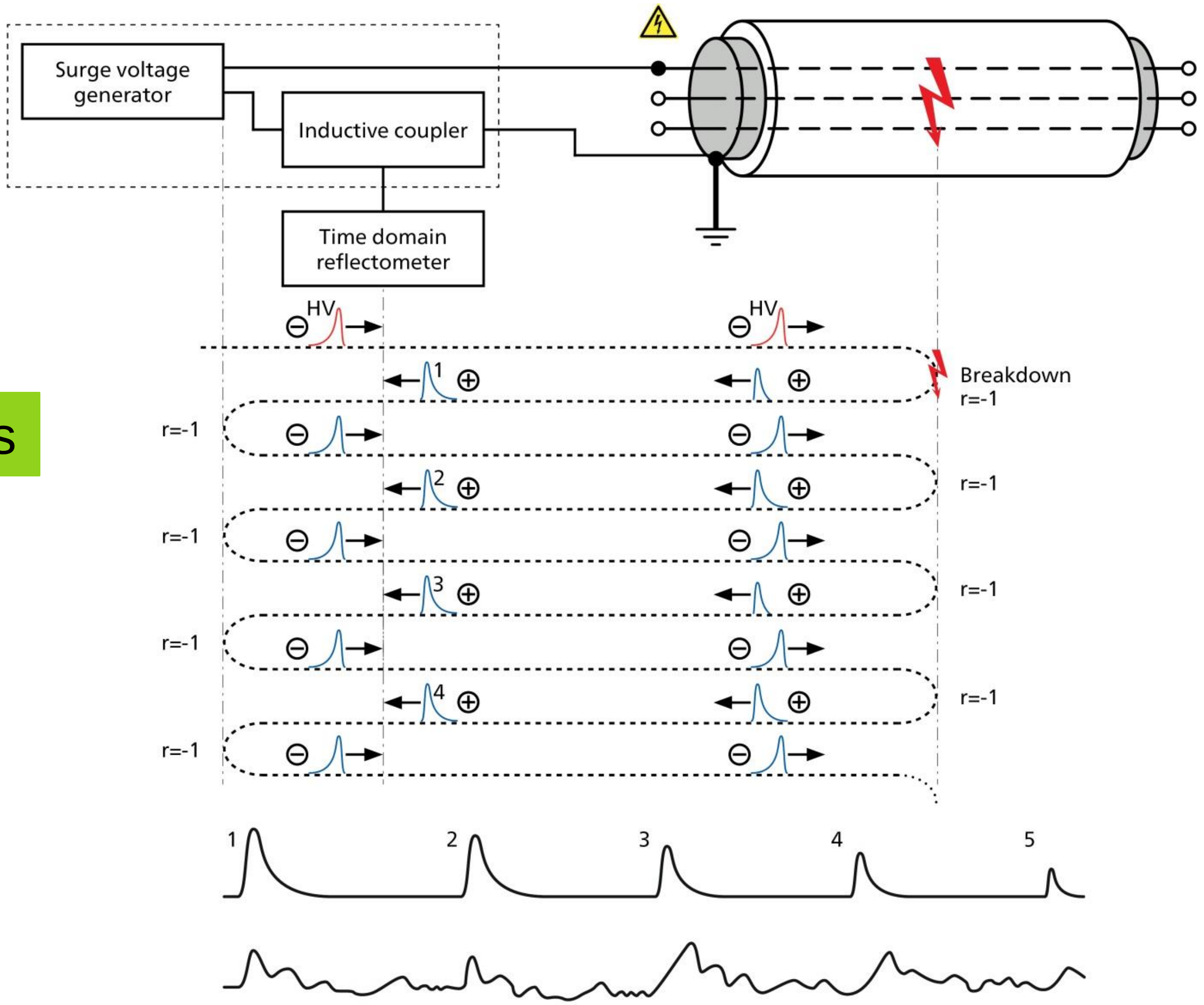
1. High Resistive Cable Fault Storage of reference trace
2. Energizing the Cable Fault with up to 90 A Current from the Burn unit
3. the Current will dry and carbonize the cable fault
4. Due this effect, the high resistive fault will become low resistive
5. Cable Fault location with the common TDR Method
6. Comparison to reference trace

Methods of cable fault pre-location

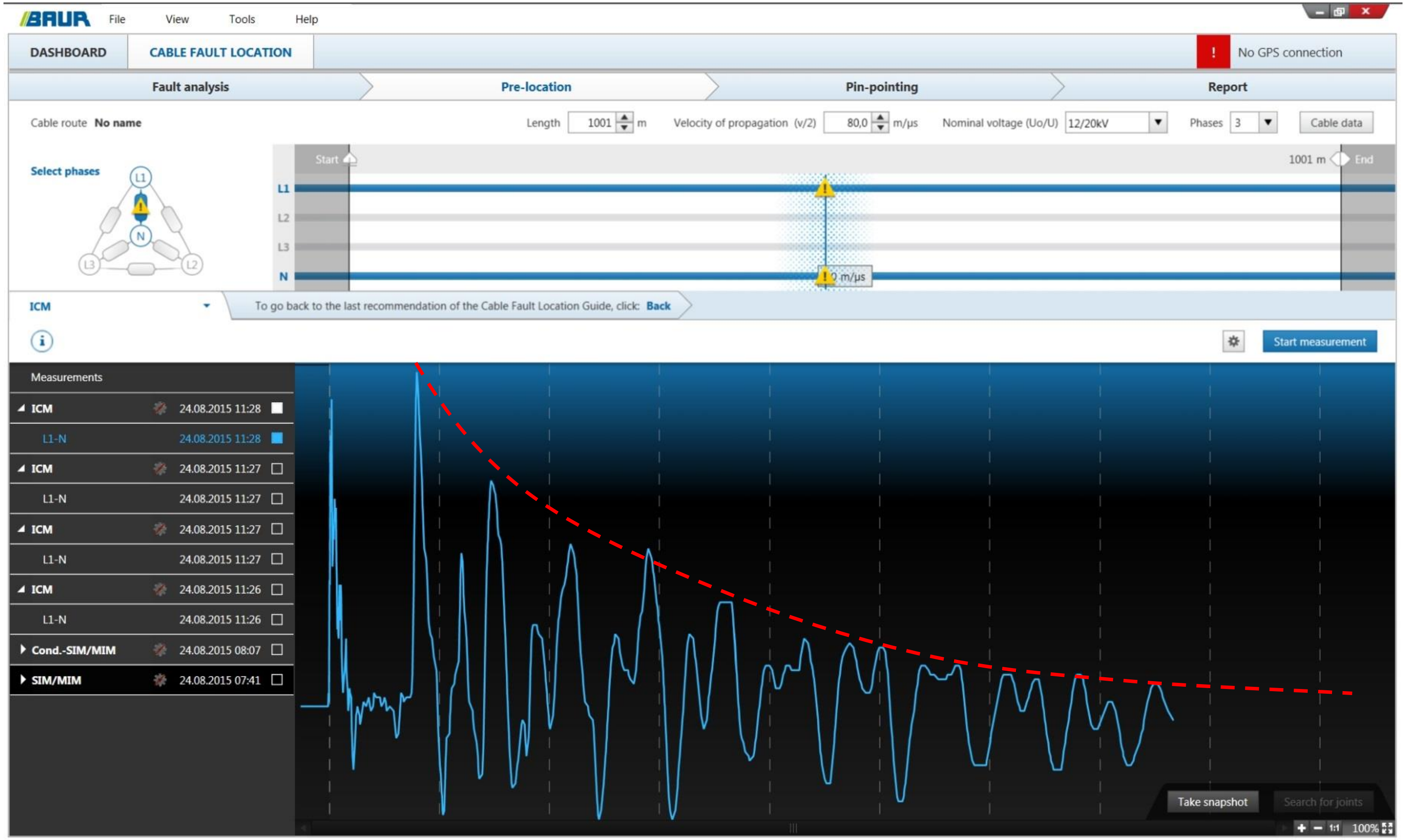
Method	Fault characteristics
Pulse Reflection Method (**TDR**)	short circuit faults (low Ω), cable cuts
SIM/MIM Secondary Impulse Method	high Ω – faults, flashing faults
Conditioning **SIM/MIM**	high Ω – faults , flashing faults, wet faults
Burn Down technique	high Ω – faults, wet Faults
Impulse Current Method - **ICM**	high Ω – faults, flashing faults (preferred for long cables)
Decay Travelling Wave Method	Flashing HV Faults
Differential Method	branched Cable systems faults
Bridge measurement	high & low Ω – faults, cable sheath faults

Impulse Current Method – ICM

D = L – Test leads



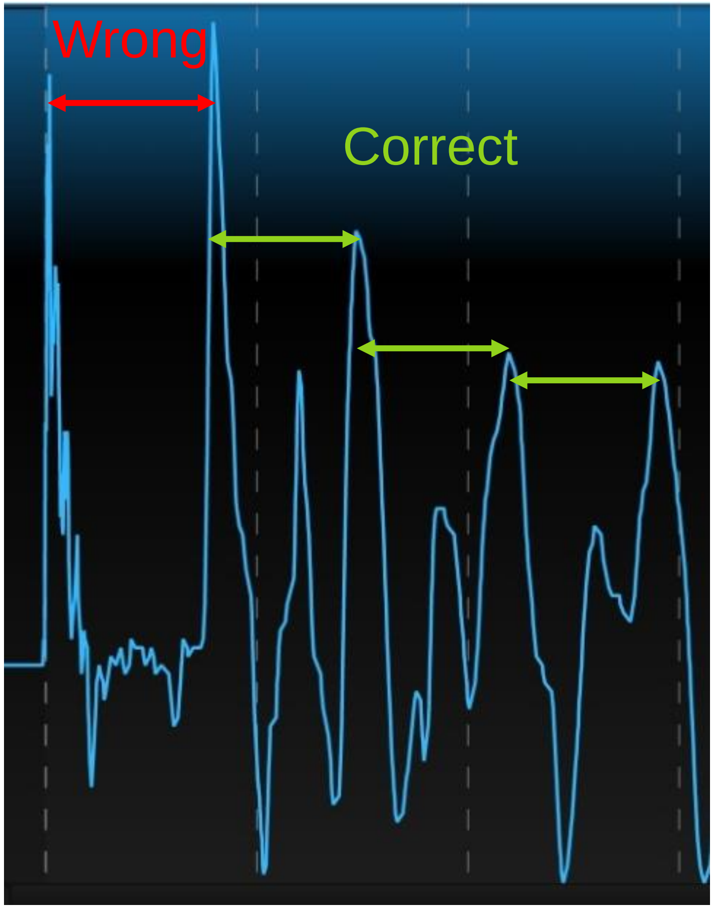
Impulse Current Method - ICM



Impulse Current Method,
measurement example

Ignition Delay ICM

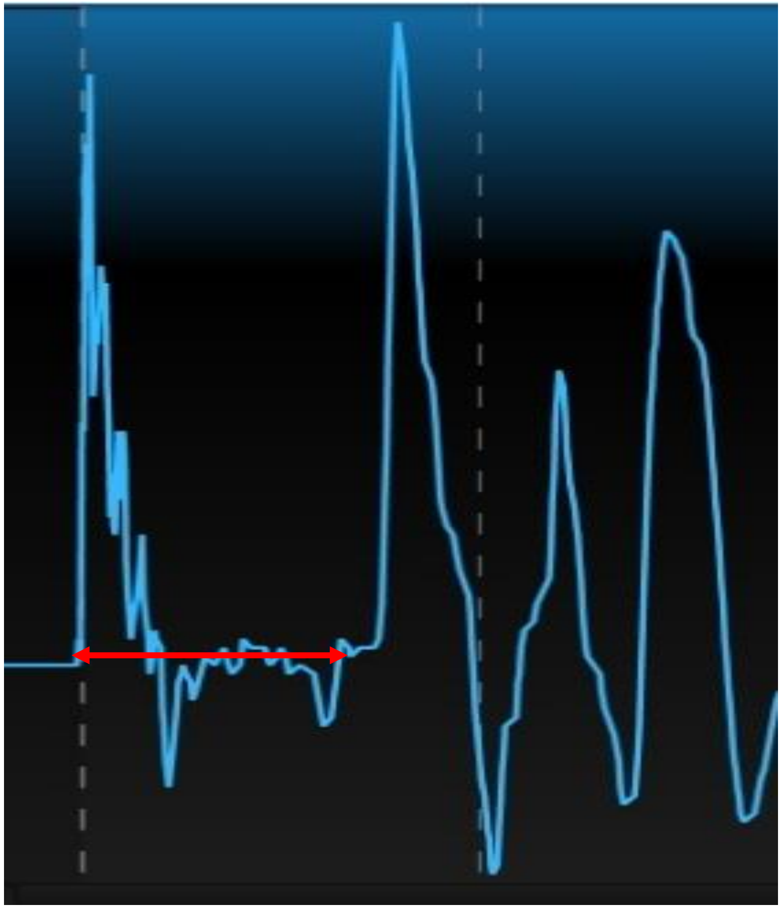
The ionisation phase causes an ignition delay of the first oscillation, when using the Impulse Current Technology
For a correct measurement, this first wave must be ignored!



Ignition Delay ICM

The effect caused by the ignition delay can be used resp. enhanced by measuring to the parasitic reflection before the next large reflection instead of the reflection itself

This method is more accurate, bur requires some experience.

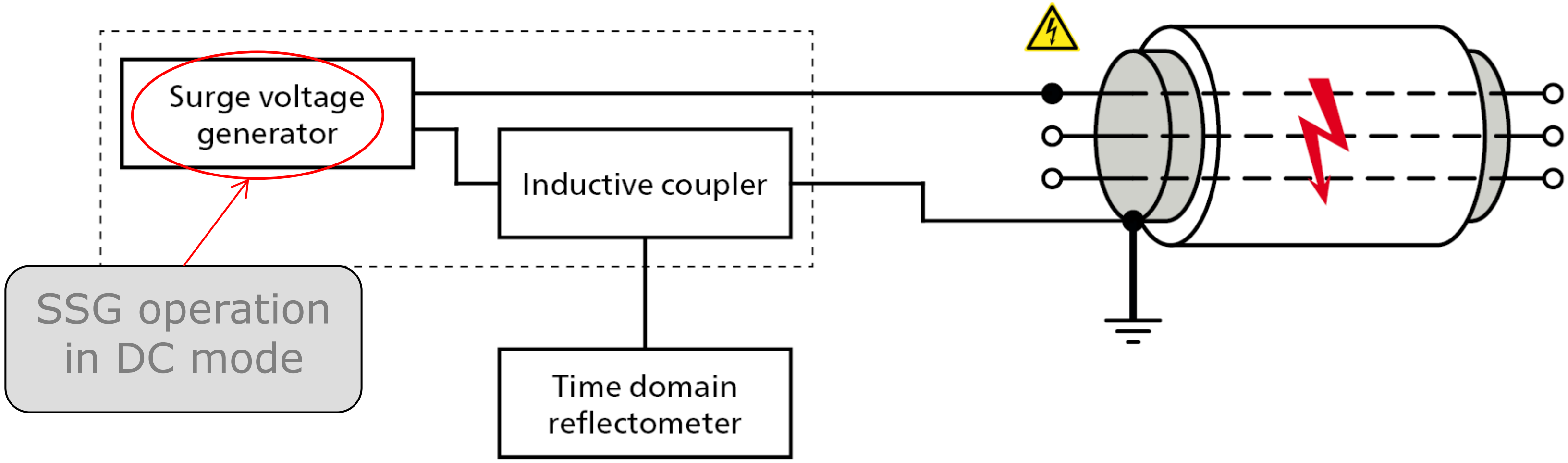


DC ICM – Impulse Current Method with DC

DC application with the SSG. Charging of SSG and cable capacity

The advantage is the added use of the SSG and the cable in parallel adding their capacities.

Useful on longer cables



Methods of cable fault pre-location

Method	Fault characteristics
Pulse Reflection Method (**TDR**)	short circuit faults (low Ω), cable cuts
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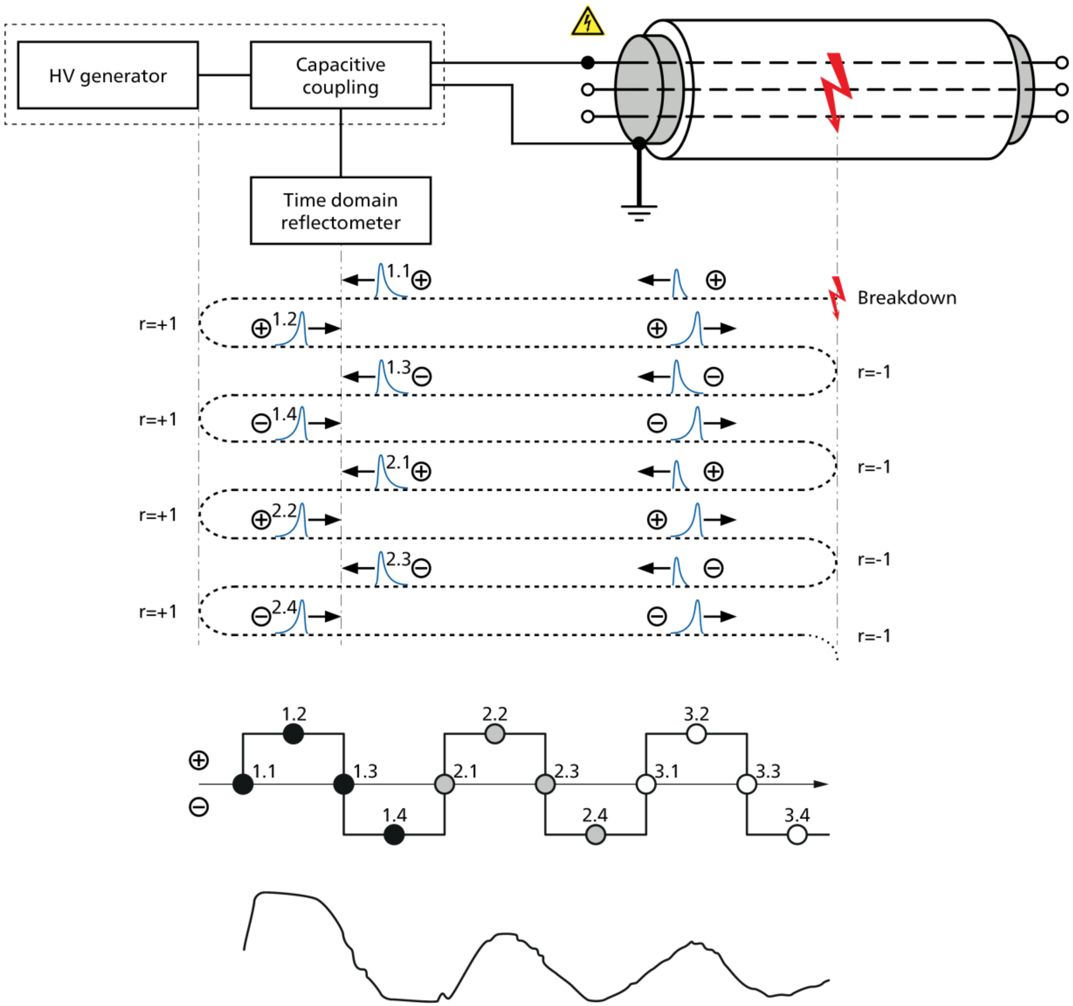
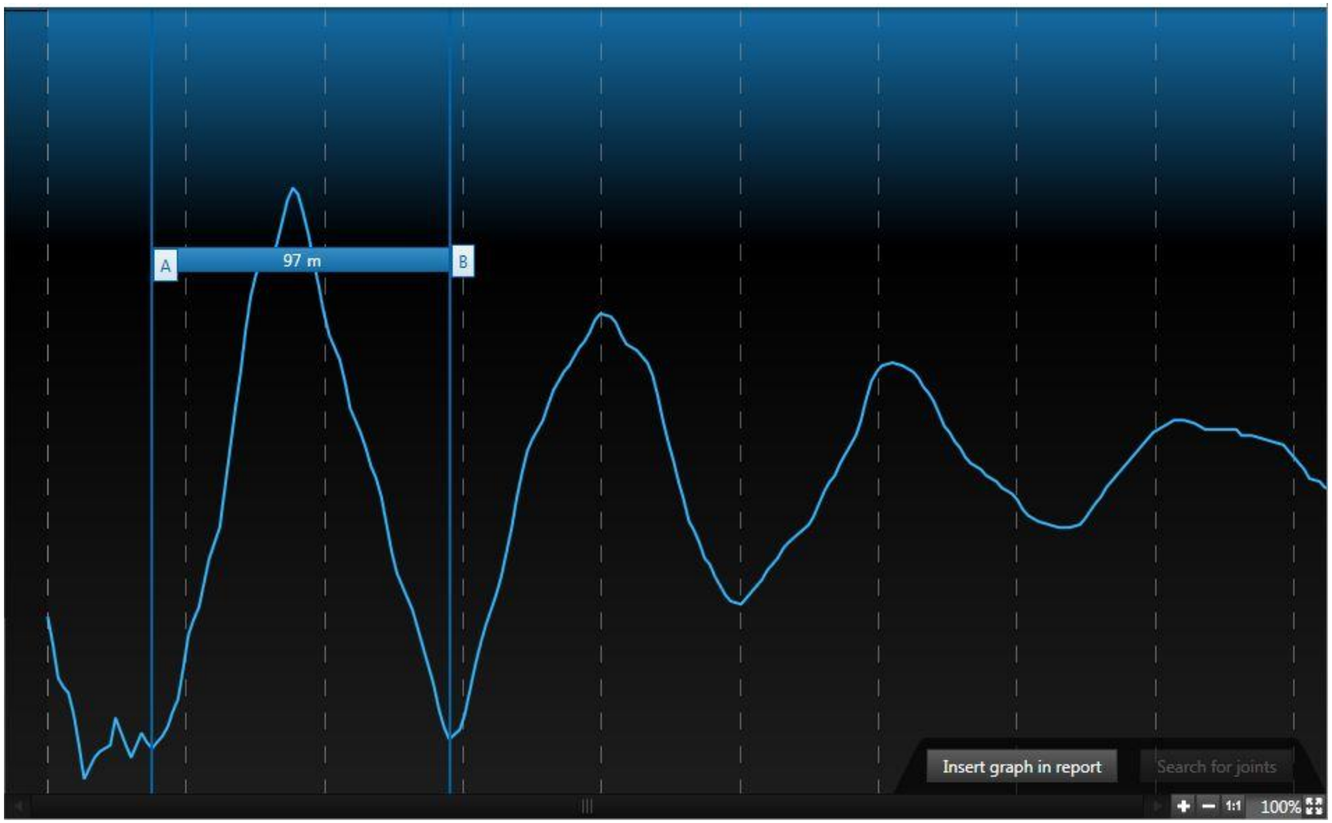
Decay Travelling Wave Method	Flashing HV Faults
Differential method	branched Cable systems faults
Bridge measurement	high & low Ω – faults, cable sheath faults

Travelling Wave Method - Decay

$$D = \frac{L}{2} - \text{Test leads}$$



Decay method



Decay method, measurement example

Comparision

SIM / MIM

- Most commonly used HV - fault locating method
- Many details are visible (Joints ,cable end,…)
- Maximum SSG-Voltage (typically 32 kV)
- Set measurement range to cable length
- Lead wire is automatically subtracted

ICM Impulse current method

- For long cables and failures in wet joints
- Max. SSG-voltage (typically 32 kV)
- Automatic setting: 500% of cable length
- Increase gain
- Measurement of the length of one period
- First period is not used for the measurement (“Ignition delay”)
- Measured length 7 to 15 % longer – due to varying v/2
- Lead wire length must be considered

Decay

- For cable faults, where a high voltage is necessary
- Faulty cables must be loaded , and then creates a breakdown .
- Failures with leakage currents can not be located
- Automatic setting: 500% of cable length
- Reduce gain
- Measure the length of a period and divide by 2
- Lead wire length must be considered

Methods of cable fault pre-location

Method	Fault characteristics
Pulse Reflection Method (**TDR**)	short circuit faults (low Ω), cable cuts
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Decay Travelling Wave Method	Flashing HV Faults
Differential Methods	branched Cable systems faults
Bridge measurement	high & low Ω – faults, cable sheath faults

Differential Methods

- The three-phase current decoupling methods are used specially in branched medium voltage networks for cable fault location.

- For the measurement it is necessary to establish a bridge between healthy and faulty wire at the far end of the cable

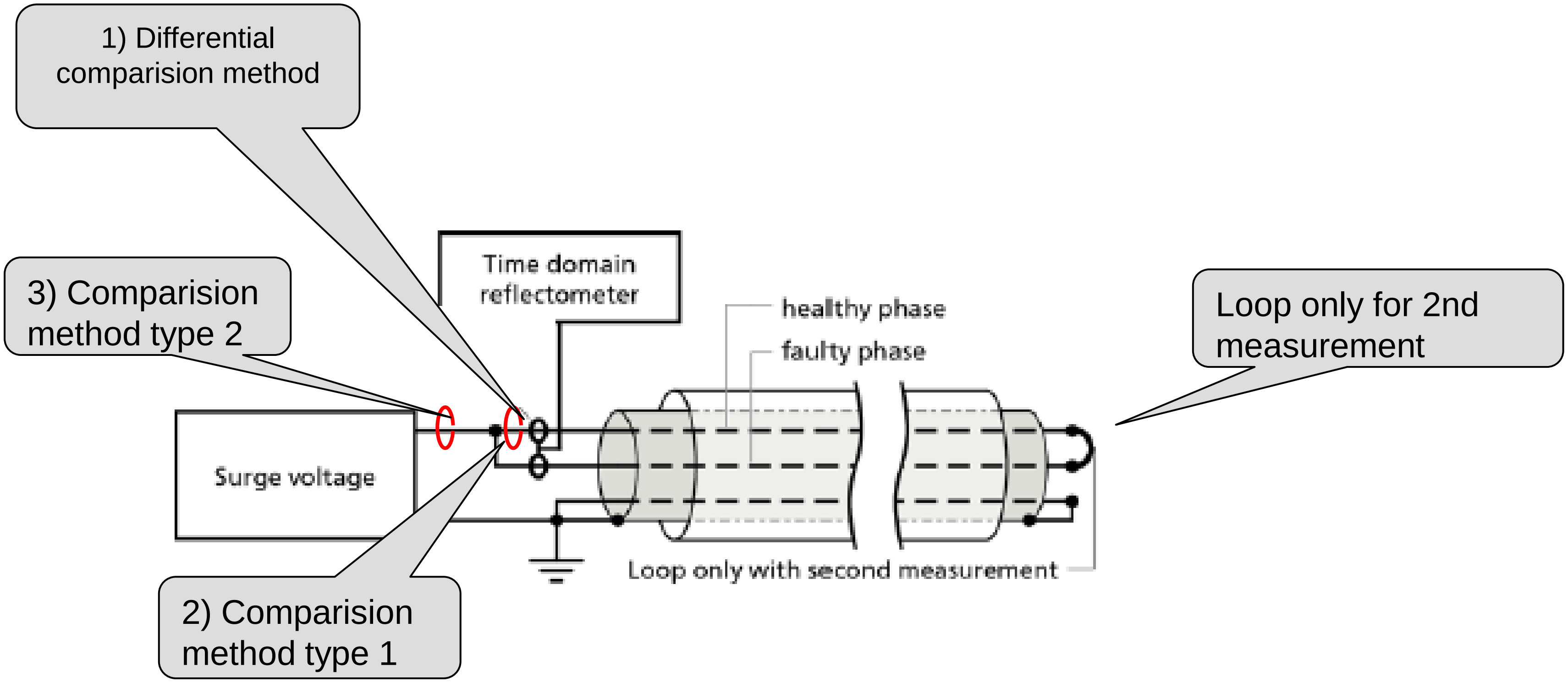
3 Methods available:

1) **Differential-comparision method** – Differential current coupler for two phases (transcable, titron)

2) **Comparision method type 1**– Current coupler in the healthy phase (titron)

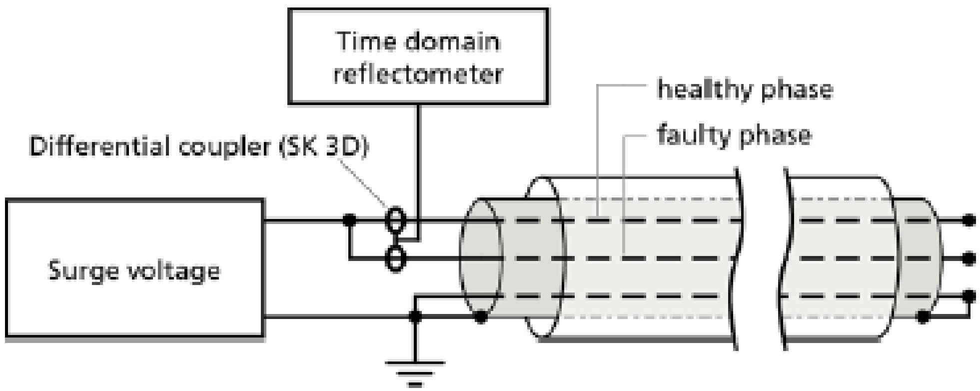
3) **Comparision method type 2** – Sum coupler in both phases (titron)

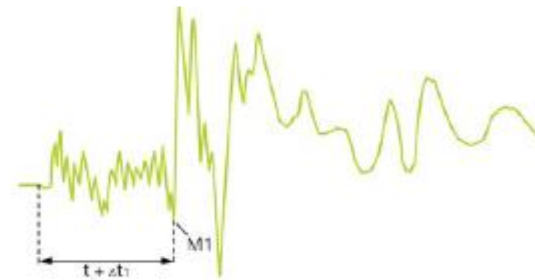
Differential methods



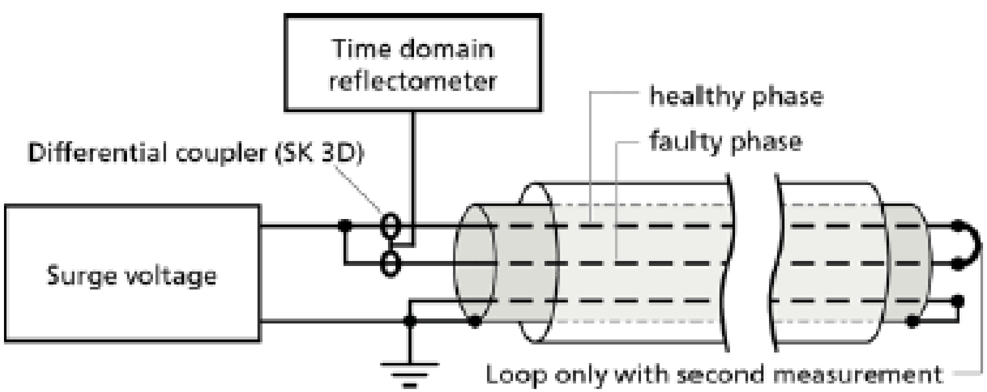
1) Differential comparision method

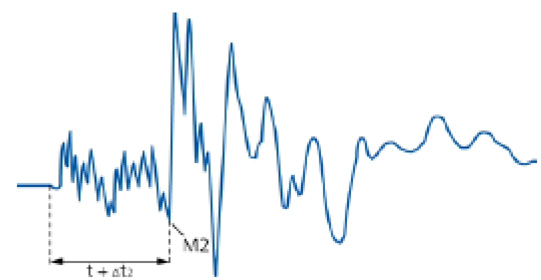
First measurement without loop at the far end



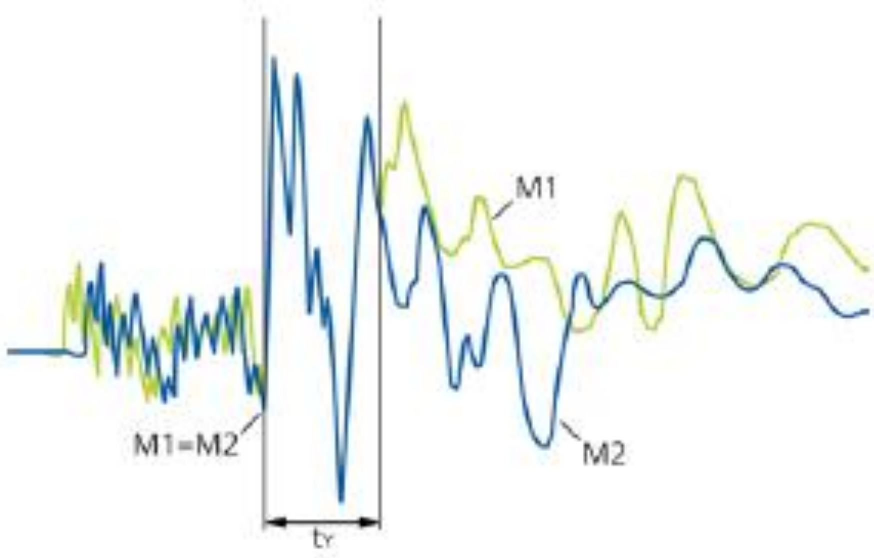


Second measurement with loop at the far end

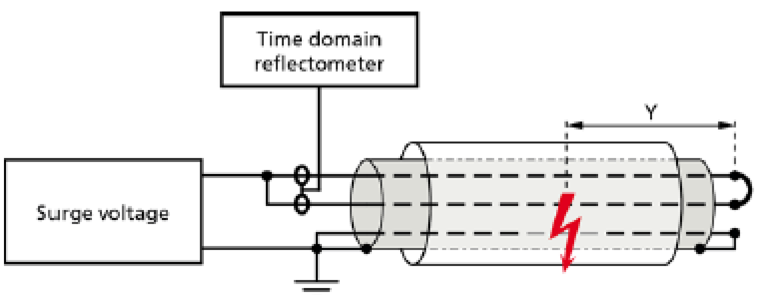




1) Differential comparision method

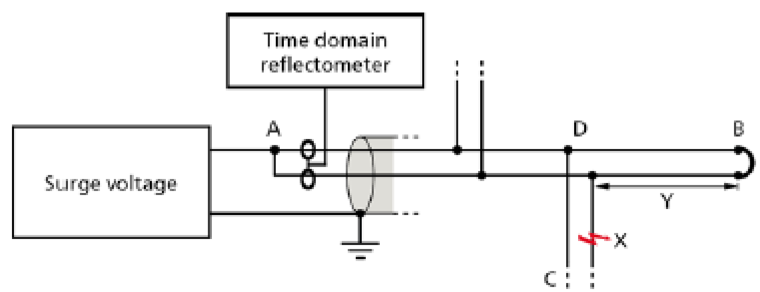


Fault in the main phase:



Measured distance Y: Shows the distance Y from the loop at the far end to the fault. This completes pre-location

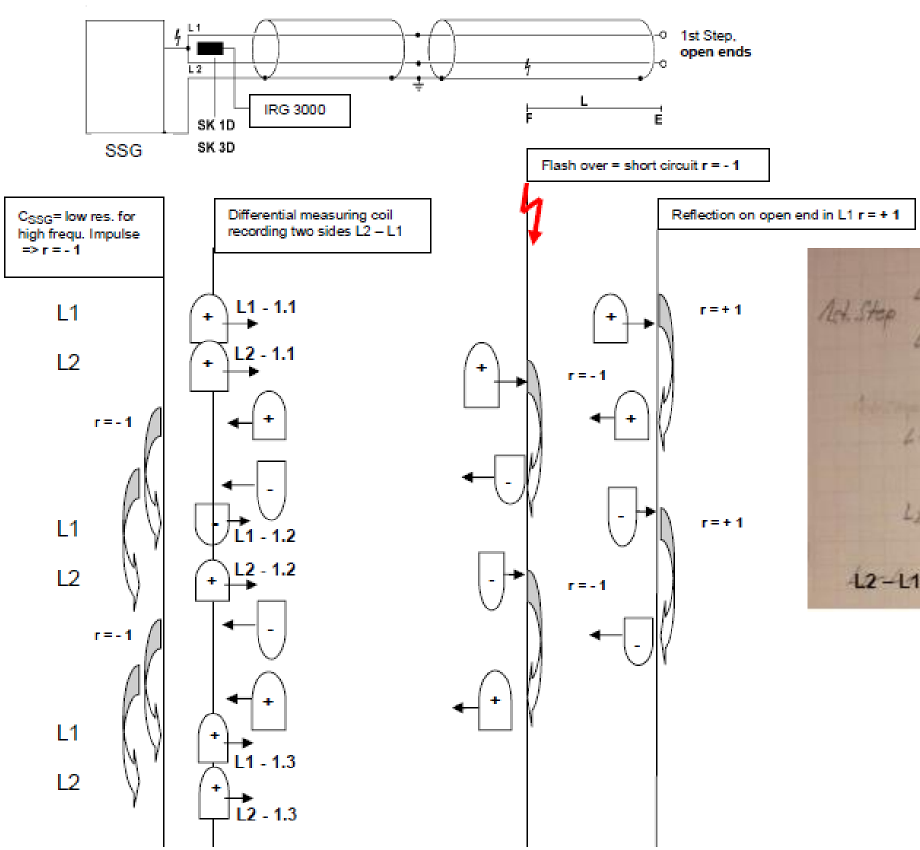
Fault in a branch:

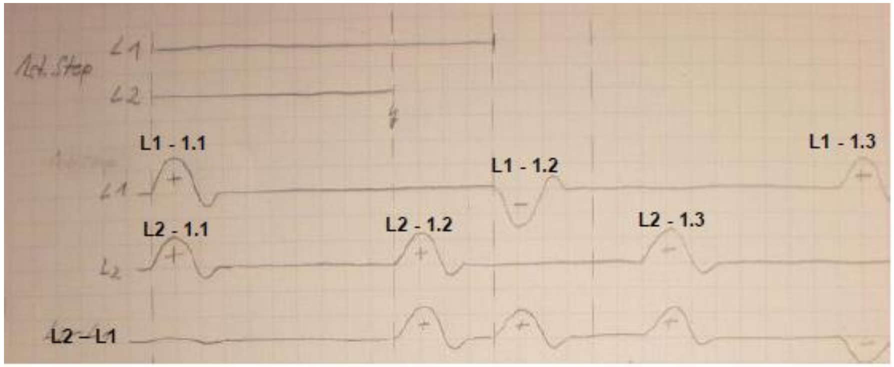


Measured distance Y: Distance from the loop to the starting point of the branch. (→ Repeat measurement with bridge in the branch where the fault is located)

1) Differential comparision method

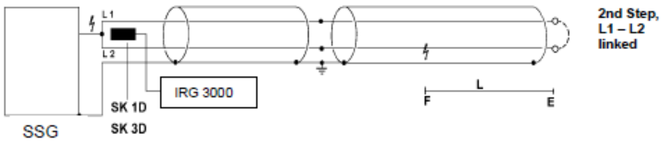
Why do we get different measurment results with and without a bridge at the far end?

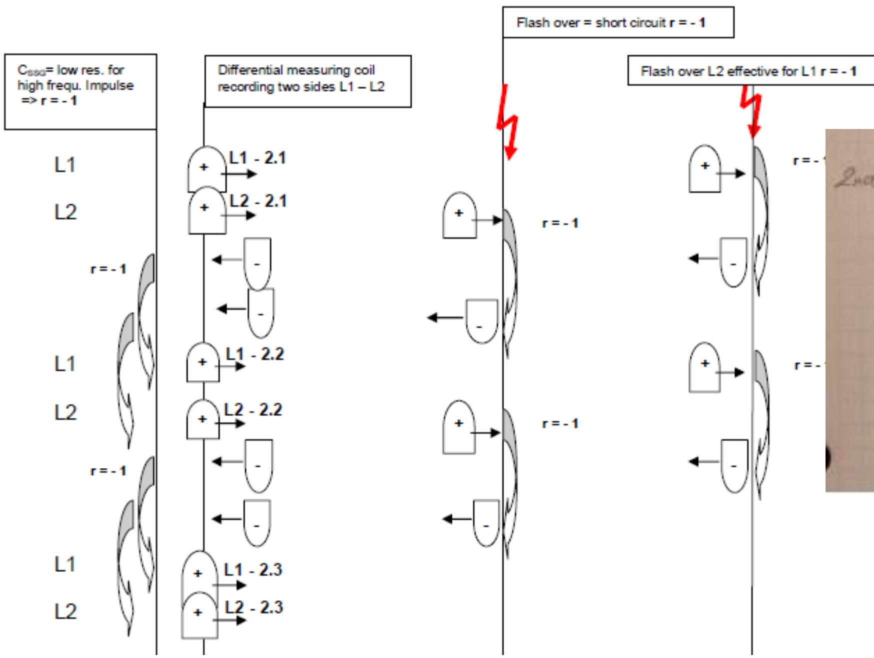




1) Differential comparision method

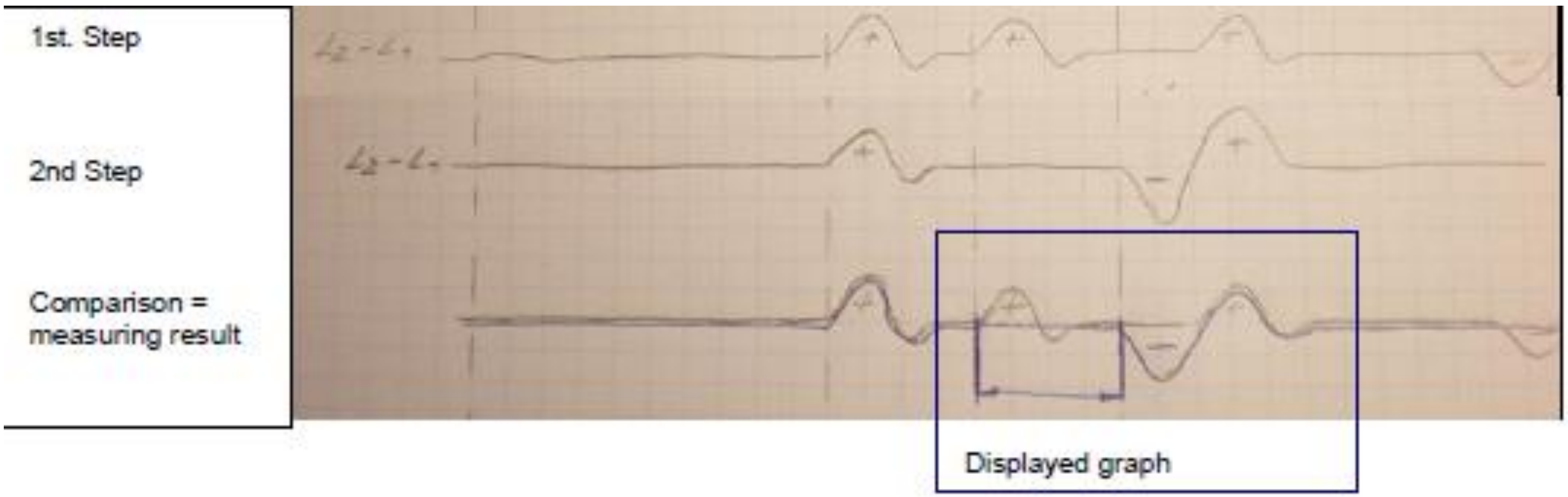
Why do we get different measurement results with and without a bridge at the far end?





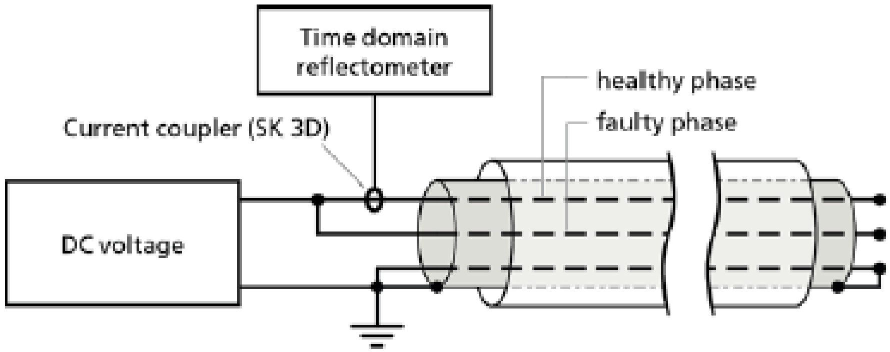
1) Differential comparision method

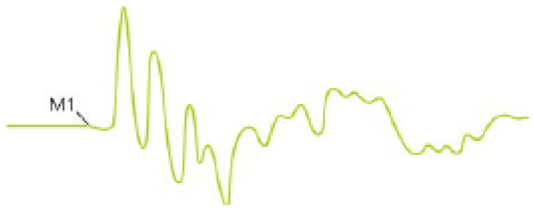
Why do we get different measurement results with and without a bridge at the far end?



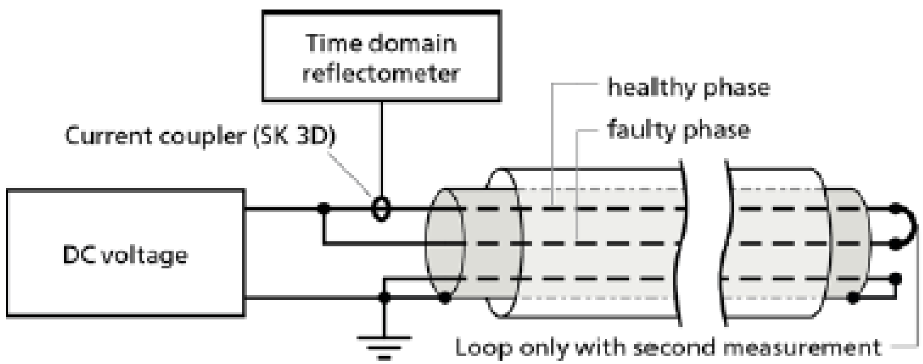
2) Comparision method type 1

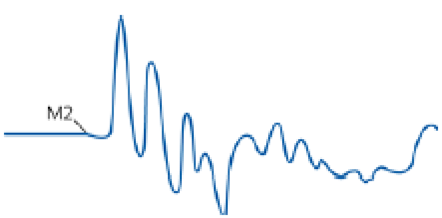
First measurement without loop at the far end





Second measurement with loop at the far end





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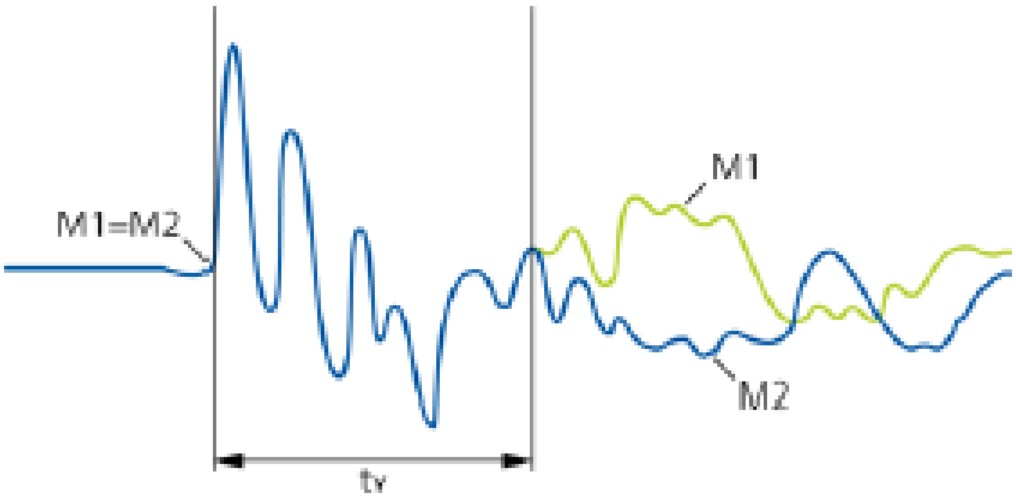
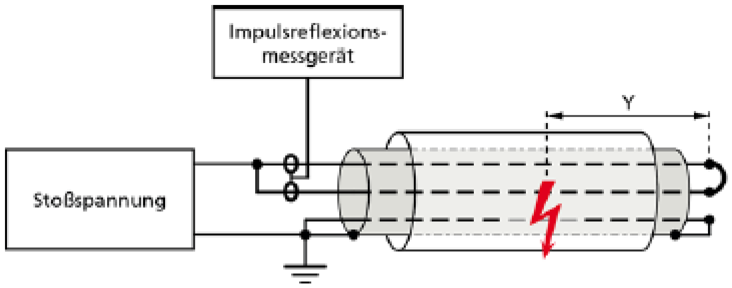
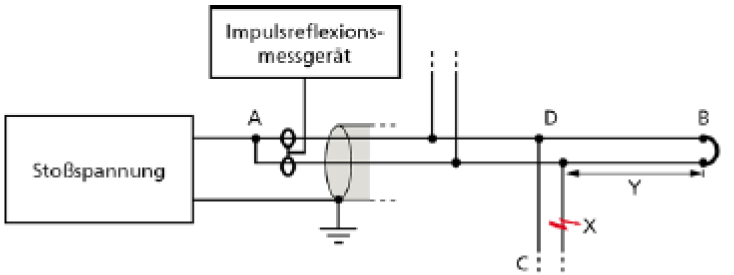


Fault in the main phase:



Measured distance Y: Shows the distance Y from the loop at the far end to the fault. This completes pre-location

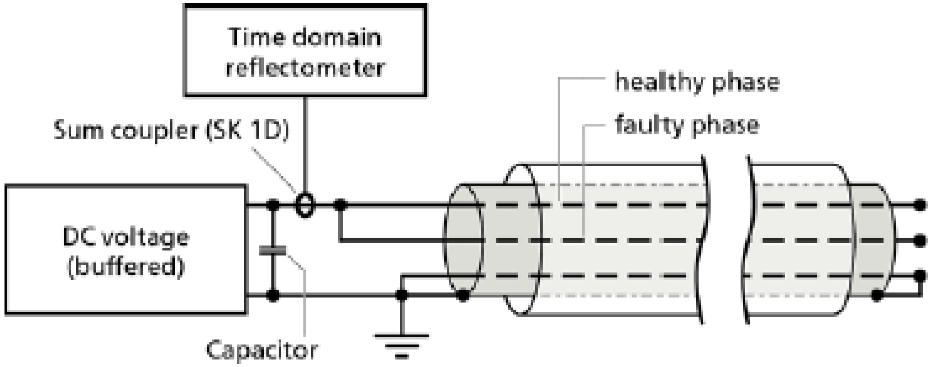
Fault in a branch:

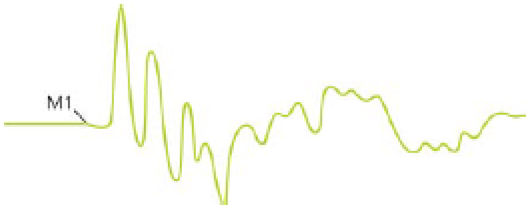


Measured distance Y: Distance from the loop to the starting point of the branch. (→ Repeat measurement with bridge in the branch where the fault is located)

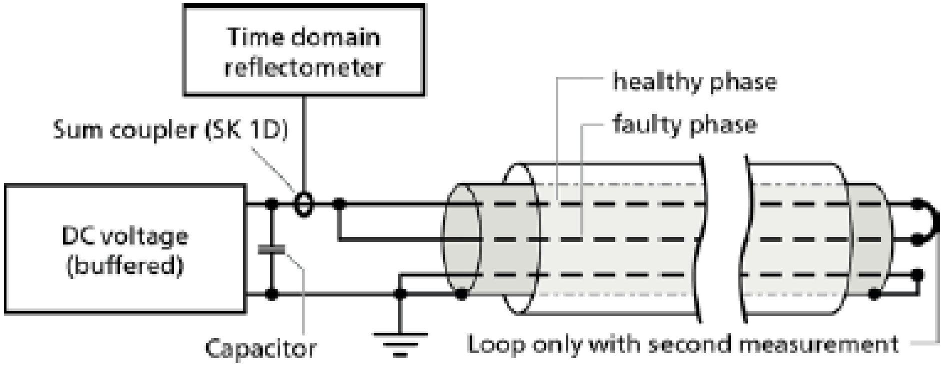
3) Comparision method type 2

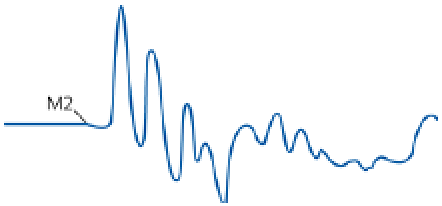
First measurement without loop at the far end



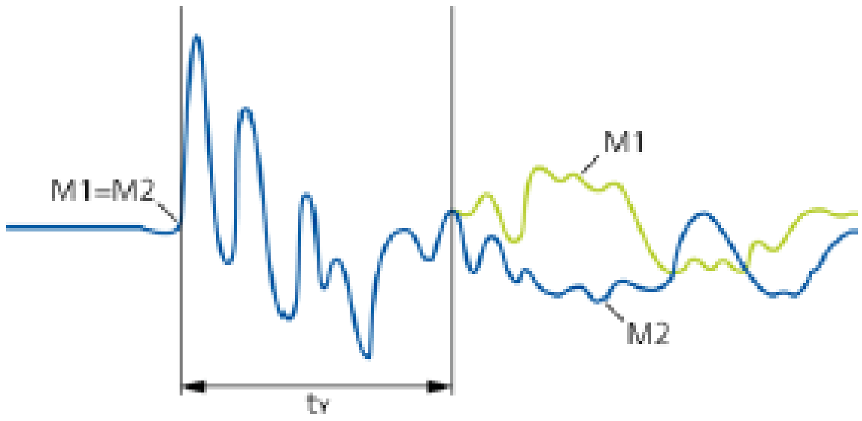


Second measurement with loop at the far end

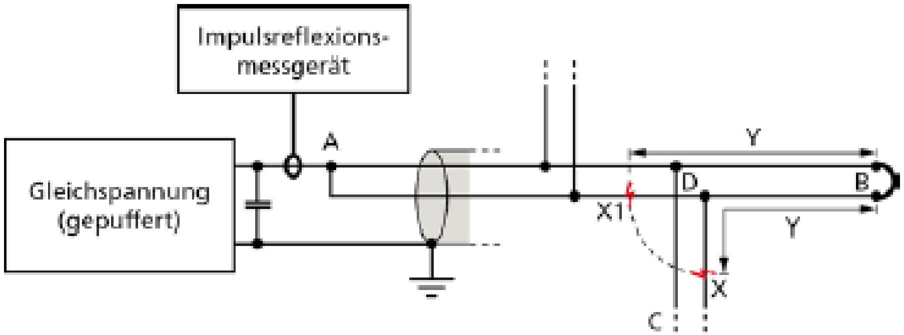




3) Comparision method type 2



Fault in a branch:



Measured distance Y: Depending on the determined distance Y, the fault can be located at both locations X and X1

Comparision

	Differential comp. method	Comp. method type 1	Comp. method type 2
Application	Failures >50Ohm in branched networks	High resistive fault • One healthy core available • The core with the fault can be loaded by DC voltage	Breakdown voltage fault • One healthy core available • The core with the fault can be loaded by DC voltage
Voltage source	SSG surge voltage generator	SSG in DC mode	SSG in DC mode
Coupling unit	SK3D – differential coupler	SK3D – am fehlerfreien Leiter	SK1D – Summenkoppler über beiden Leitern
Result Main phase	Distance from loop to failure	Distance from loop to failure	Distance from loop to failure
Result Branch	Distance from loop to branch	Distance from loop to branch	Distance from loop to failure

Methods of cable fault pre-location

Method	Fault characteristics
Pulse Reflection Method (**TDR**)	short circuit faults (low Ω), cable cuts
SIM/MIM Secondary Impulse Method	high Ω – faults, flashing faults
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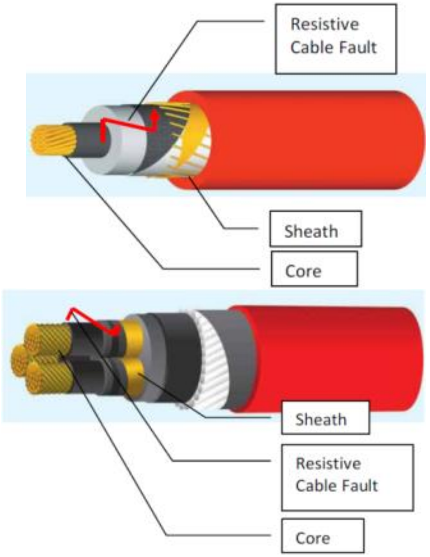
Bridge measurement	high & low Ω – faults, cable sheath faults

Bridge measurement – application

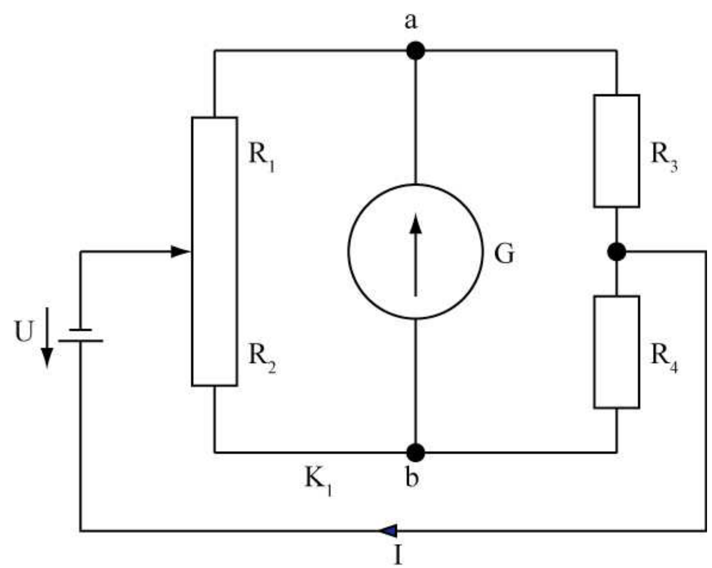
Fault location of:

- Sheath faults in MV and **HV** cables, sources for water tree development
- Any kind of resistive faults in **MV** cables, back-up for Syscompact
- Fault location in **LV** cables and **pilot / control - cables**



Bridge measurement

Wheatstone circuit
(basic principle)

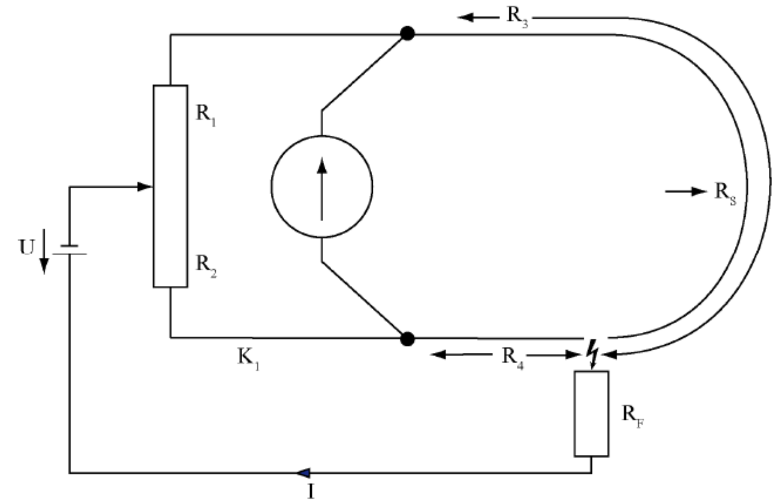


$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \qquad R_4 = \frac{R_2}{R_1} \cdot R_3$$

Example

115 kV, Cable characteristic

Shield, 175 mm² ~0,1 Ohm/km length resistance



Fault current defining accuracy!

→ 2 – 3 mA required

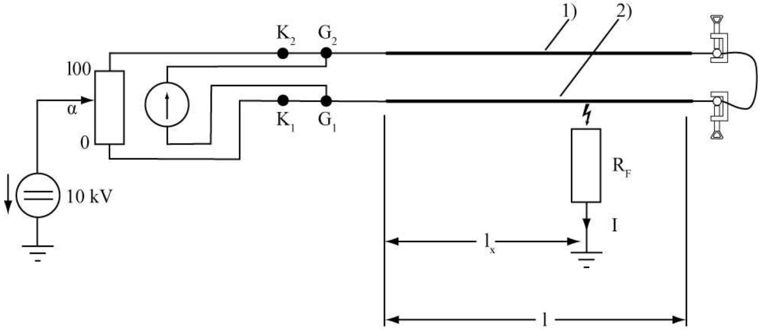
→ @10 kV = ~ 5 MOhm R_F

Bridge measurement

Murray bridge

- with <u>one auxiliary</u> line and constant cross section
- 2 lines with the same cross section are requested. E.g. 2 cable sheaths

<u>Principle:</u>



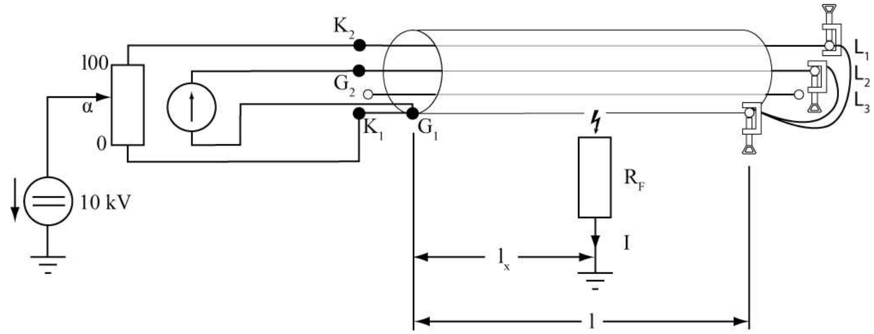
<u>Equation:</u>

$$l_x = \frac{\alpha}{100} * 2l_0$$

Glaser bridge

- with <u>two auxiliary</u> lines and constant cross section

<u>Principle:</u>

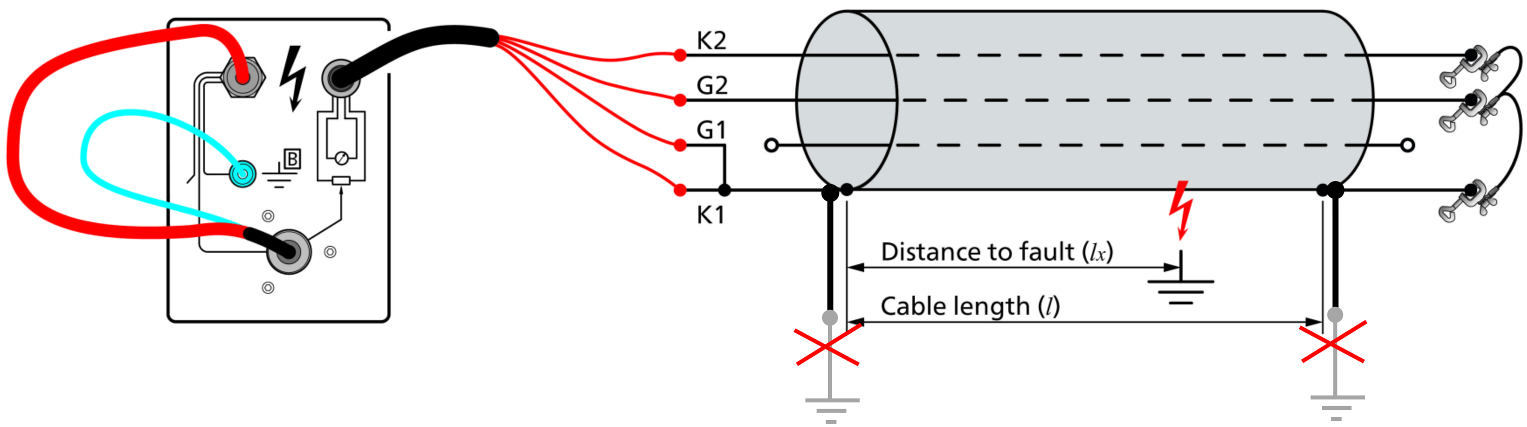


<u>Equation:</u>

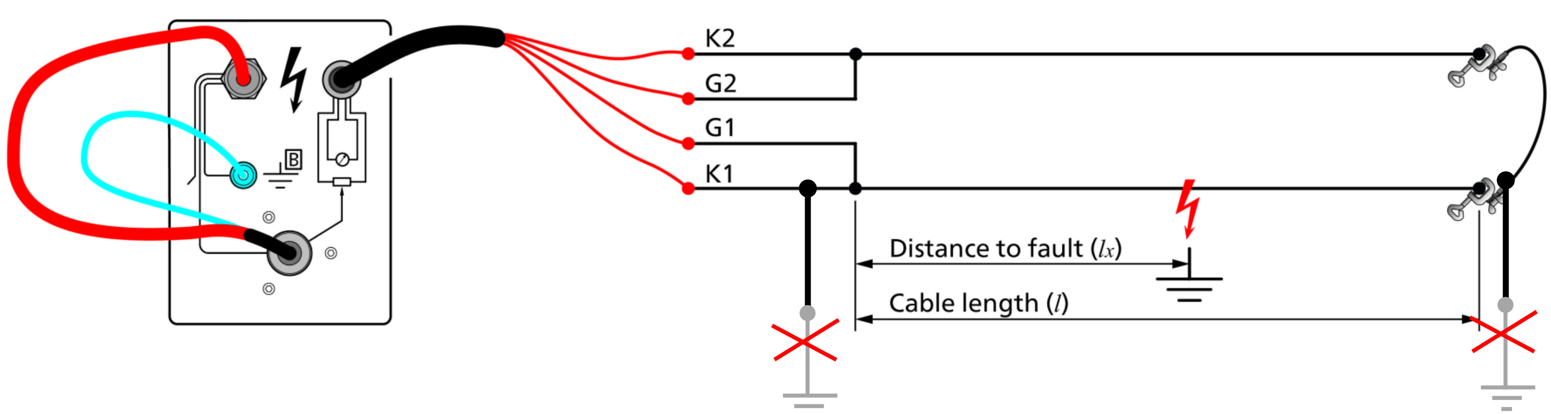
$$l_x = \frac{\alpha}{100} * l_0$$

Prelocation - Connection

Glaser measuring bridge



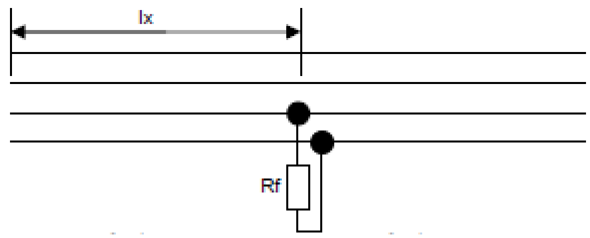
Murray measuring bridge



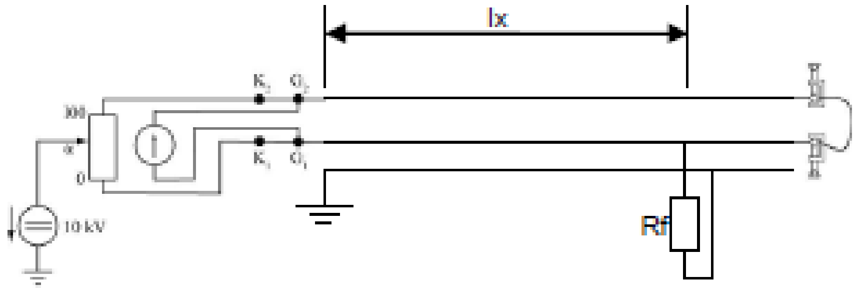
Shirla prelocation – application examples

Signal cable

Core to Core Fault:



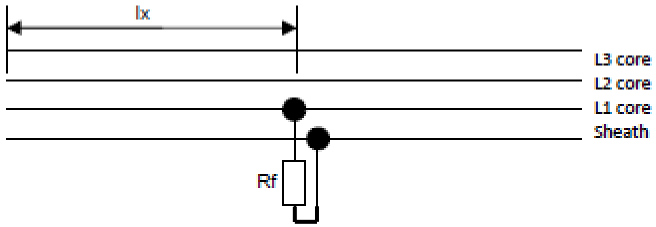
Test setup: Murray - bridge



- One healthy core with same cross-section as the faulty core is required
- Faulty core must be grounded at the near end

Shirla prelocation – application examples

LV cable



Test setup: Glaser with two auxiliary cores – if no healthy core is available

Connection acc. to GLASER

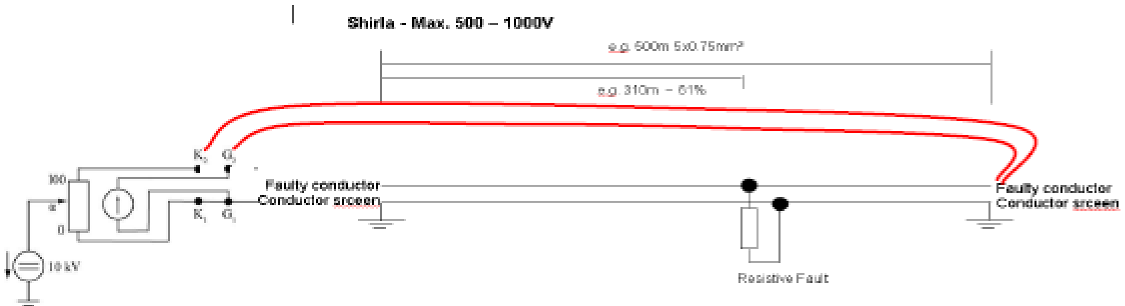
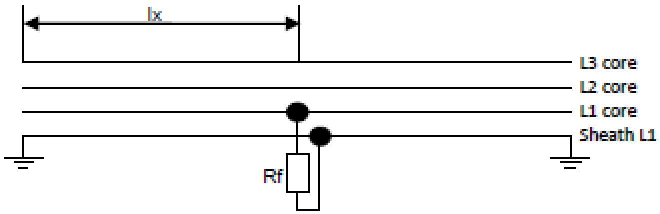
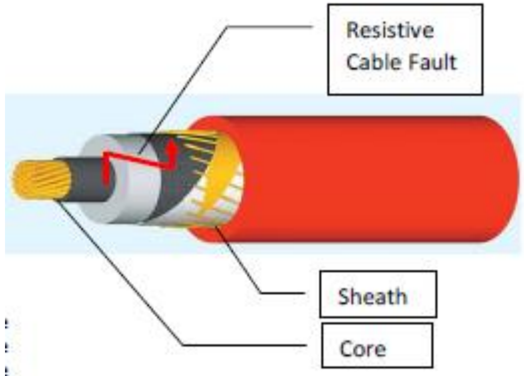


Fig. 4.3.1; connection acc. to Glaser, extended measuring leads K2, G2

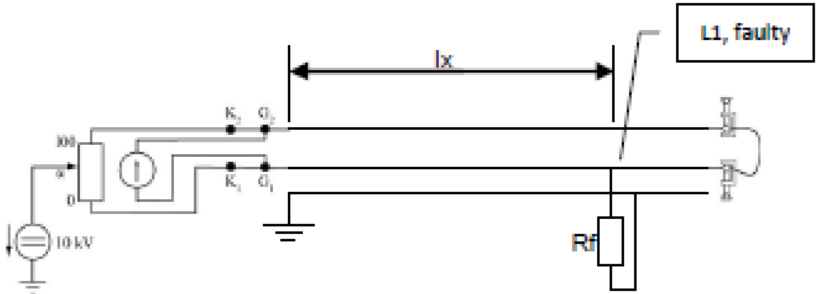
Shirla prelocation – application examples

MV cable



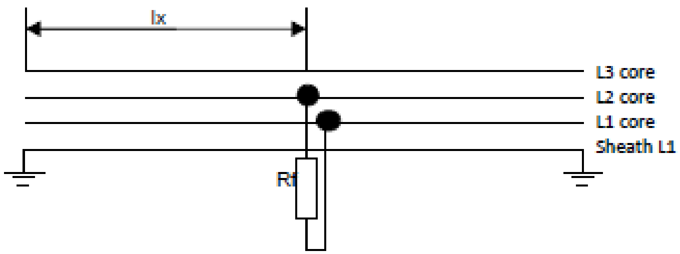


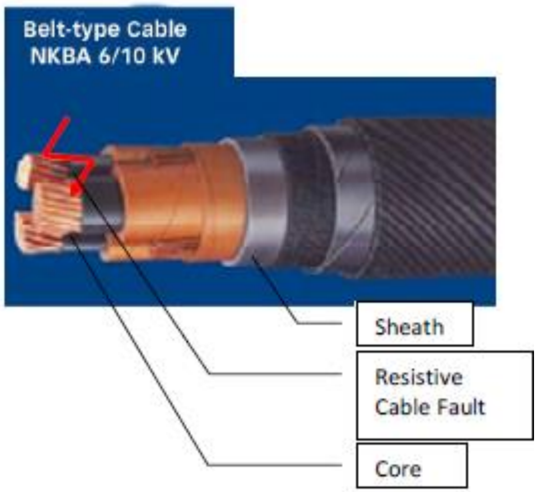
Test setup: Murray: One healthy core necessary



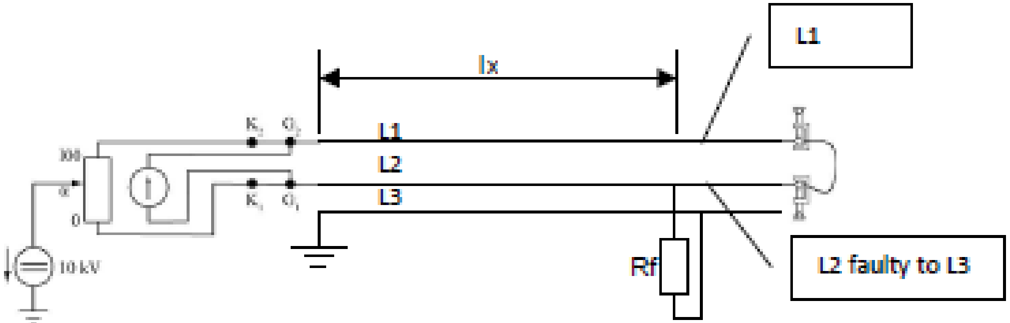
Shirla prelocation – application examples

MV –cable – 3 phase - PILC



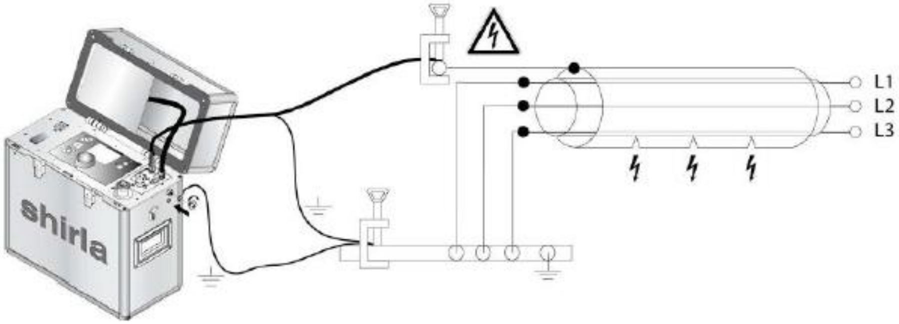


<u>Test setup:</u> Murray

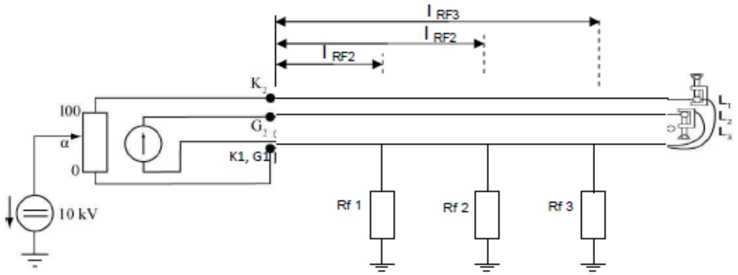


Shirla prelocation – application examples

Multiple sheath faults



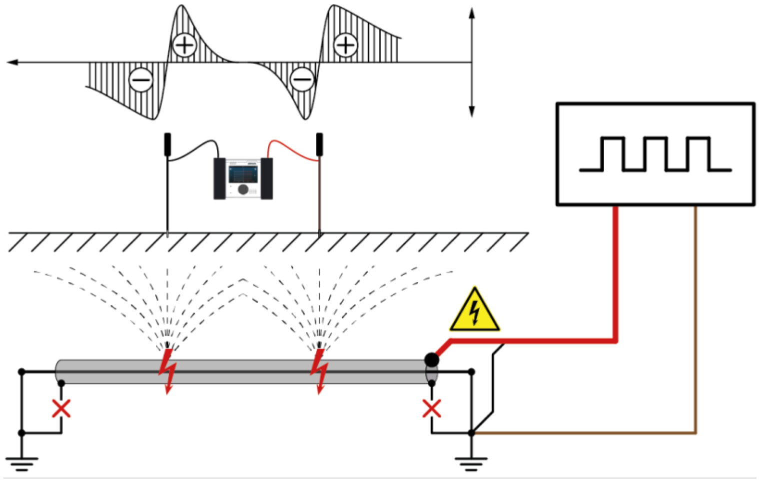
Einfluss mehrfacher Mantelfehler auf das Resultat:



Total length 1000m, U= 10kV I set = 3mA	Fault No. 1 Rf 1	Fault No. 2 Rf 2	Fault No. 3 Rf 3	Indicated average Fault Distance
Equal resistance ratio R total = 3,3kOhm	10kOhm, 1mA 250m	10kOhm, 1mA 500m	10kOhm, 1mA 750m	**Approx. 500m**
R total = 476Ohm	1kOhm, 1,43mA 250m	1kOhm, 1,43mA 500m	10kOhm, 0,14mA 750m	**Approx. 386m**
R total = 476Ohm Symmetrical ratio	1kOhm, 1,43mA 250m	10kOhm, 0,14mA 500m	1kOhm, 1,43mA 750m	**Approx. 500m symmetric**
R total = 667Ohm	1kOhm, 2mA 250m	2kOhm, 1mA 500m	-	**Approx. 333m (250m +1/3 of 250m)**
R total = 667Ohm	-	1kOhm, 2mA 500m	2kOhm, 1mA 750m	**Approx. 583m (500m +1/3 of 250m)**
R total = 667Ohm	1kOhm, 2mA 250m	-	2kOhm, 1mA 750m	**Approx. 416m (250m + 1/3 of 500m)**

Multiple sheath faults

If there are several earth faults on a cable route, the determined value of the cable fault pre-location does not match with the real positions. Since the pre-location only gives an arithmetic mean of the individual resistance ratios. The determined fault distance reveals a phantom fault. This applies to all pre-sorting procedures!

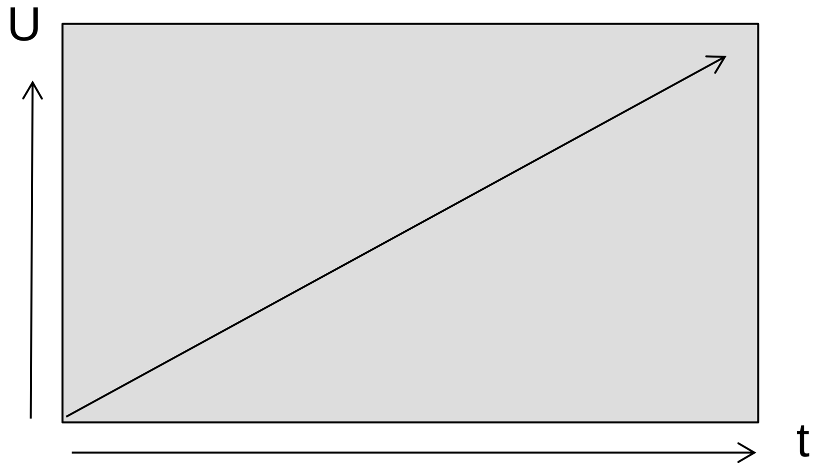


However, there are ways to recognize the existence of multiple errors anyway, and to determine these individually.

Multiple sheath faults

For multiple errors, there are several approaches to recognize them. **The first approach to detection is via the sheath test.**

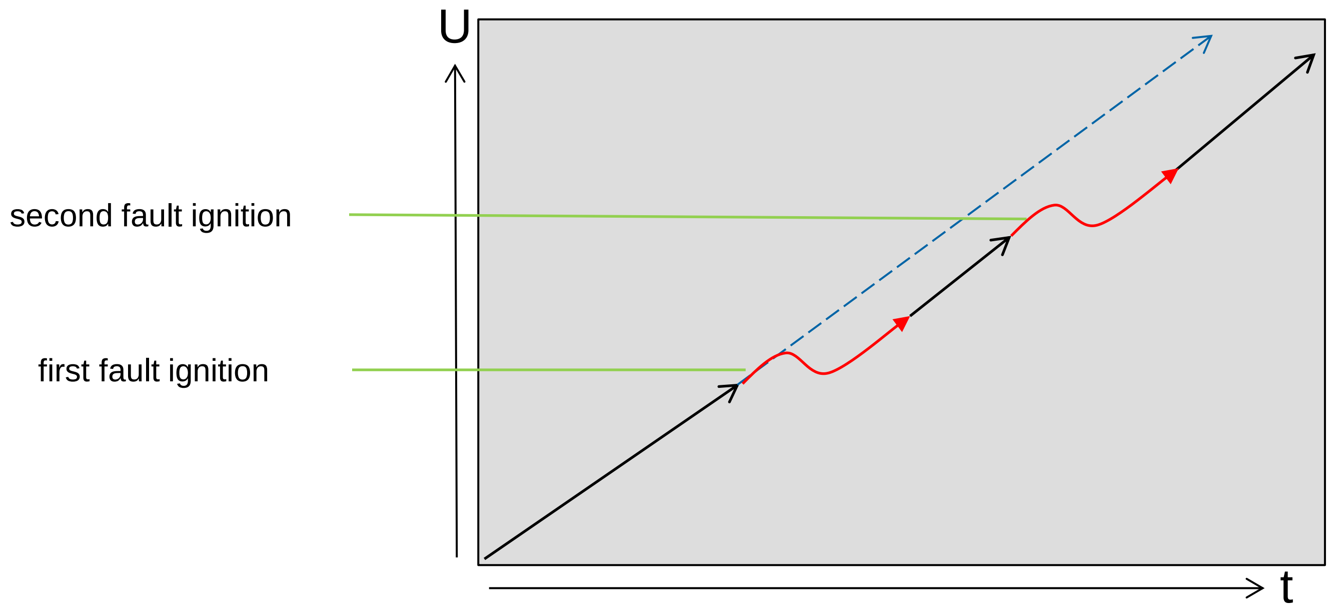
During the sheath test, it is important to increase the voltage slowly over a period of at least one minute. This makes it easier to detect faults when they ignite. Due to the slow ramping up of the voltage, an existing sheath failure ignites above a certain voltage and causes a temporary voltage drop and an increase in the output current.



Shirla prelocation – application examples

Multiple sheath faults

If the cable has multiple sheath faults, it is very unlikely that these will have the same ignition voltage.
Since the sheath test voltage is slowly increased up to the selected voltage, the ignition of another second sheath fault has the same effect, but at a different, higher voltage.



Shirla prelocation – application examples

Multiple sheath faults

- Based on this observation, which is only possible by slowly increasing of the voltage, the user can set the nominal voltage for the pre-location slightly above the ignition voltage but below the ignition voltage of the second detected fault.

- After the first error has been repaired - often the exposure of the fault location is sufficient - the second fault can be pre-located by following the same procedure.

- If such faults are highly resistive, e.g. by very wet environment, there is a continuous flow of current, and an ignition behavior as described, will not be found. In this case, the voltage can not be used to limit the errors. But that can be different with the second fault!

Multiple sheath faults

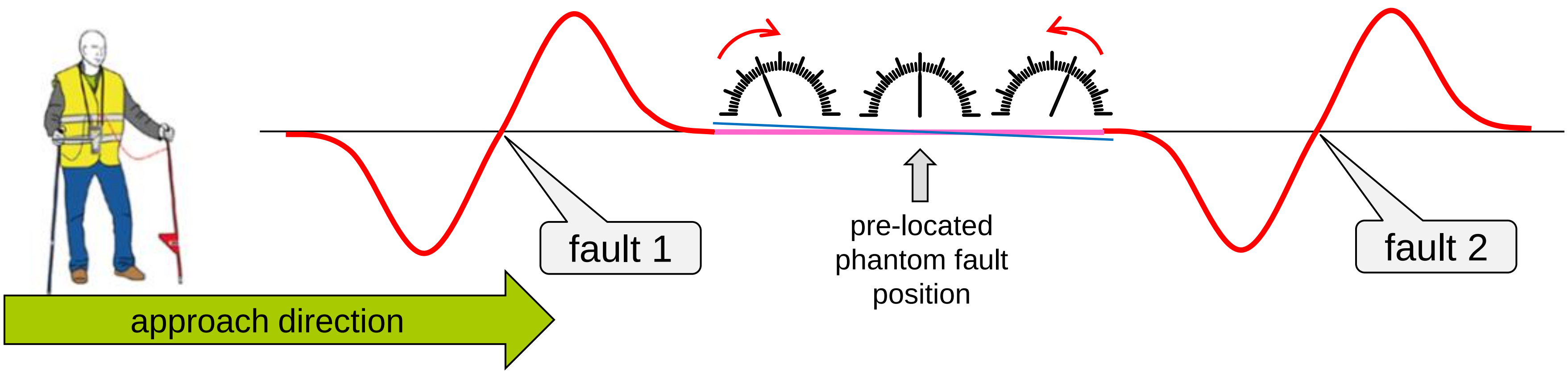
Another indication of multiple errors could be if the pre-located position is in the middle of the cable.
This is the second approach to detecting a multiple error.

In this case the user should pay attention to the behavior of the voltage during the pinpointing while using the step voltage method.
If the voltage curve runs, as described on the following pages for a phantom error, this would be a second indication and confirms the presents of a multiple failures!
This is the third approach to detecting a multiple mistake.

Shirla prelocation – application examples

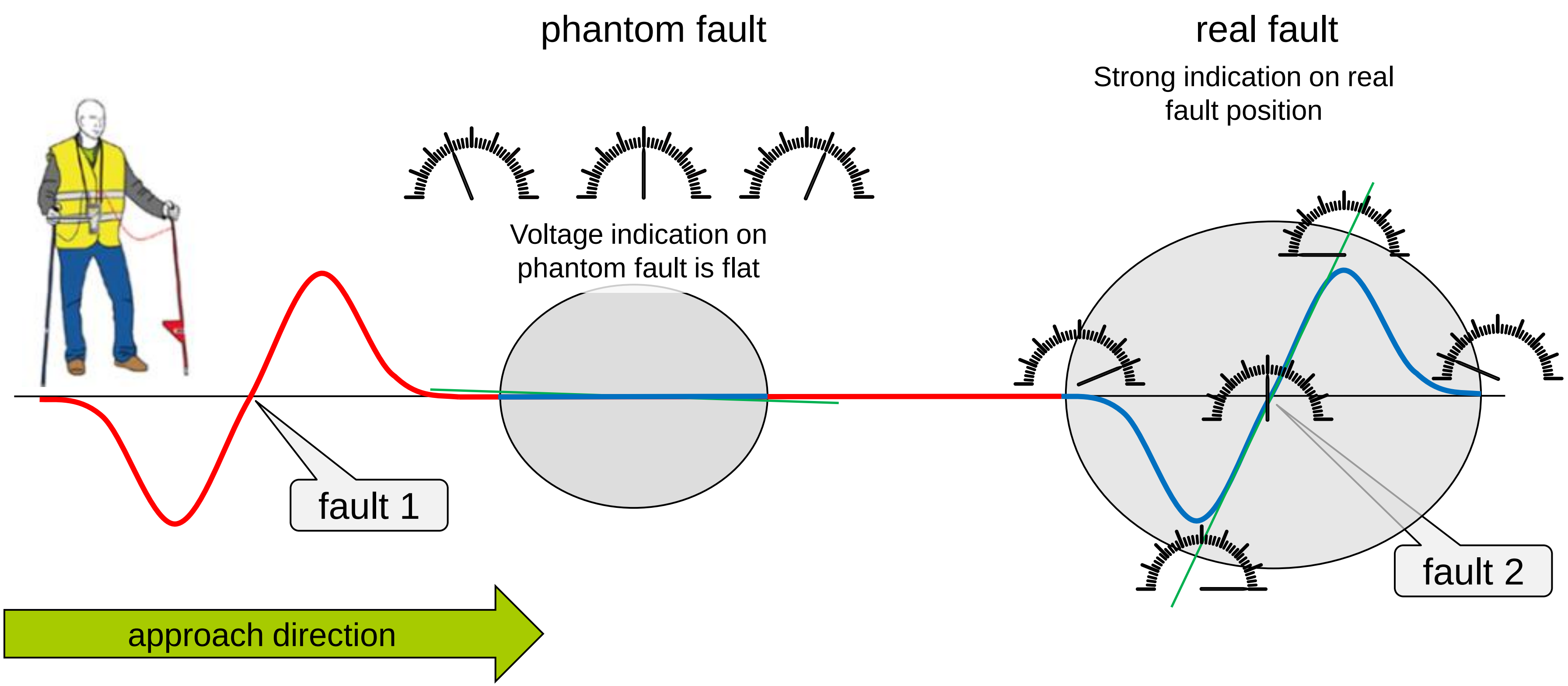
Multiple sheath faults

If an indication of multiple errors has been observed during the sheath test. The result of the pre-location with max. voltage will most likely show the average of the two (or more) faults. At the pre-located position the instrument behaves reverse, the needle points away from the pre-located position and the indication becomes smaller while approaching towards to the phantom error position.
However, this procedure requires sensitiveness, since the voltage changes are very small and the polarity change is very flat, without the typical previous strong rise and fall.



Multiple sheath faults

If the user moves away from the phantom fault the normal, correct behavior is shown with strong and distinct polarity changes.



Shirla prelocation – application examples

Multiple sheath faults - summary

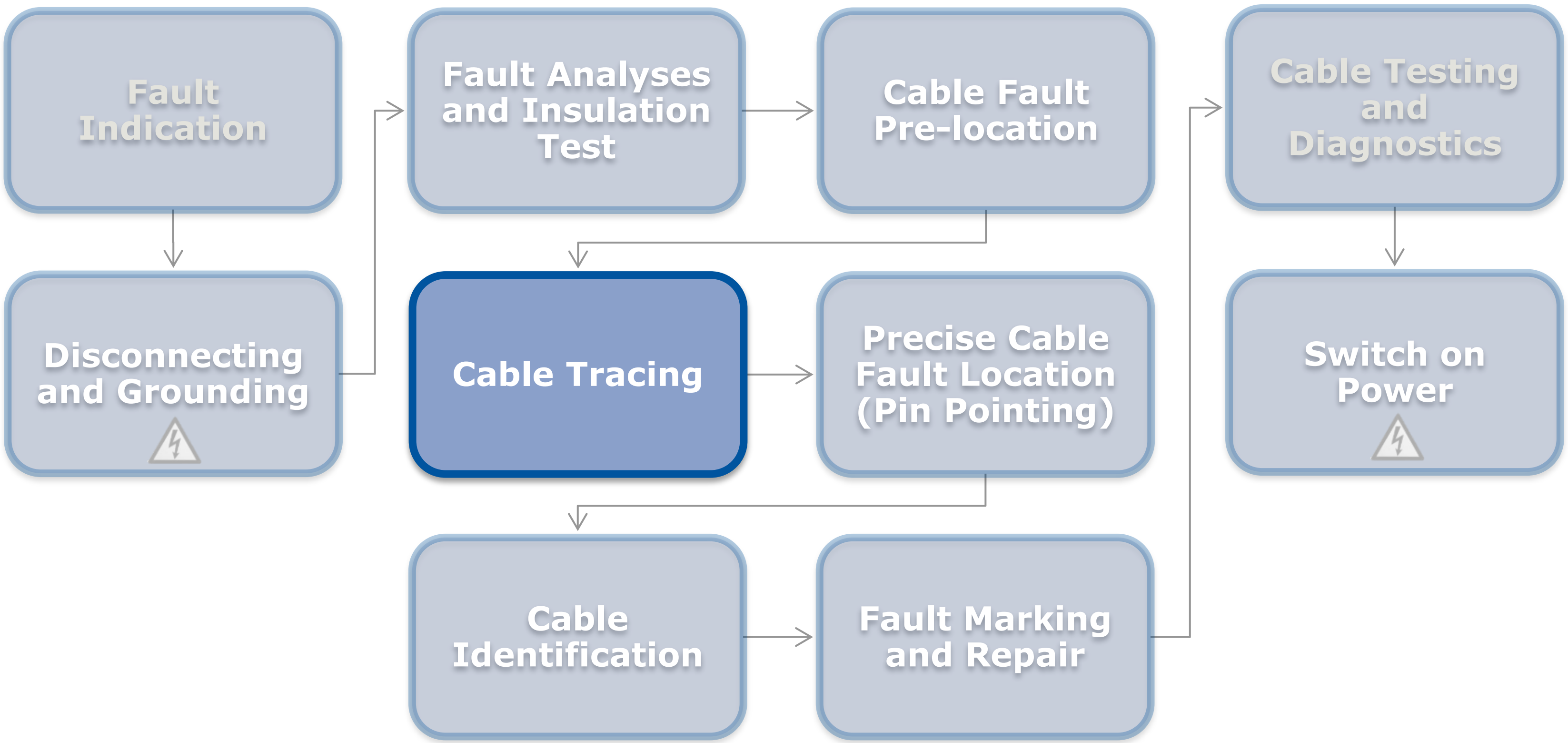
- Multiple errors can theoretically be detected during the sheath test by their different ignition behavior. For a reliable procedure, this procedure should be repeated several times in the case of multiple faults. (dehydration effects)
- By considering the determined ignition voltages the faults can be individually pre-located.
- An error in the middle of the cable is always a warning!
- Also during the pinpointing multiple faults can be recognized by the fact that at a pre-located phantom fault position the error behavior differs clearly from the expected voltage course of a real fault location.

Conductive layer

- When discussing whether an outer conductive layer makes sense, following points should be taken into account.
- A conductive layer could be very helpful for the pre-location, especially in poorly conductive environments (e.g., dry pipes, deserts).
- On buried cable the currents from the sheath fault are derived by the conductive layer so far that a pinpointing of the fault position is not possible.
- For buried cables there are two scenarios
  - The pipe is dry: A sheath fault doesn’t cause any problems anyway. (no water → no corrosion)
  - The pipe is wet: The fault can also be pre-located. A pinpointing or a repair makes little sense, as a cable fault in a pipe won’t located exactly. The whole cable in the pipe will be cutted on both ends and replaced.

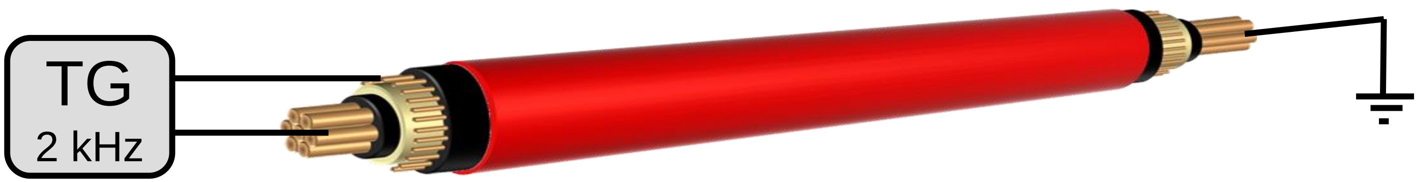
4th step

Cable tracing



Possible connections - Galvanic

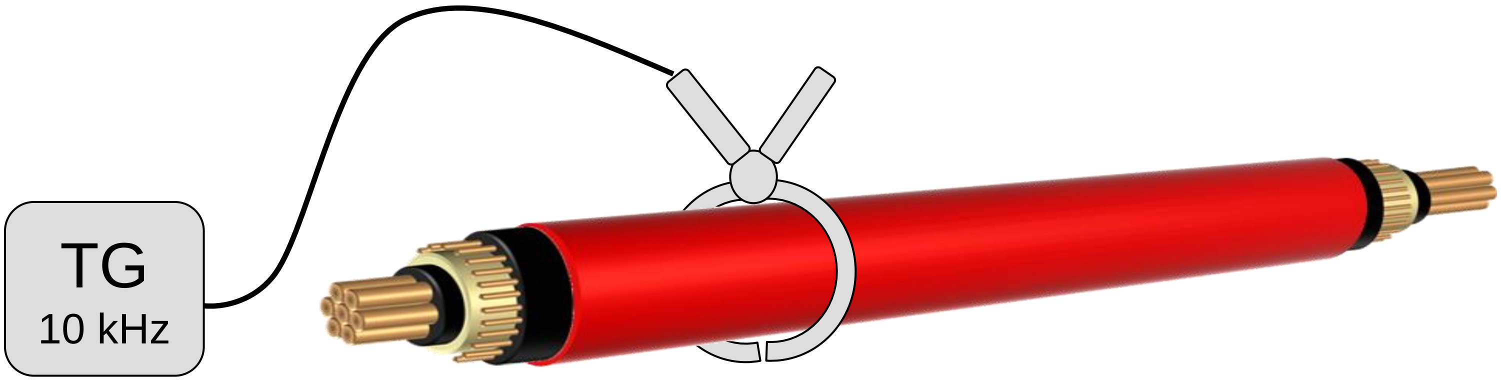
1. Galvanic connection



Advantage: Maximum Performance
Full control of the current flow
Works with low frequencies
100 % transmission power

Possible connections - Inductive

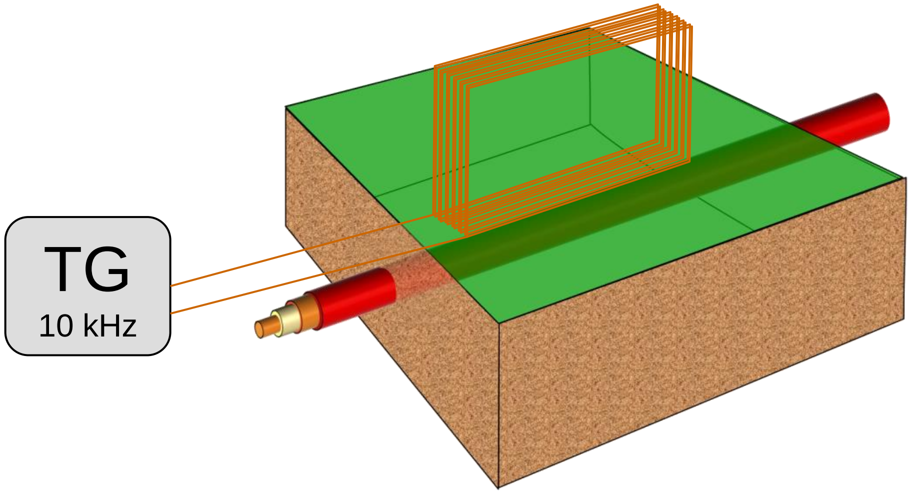
2. Inductive connection with current clip on device



Advantage: reduced Performance
Control of the current flow
20 % transmission power

Possible connections – Frame antenna

3. Inductive connection with frame antenna

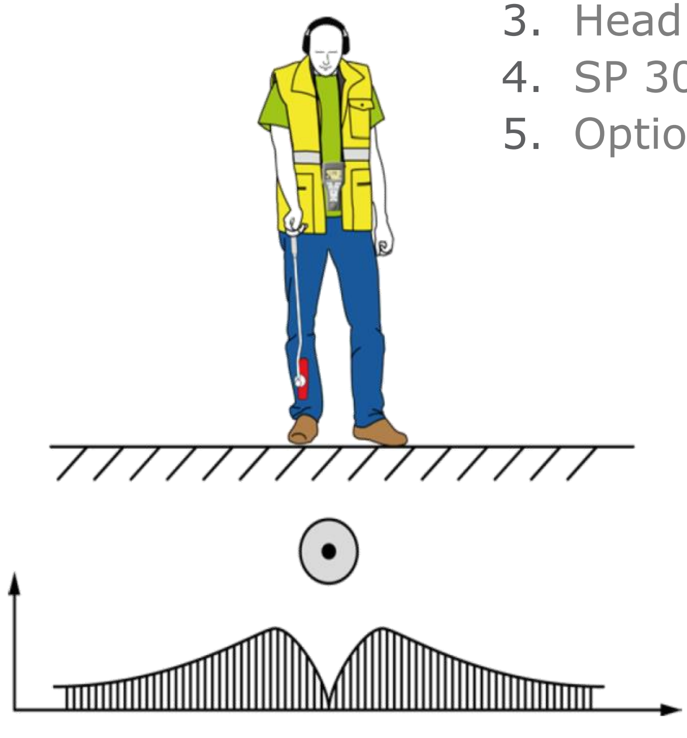


Problems:	Low Performance No control of the current flow 5 % transmission power Requires higher frequencies Induction into all neighbouring lines reduced range (200 - 500 m)

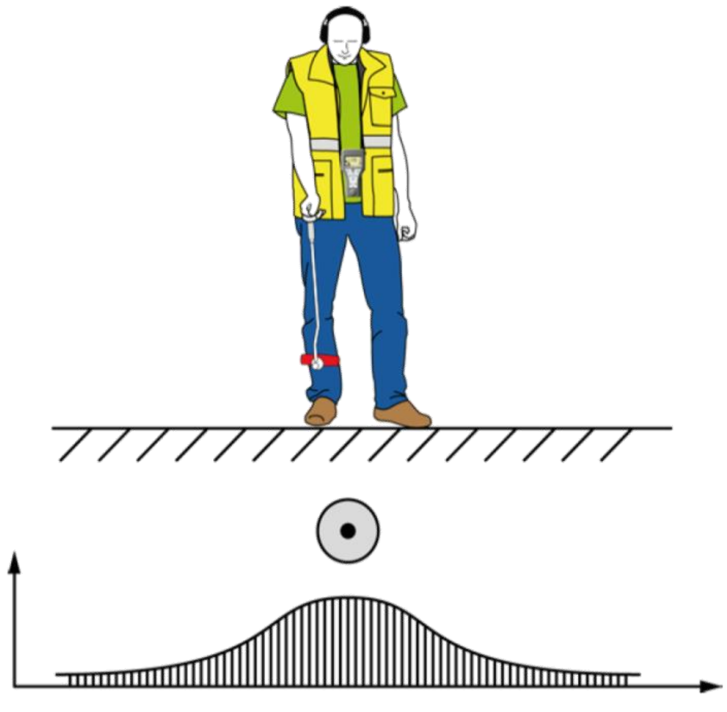
How to use the search coil

Cable tracing with

1. TG („tone" generator)
2. UL 30 („hand held" device)
3. Head phones
4. SP 30 (coil)
5. Option: CL 20



1. Minimum method

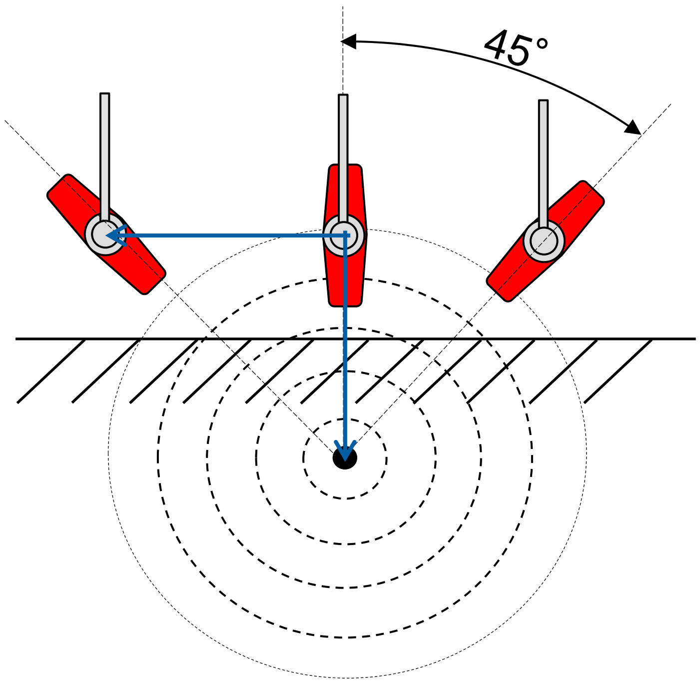


2. Maximum method

Depth measurement

The minimum method allows a geometrical depth measurement by flipping the search coil to a 45° position.
The distance between the minimum at 45° and the vertical location at 0° is equal to the depth of the cable.
To verify this measurement it should be repeated from the other side.

Distance = Depth



3. Depth measurement acc. to the minimum method

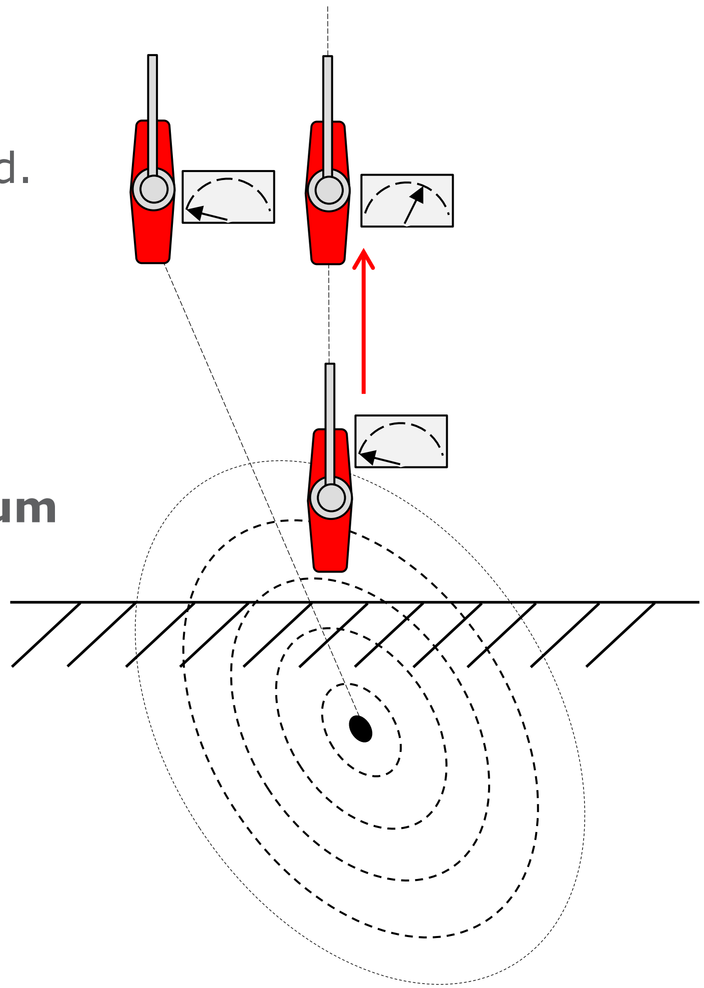
Depth measurement

The magnetic field around a cable may be distorted.

This results into:

a. A false depth indication
b. A wrong position on the surface

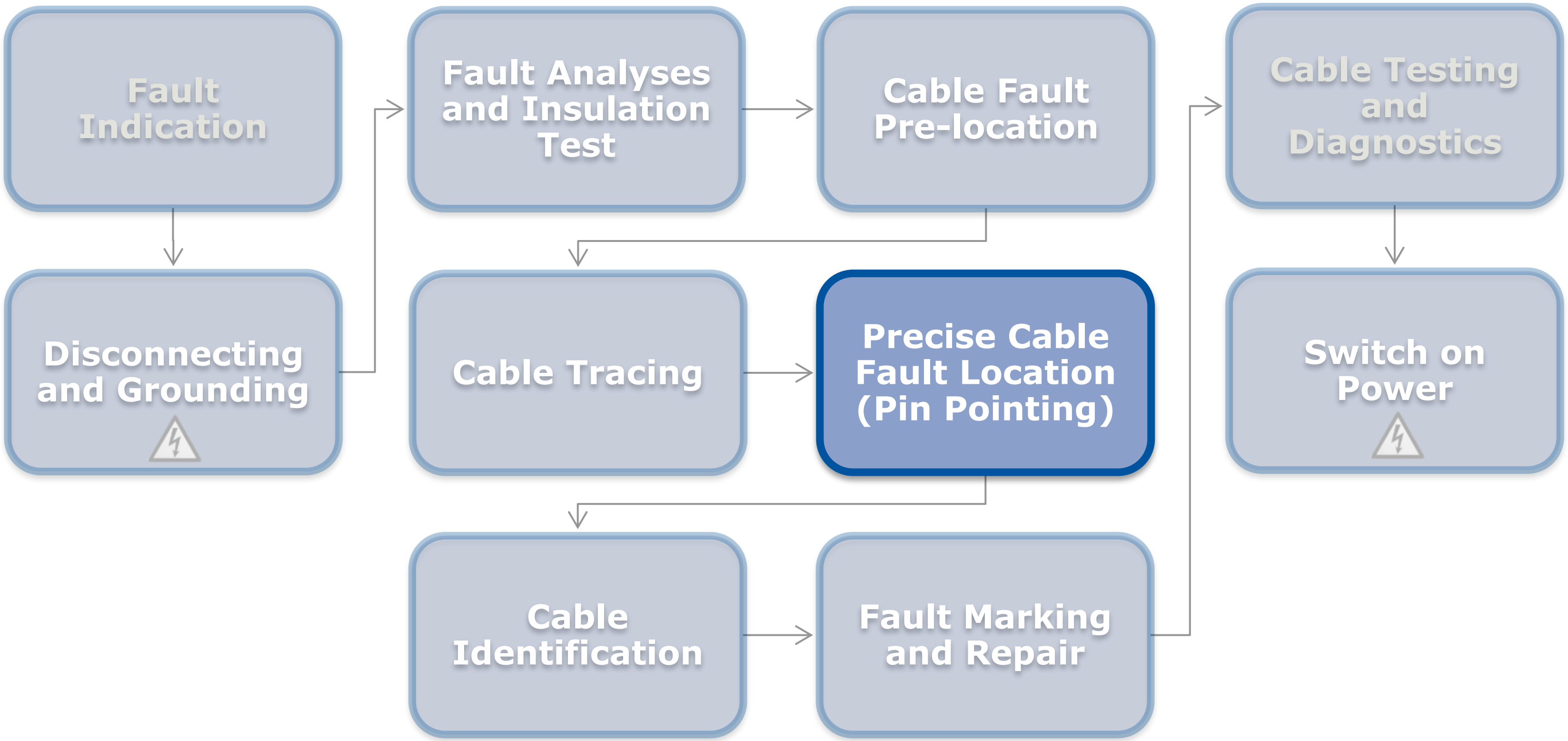
This can be easily recognised by using the **minimum method** while lifting the search probe vertically.
A change of the minimum indicates a distorted field.
The evaluation to correct this distortions is done geometrically.



4. Detection of a distorted field

5th step

Precise cable fault location (pin pointing)



5th step: precise cable fault location (pin pointing)
The different methods

Acoustic fault location
- Coincidence Method with acoustic receiver

Fault pin pointing of low resistive cable faults
- Minimum Distortion Method
- Twist method

Fault pin pointing of earth faults
- Step Voltage Method with pulsed DC
- Step Voltage method with AC (Audio Frequency)

5th step: precise cable fault location (pin pointing)

Acoustic fault location

Important is the correct use of the available SSG surge energy to get the maximum possible energy discharged into the cable fault to obtain maximum loudness from the flash over.

In simple term this means to use the SSG always at the maximum Voltage of the selected Voltage range,

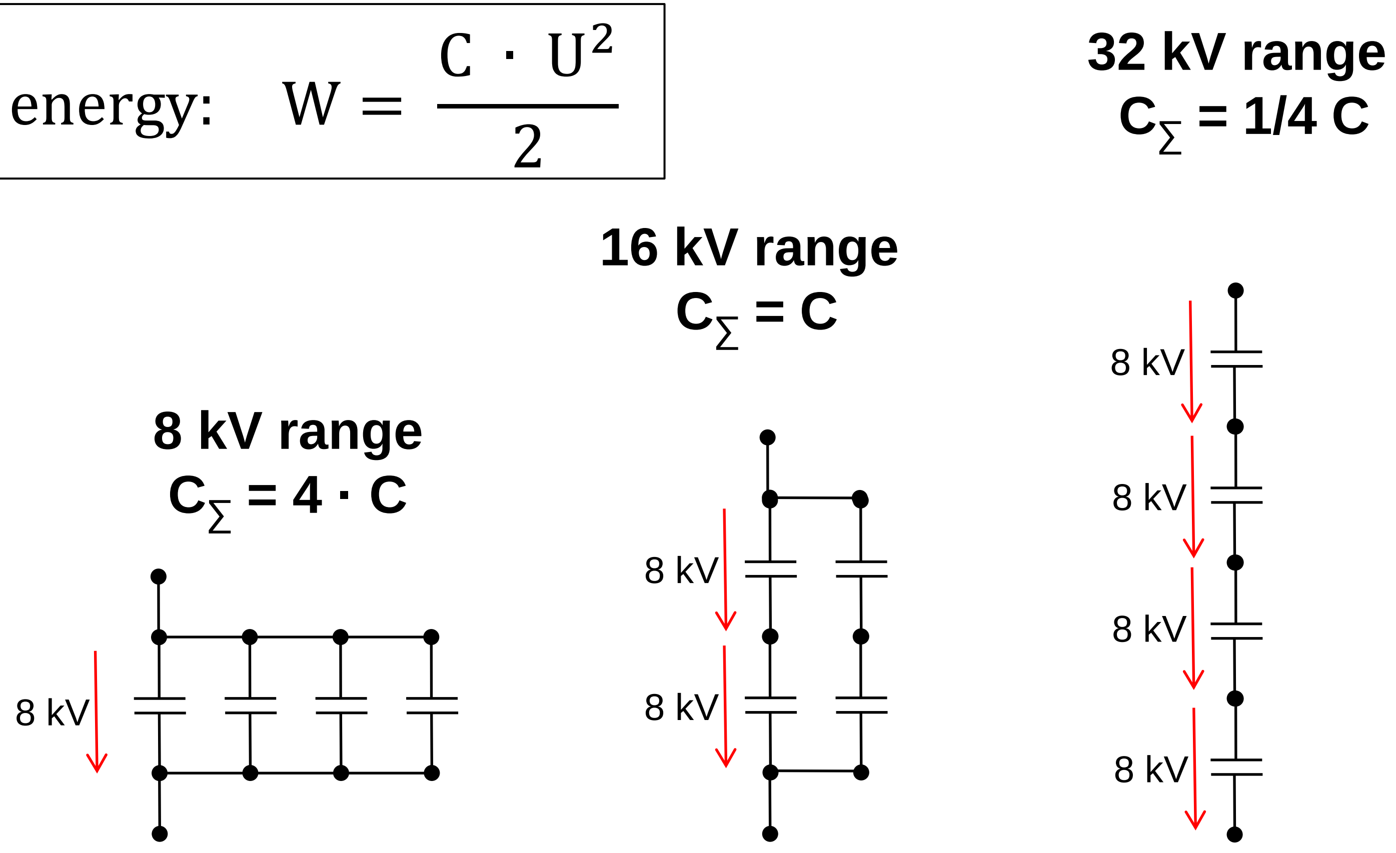
The following equation shows the dependency on Voltage.

$$\boxed{W = \frac{C \cdot U^2}{2}}$$

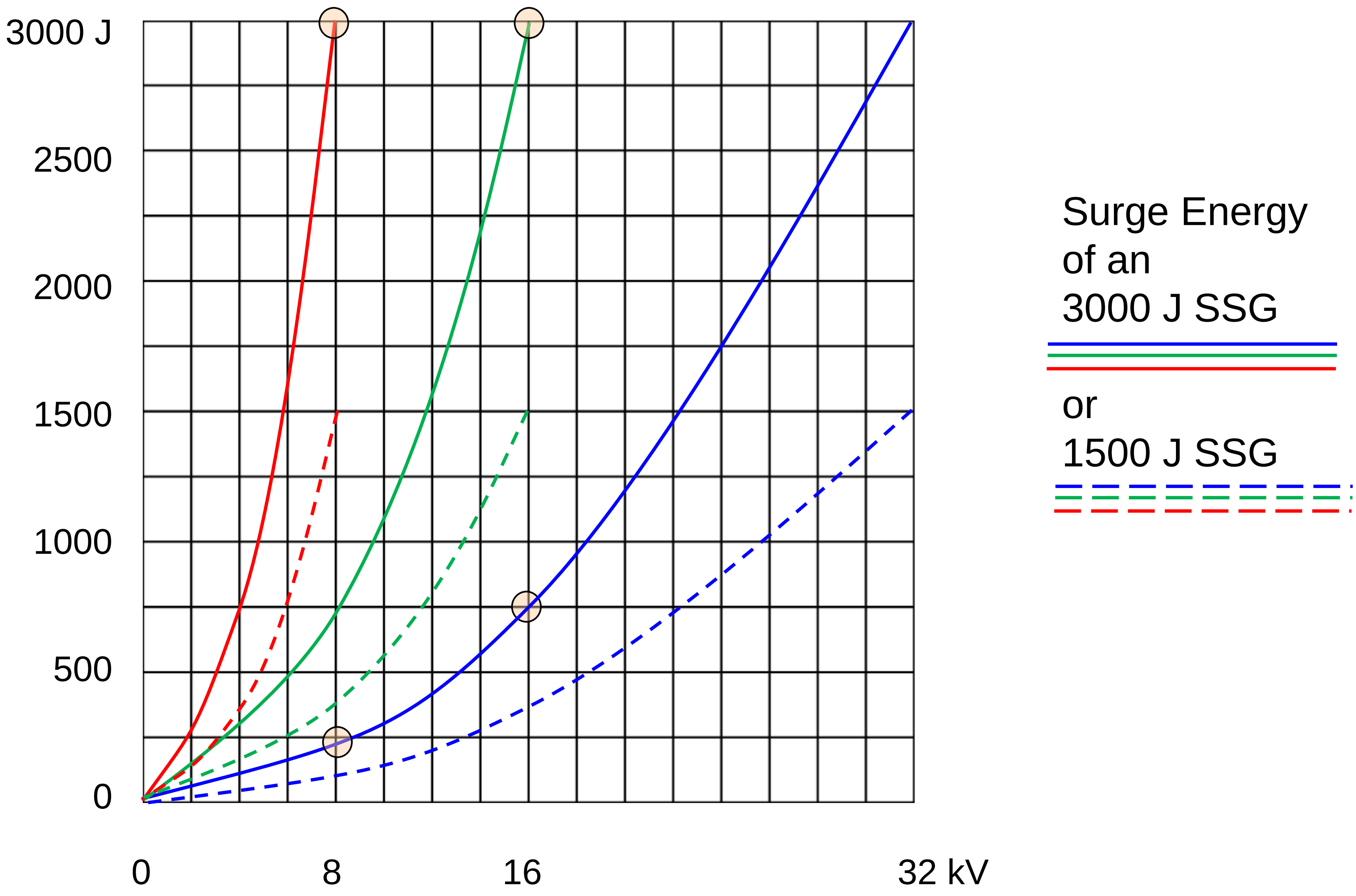
Surge generator set up

Switching of the single capacitors of the SSG capacitor banks

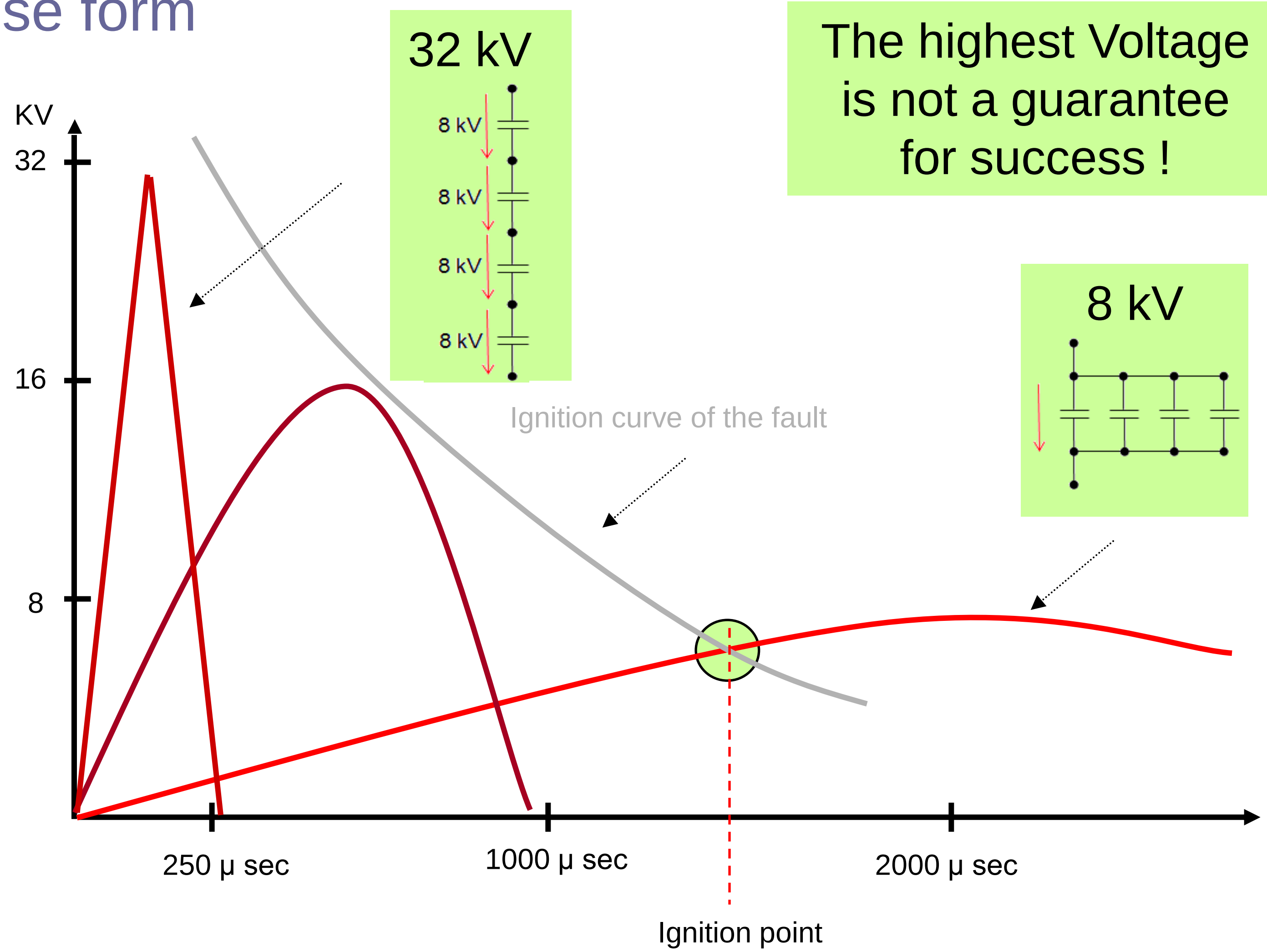
$$\text{surge energy:} \quad W = \frac{C \cdot U^2}{2}$$



Surge energy and voltage range



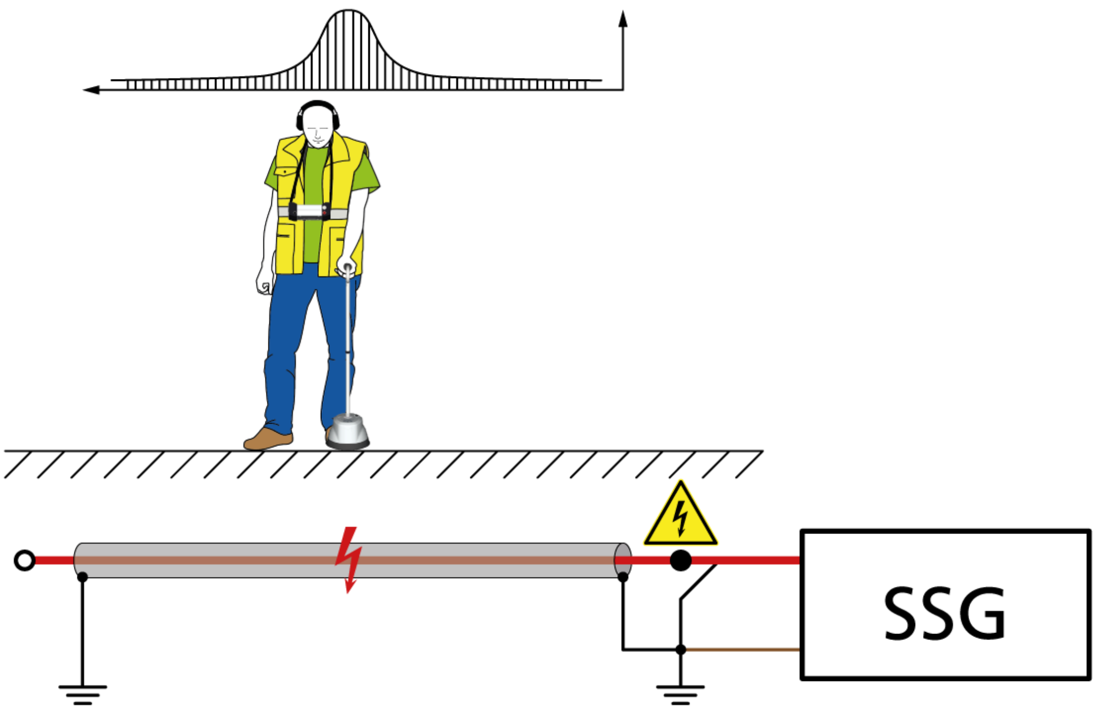
Progression of fault ignition voltage and surge generator Surge impulse form



BAUR
ensuring the flow

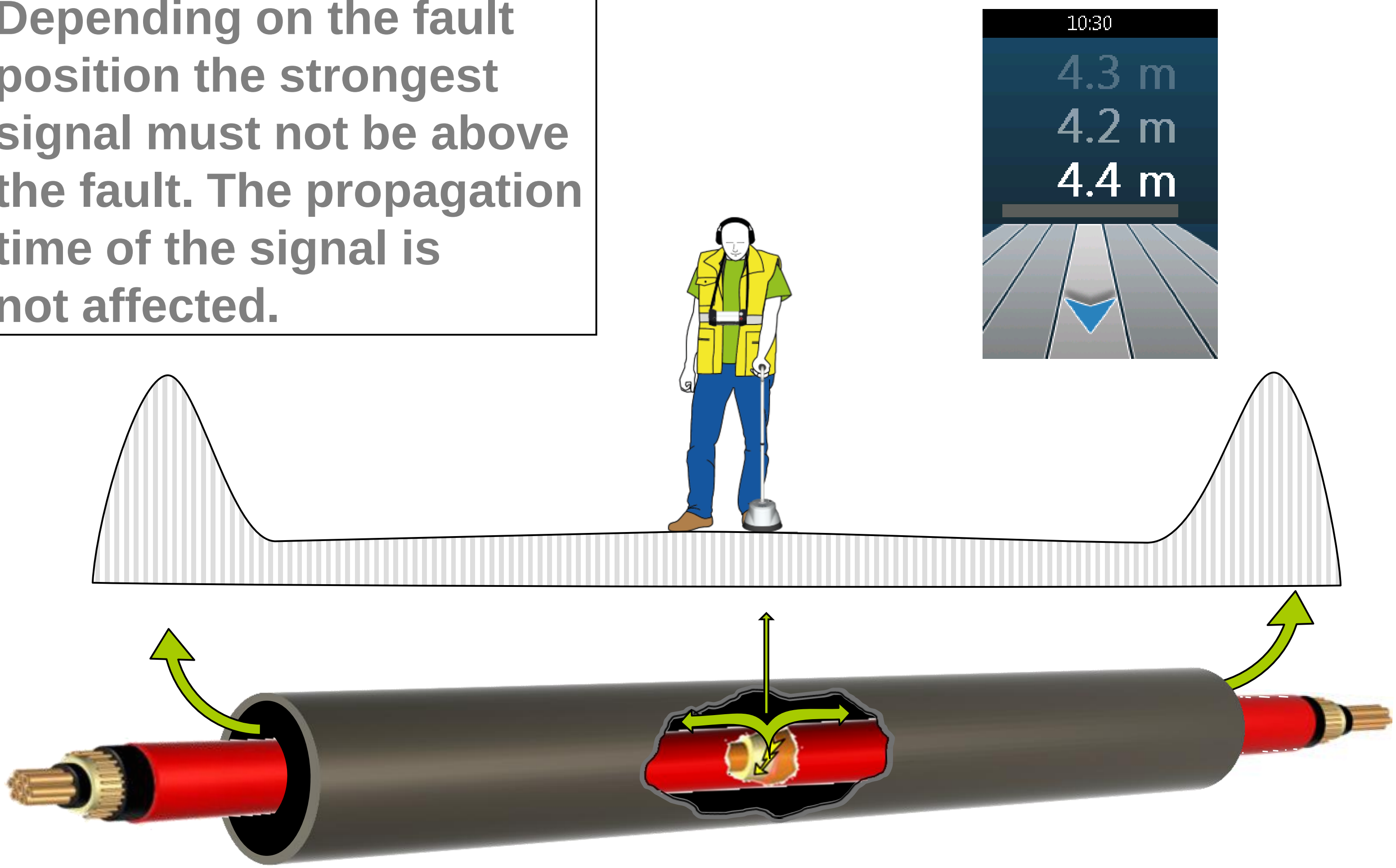
Acoustic fault location

The closer, the louder ?



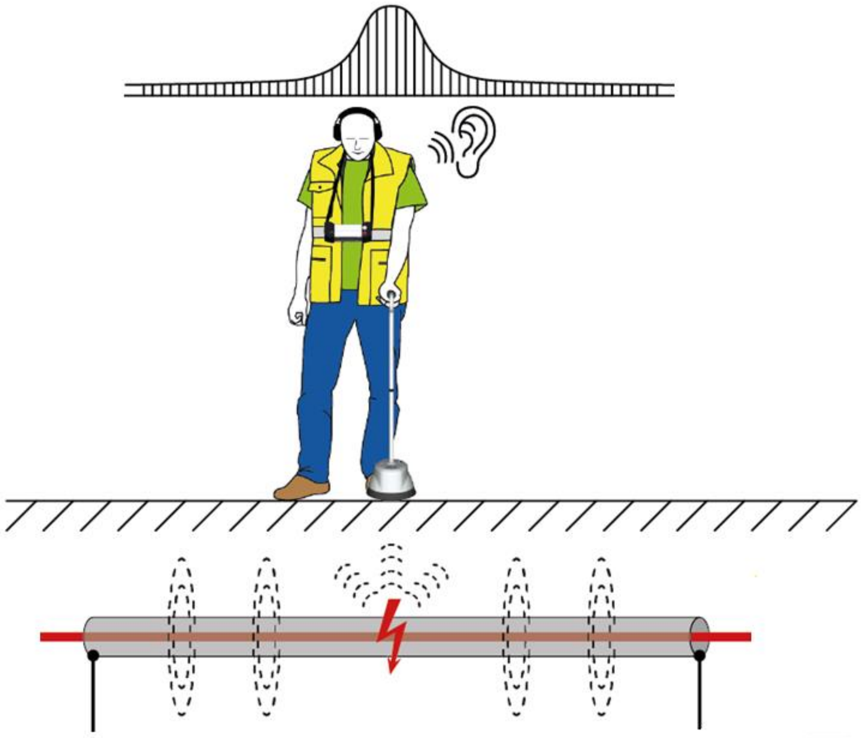
Acoustic fault location of cables in pipes

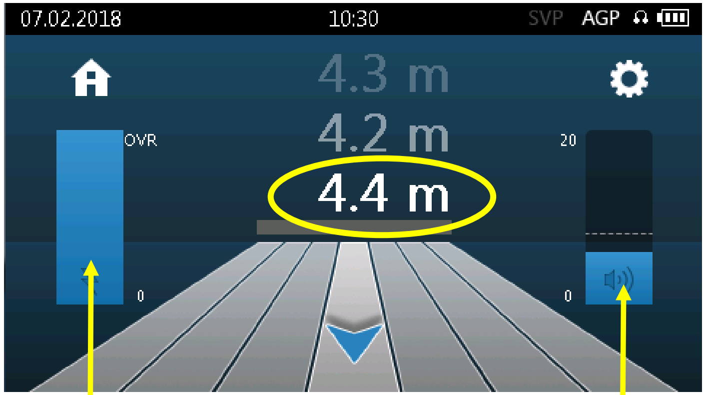
Depending on the fault position the strongest signal must not be above the fault. The propagation time of the signal is not affected.



Acoustic + coincidence fault location

The shortest time delay shows the fault position, not the loudest signal!

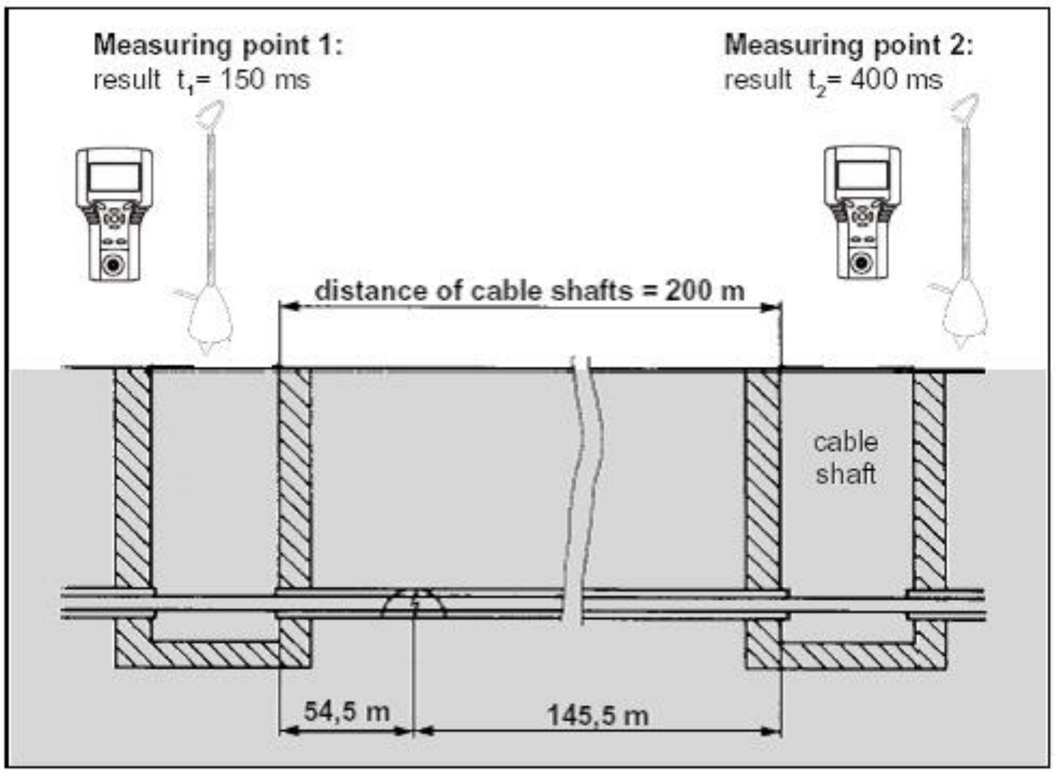




magnetic pick-up
+ acoustic pick-up
⇒ Propagation time
⇒ Meter - indication

5th step: precise cable fault location (pin pointing)

Acoustic fault location at manholes



5^{th} step: precise cable fault location (pin pointing)
Different methods

Acoustic fault location

- Coincidence Method with acoustic receiver

Fault pin pointing of low resistive cable faults

- Minimum Distortion Method
- Twist method

Fault pin pointing of earth faults

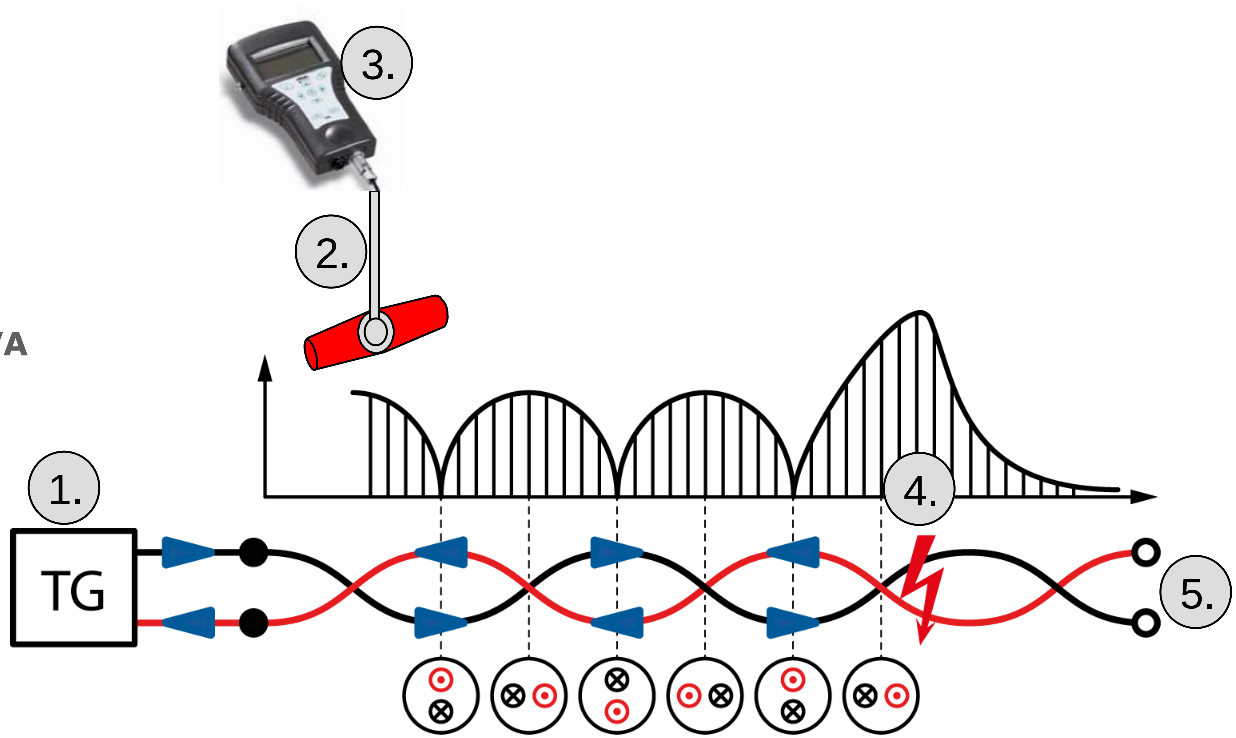
- Step Voltage Method with pulsed DC
- Step Voltage method with AC

Twist method

Perfect for detecting

- Low resistive faults in
- Twisted cables

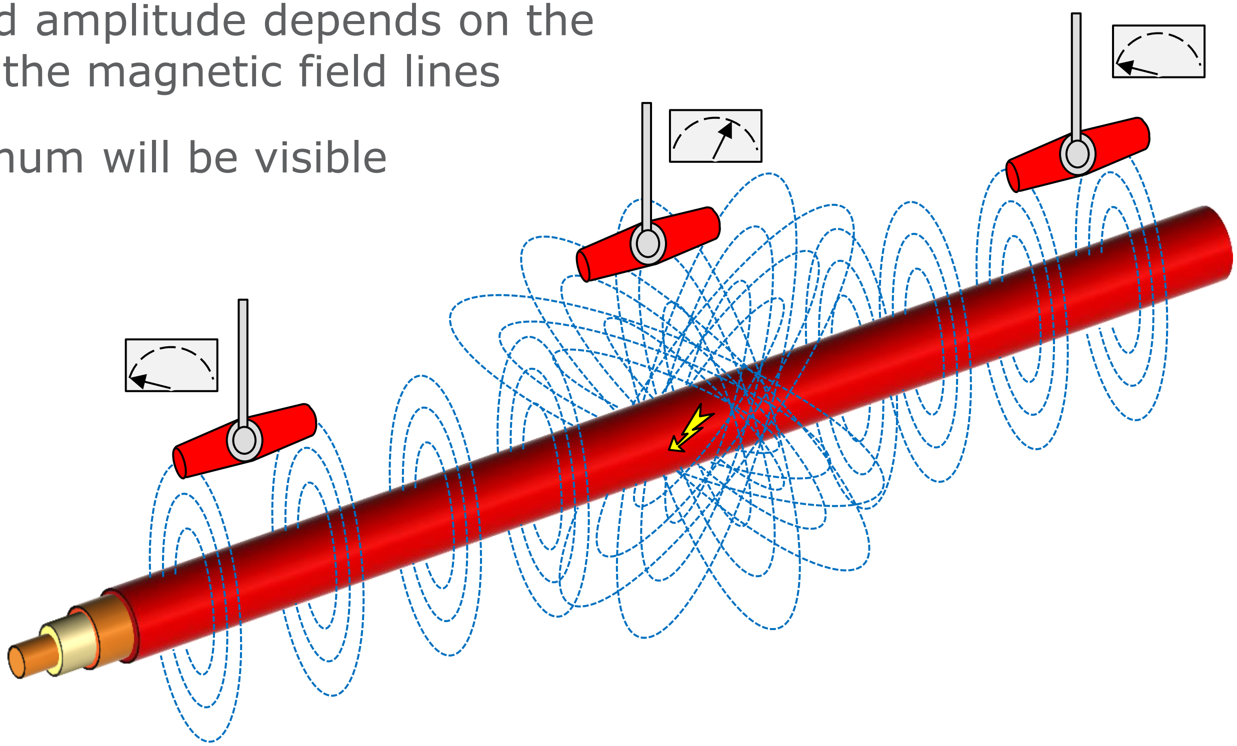
1. Audio transmitter 2 kHz, **600 VA**
2. Search coil
3. UL Audio receiver
4. Fault (< 10Ω)
5. open end



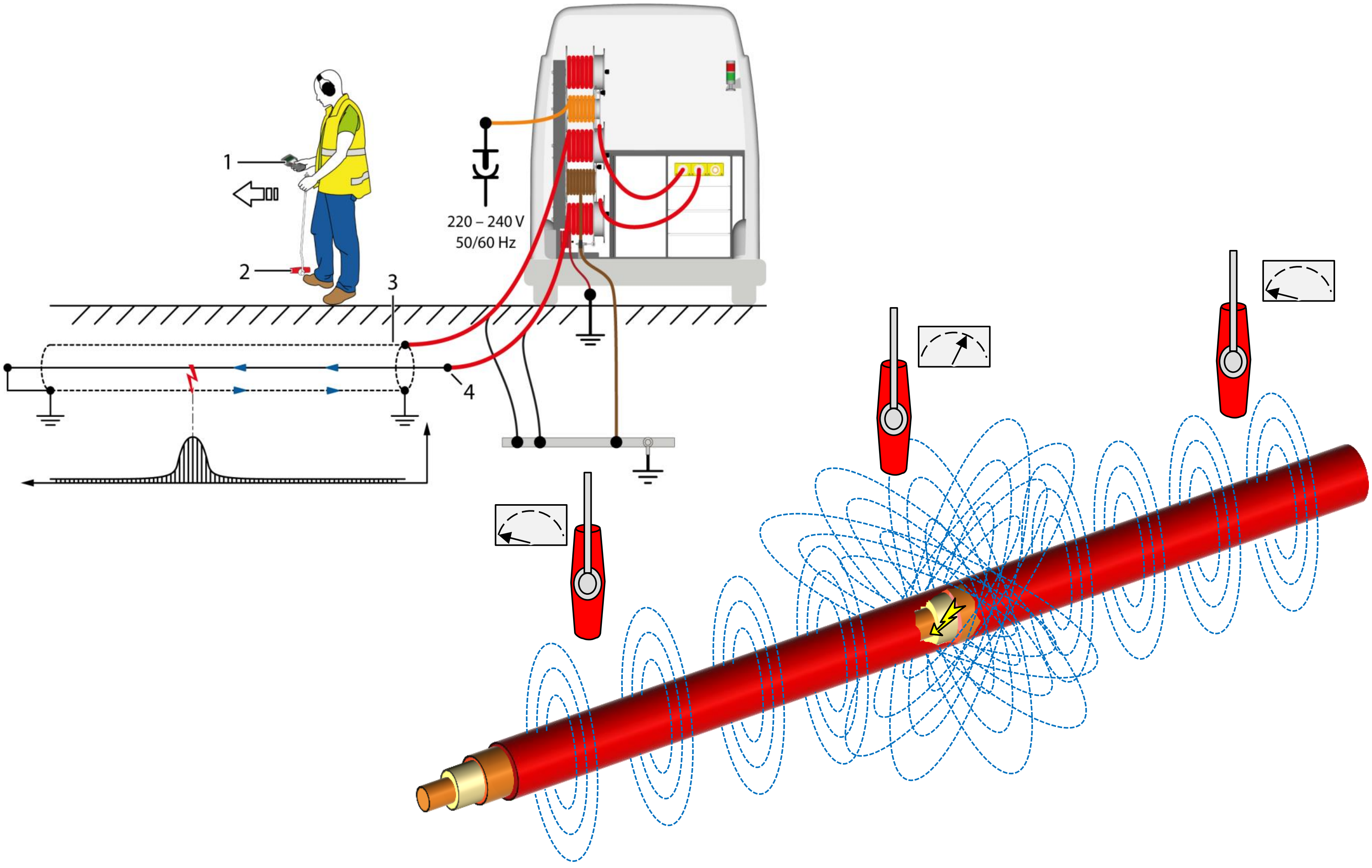
Minimum Distortion method

Perfect for detecting

- Low resistive faults / short circuits in straight, shielded MV cables
- Receiving coil horizontal and parallel to the cable
- Displayed amplitude depends on the effect of the magnetic field lines
- No minimum will be visible



Minimum Distortion method



5th step: precise cable fault location (pin pointing)
Different methods

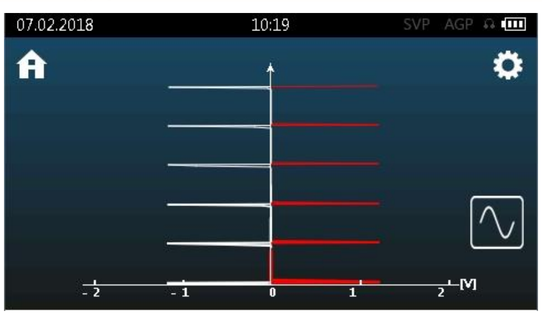
- Acoustic fault location
  - Coincidence Method with acoustic receiver
- Fault pin pointing of low resistive cable faults
  - Minimum Distortion Method
  - Twist method
- **Fault pin pointing of earth faults**
  - Step Voltage Method with pulsed DC
  - Step Voltage method with AC

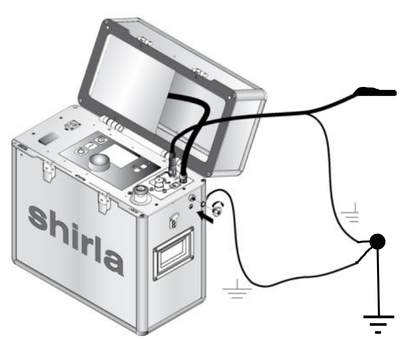
5th step: precise cable fault location (pin pointing)

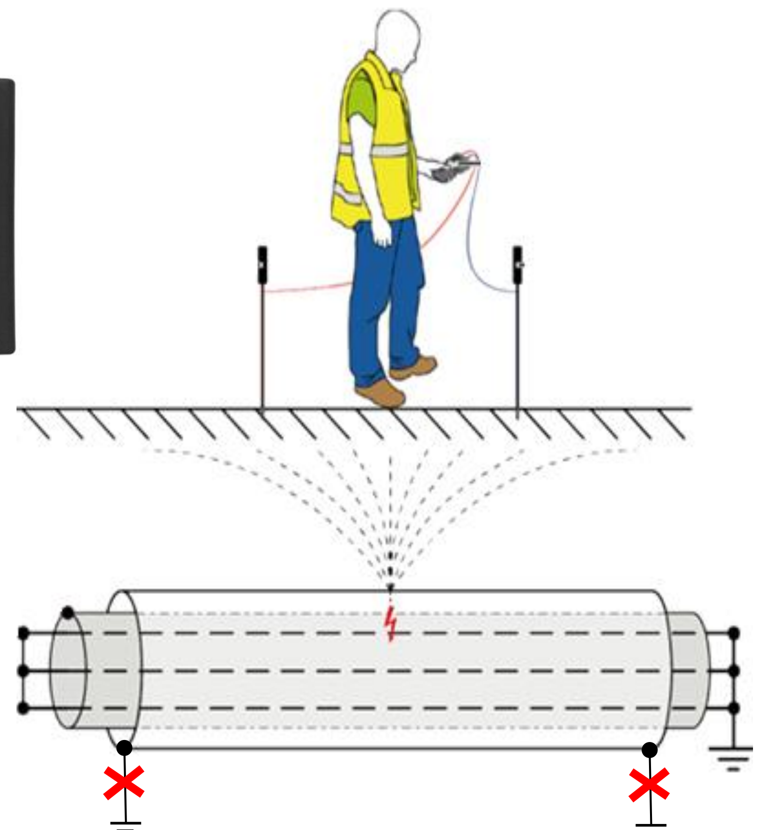
Step voltage Method

Cable sheath fault pin-pointing receiver and accessories

Always ensure that the shield is disconnected at both ends!

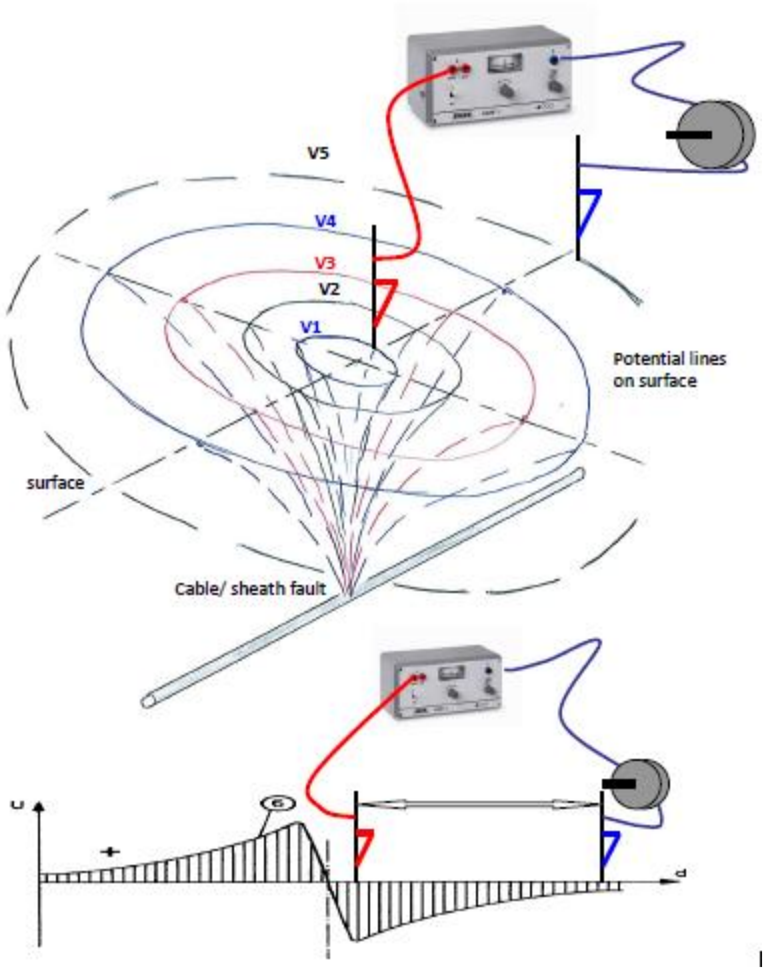






5th step: precise cable fault location (pin pointing)

Step voltage method



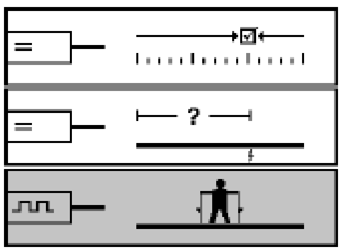
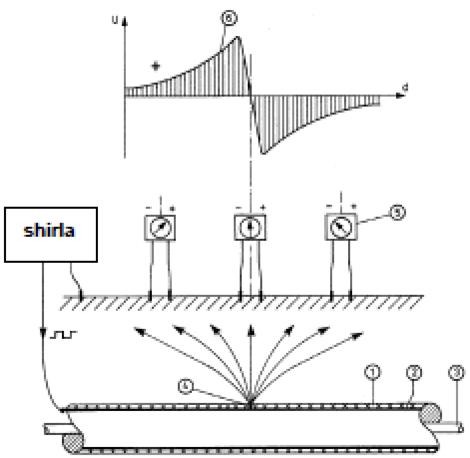


Fig. 7.2.2; Shirla display, pin-pointing mode



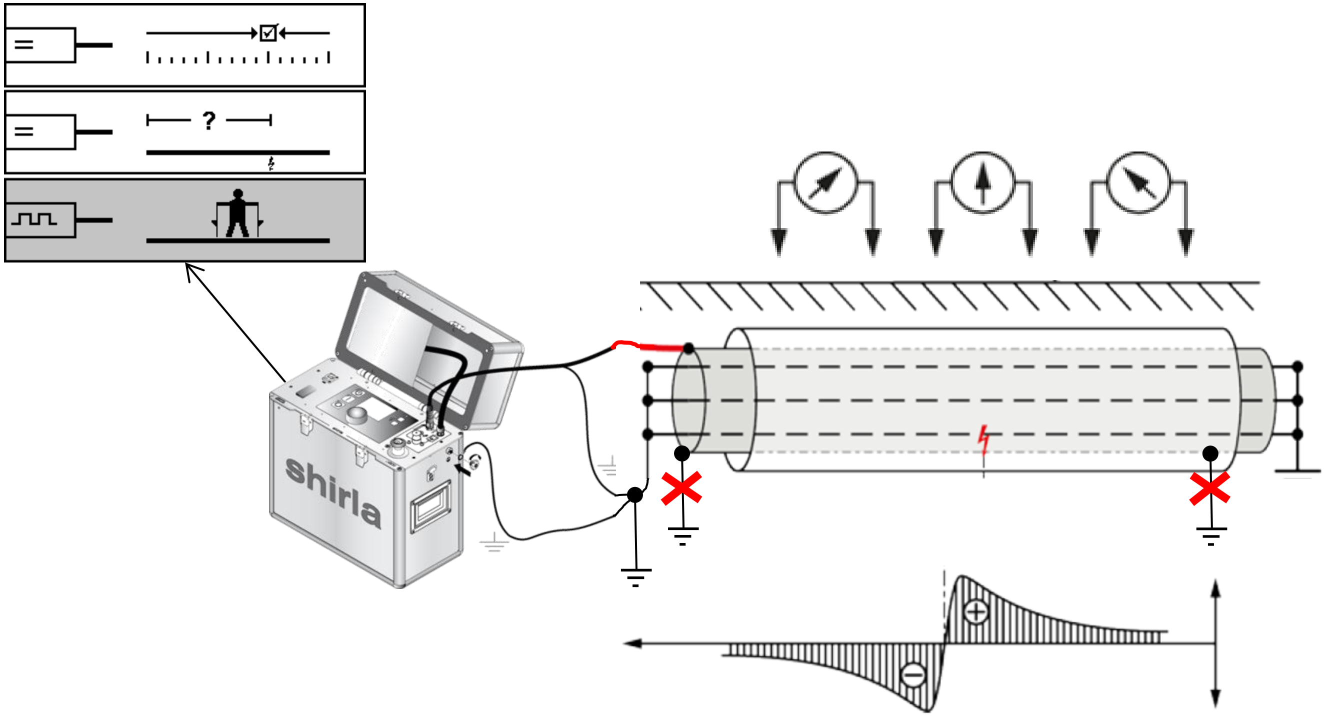
5th step: precise cable fault location (pin pointing)

Step voltage method

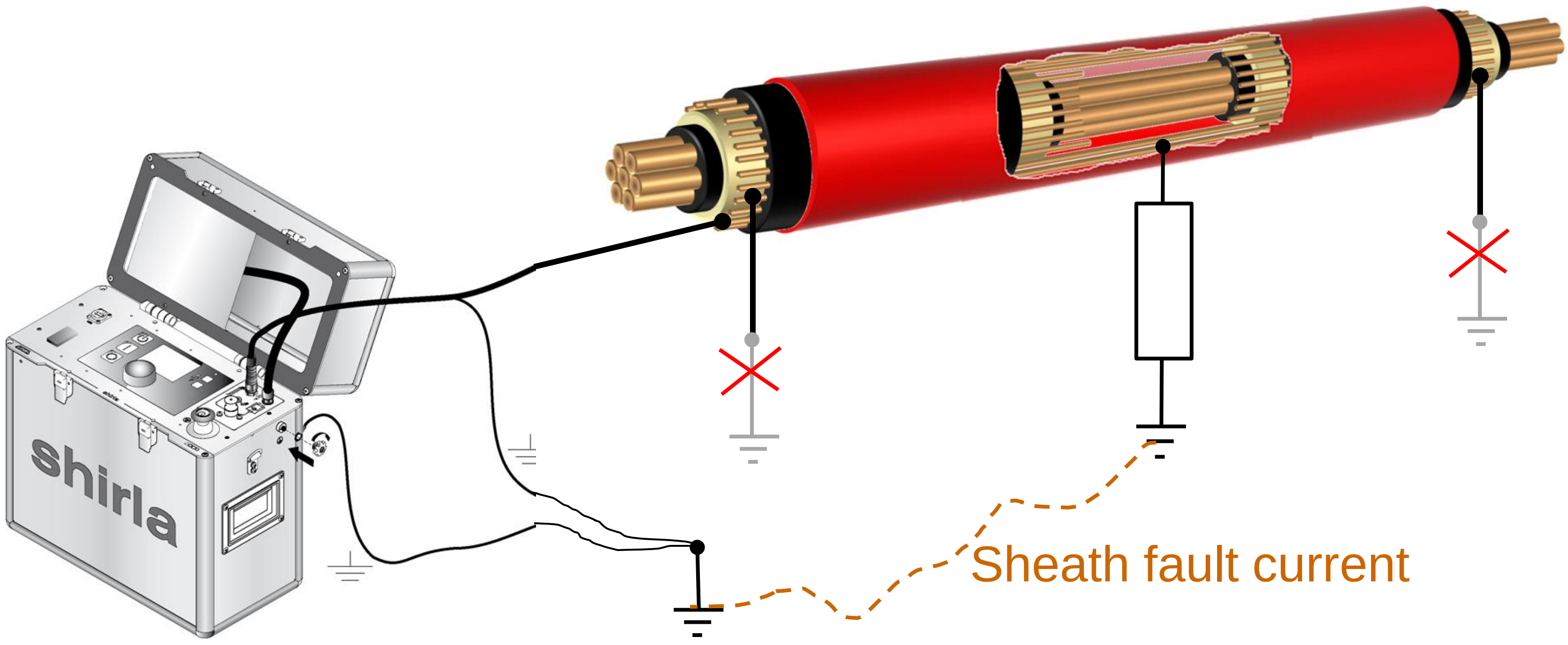
Perfect for detecting

- cable sheath faults

- any other earth related cable fault



Step voltage method – connection



To allow a direct current flow from the shield to ground, only through the fault both ends of the shield must be disconnected from Ground!

5th step: precise cable fault location (pin pointing)

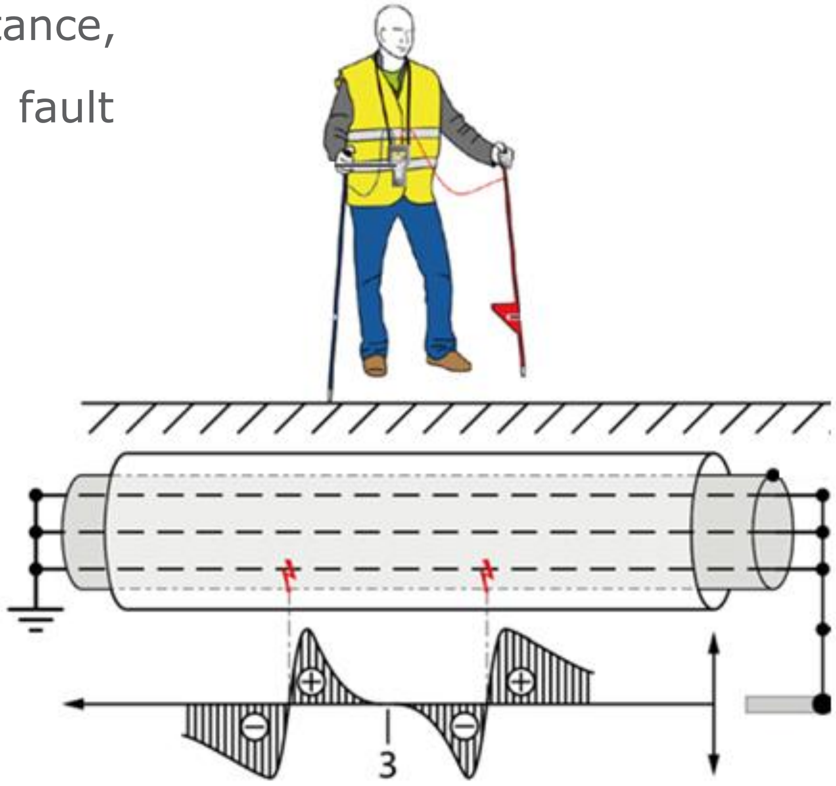
Step voltage method

Multiple earth faults

Multiple Earth faults will not be coincident with the prelocated distance.

The prelocation in this case will show a distance, which is the average between both existing fault positions.

This can be recognised by the uncommon response of the polarity change



5th step: precise cable fault location (pin pointing)

Step voltage with AC

Fault location with capacitive plates

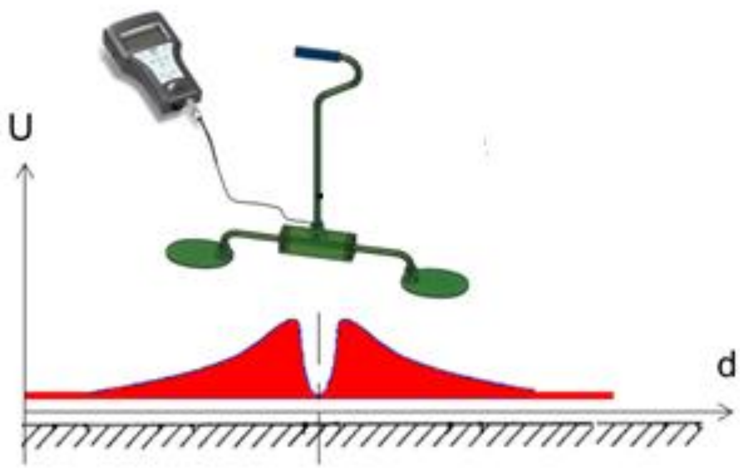
- Solid surfaces like concrete or asphalt may prevent a direct electrical contact, to measure the step potential in the underground.
- For these cases there is the possibility to use Audio Frequency and contactless capacitive plates for the location of earth faults.
- Similar to the DC step voltage, the AC will also generate voltage gradients that can be detected by capacitive probes

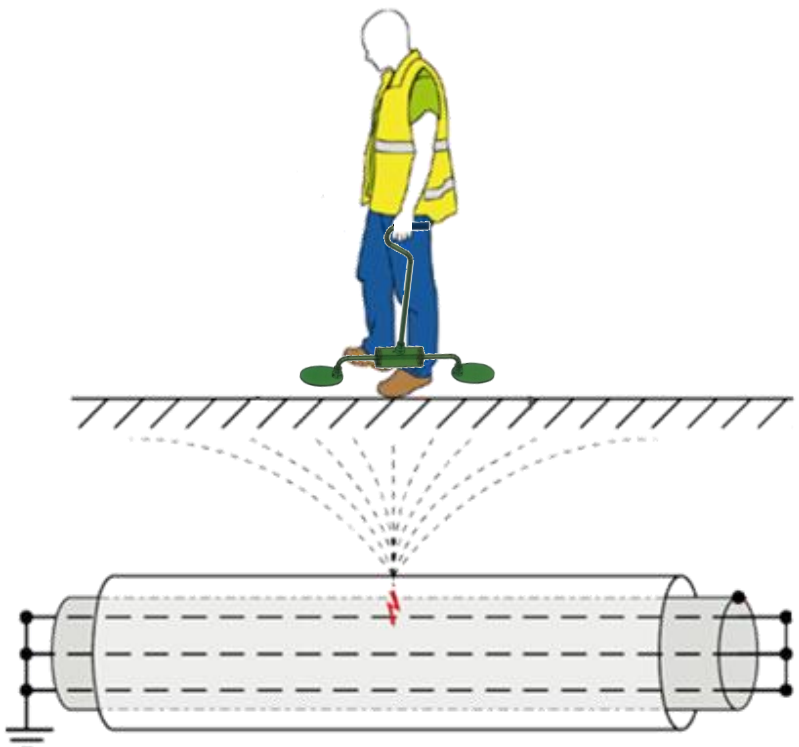
5th step: precise cable fault location (pin pointing)

Step voltage with AC

Fault location with capacitive plates

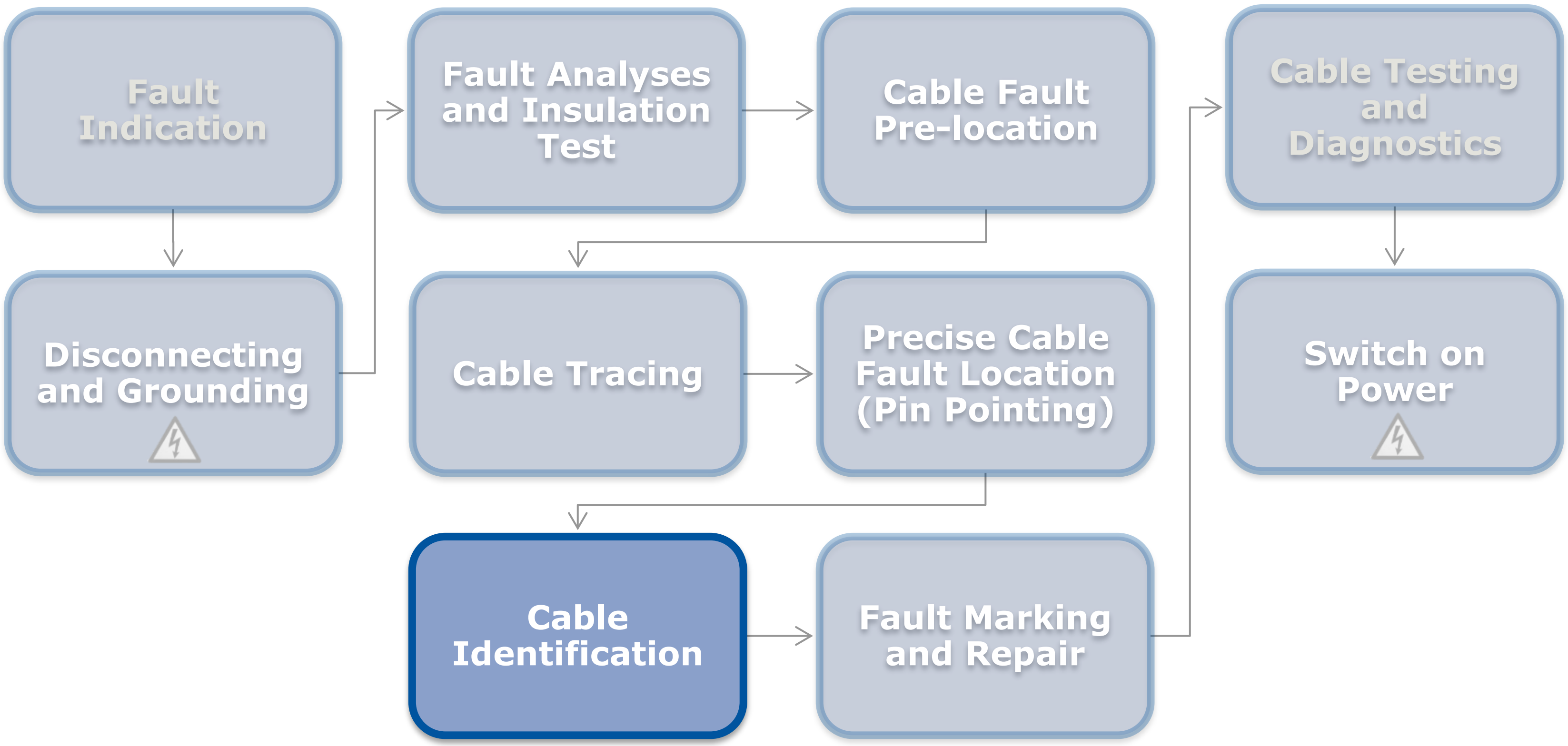
- In opposition to the DC Step method there will be no directional indication.
- The receiver will just show a null indication on top of the fault.





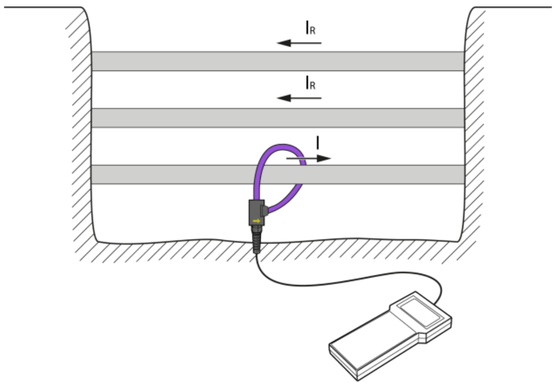
6th step

Cable identification



6th step: cable identification

Purpose of cable identification



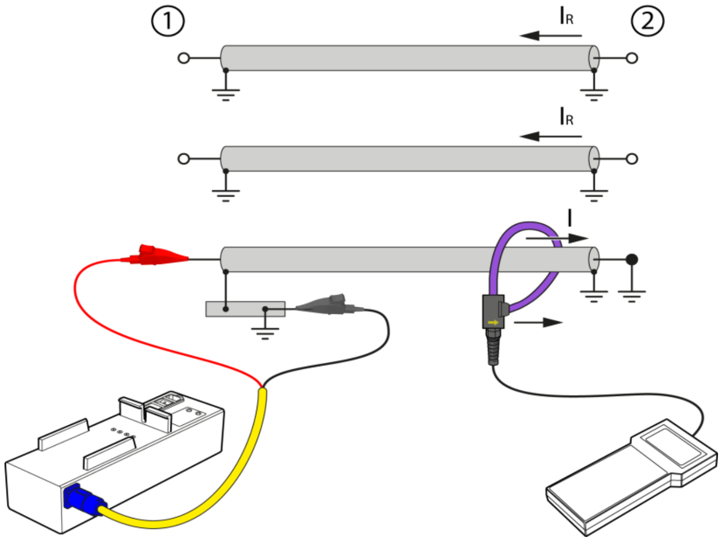
Identify one cable out of several cables!
Application possibility for nearly every existing cable arrangement.

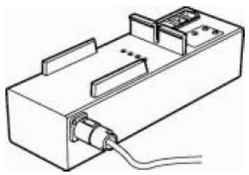
- Flexible Rogowsky coil
- Single and 3-core cables
- Reliable signal acquisition via digital analysis of

✓ **direction**

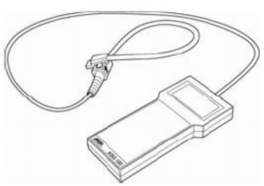
✓ **amplitude**

✓ **phase synchronisation**





Transmitter



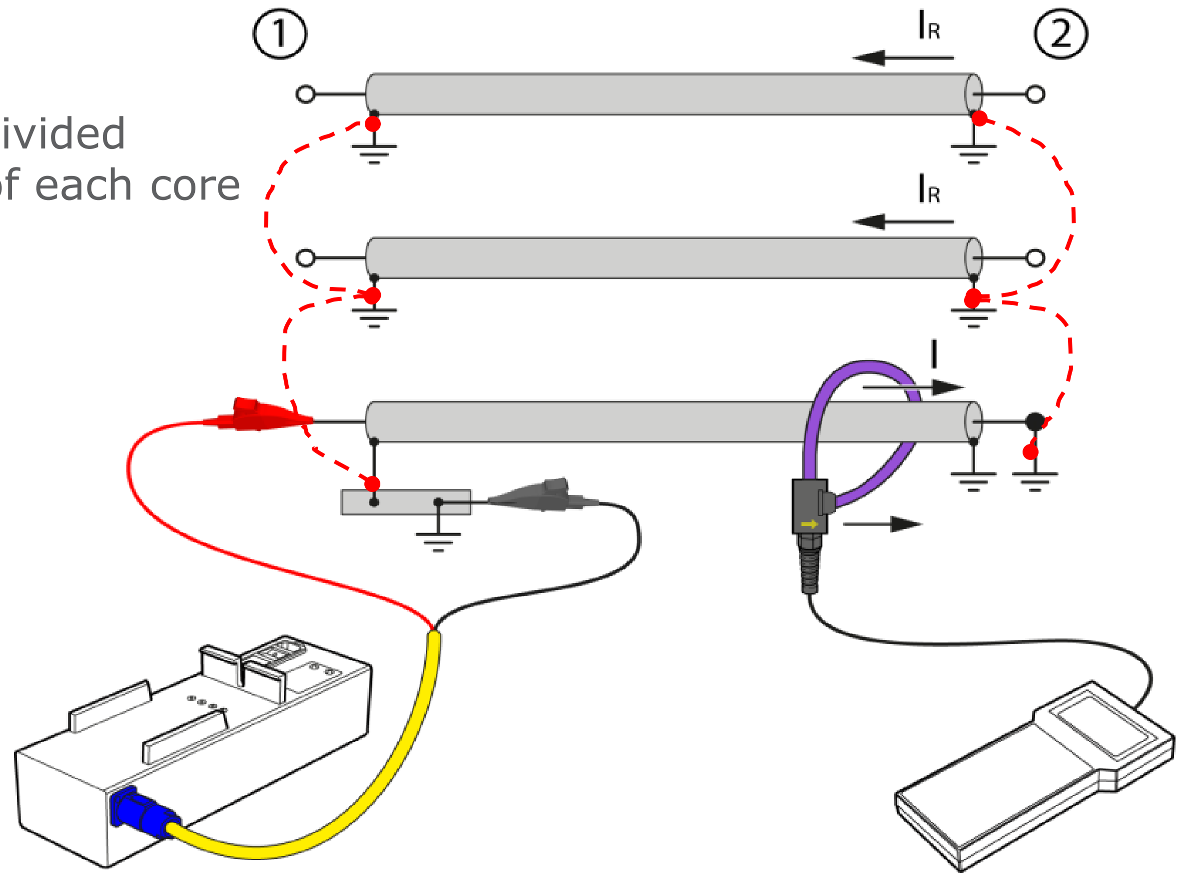
Receiver

6th step: cable identification

Purpose of cable identification

The system is following the rules of the Kirchhoff current law

The backward currents are divided according to the resistance of each core



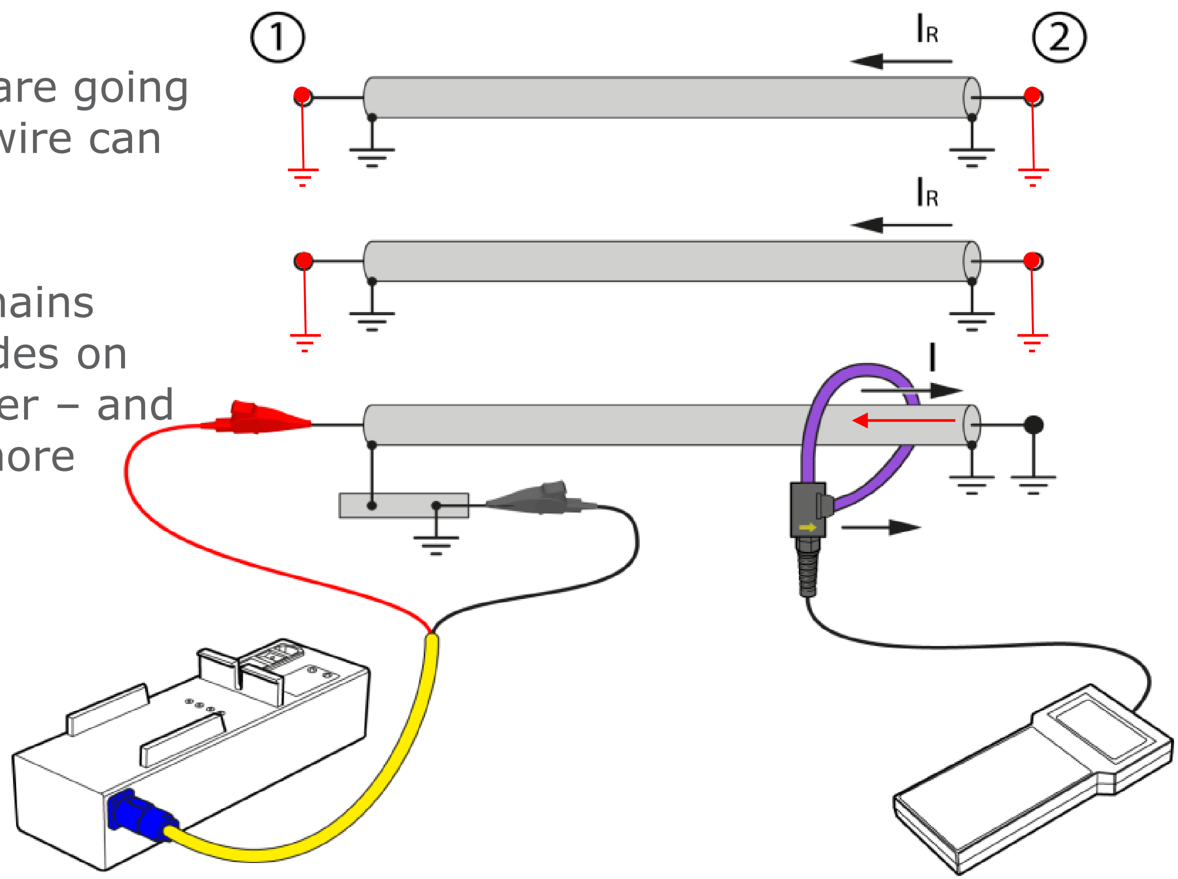
6th step: cable identification

Purpose of cable identification

Unused wires must be grounded!

Because the currents which are going back on the screen and the wire can be maximized.

The “positive” amplitude remains large – and also the amplitudes on the back wires becomes larger – and thus the reading is getting more clearly.



6th step: cable identification

Purpose of cable identification

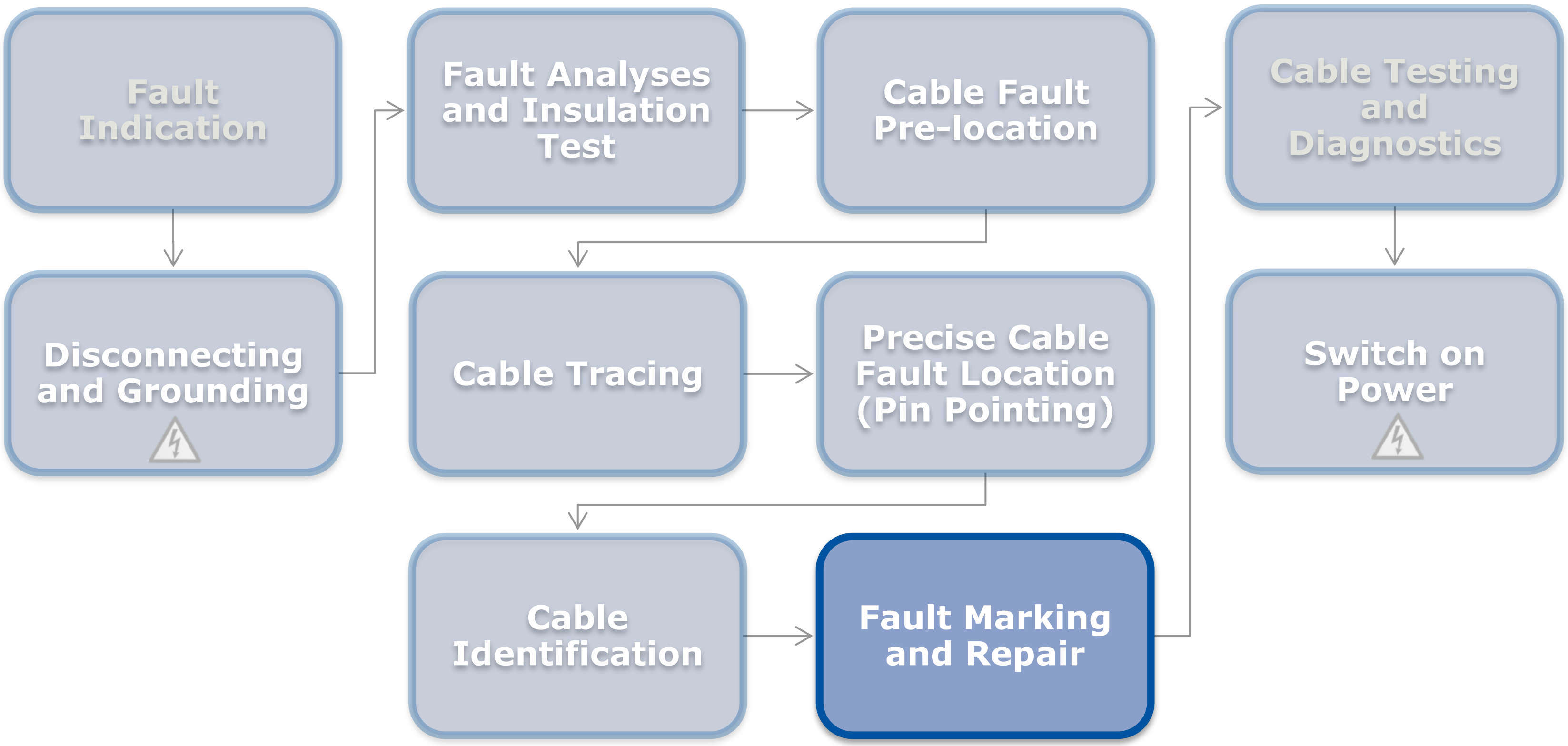
6th step: cable identification

Purpose of cable identification

Never cut a wrong cable!
Eliminate any uncertainty!

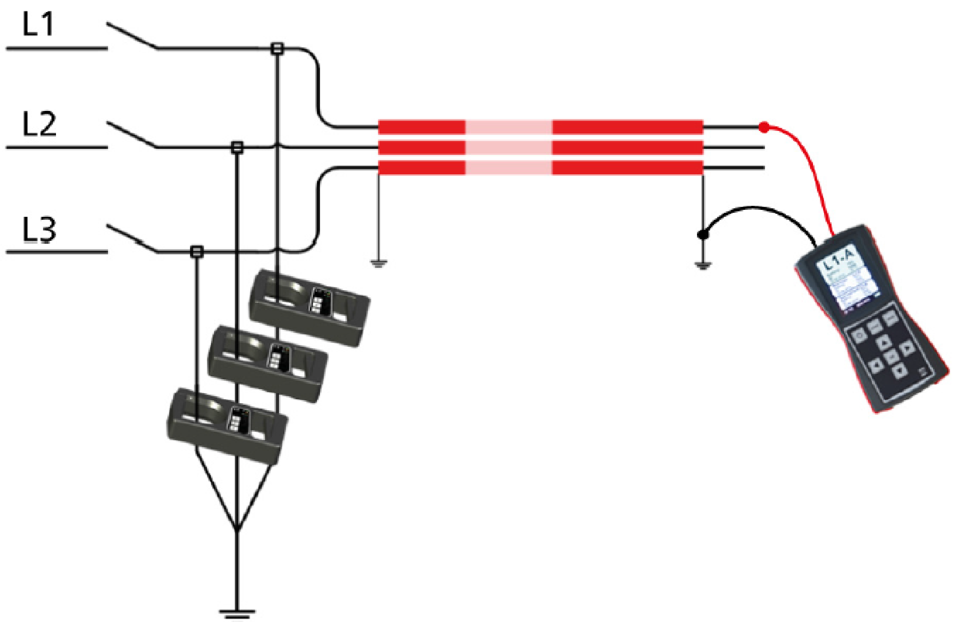
7th step

Fault marking and repair



7^{th} step: fault marking and repair

Phase Identification



Safety Standard:
EN 50110

Operation of electrical installations

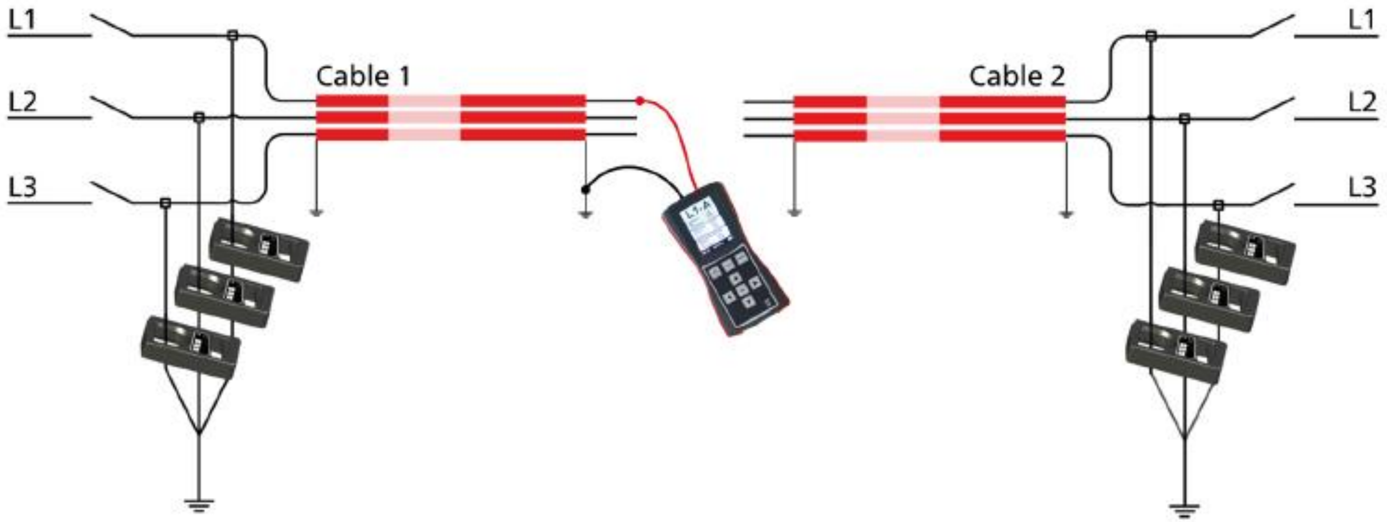
International Safety Standards require the cable to be grounded during repair process or jointing on the cable. Safety requirement for **permanent grounding of all cores** does not allow easy phase identification by Ohmmeter or buzzer.

Whereas Phase identification is mandatory needed to avoid Phase- Phase short circuit.

Paula allows simultaneous identification of up 10 cables

7th step: fault marking and repair

Phase Identification on multiple cables

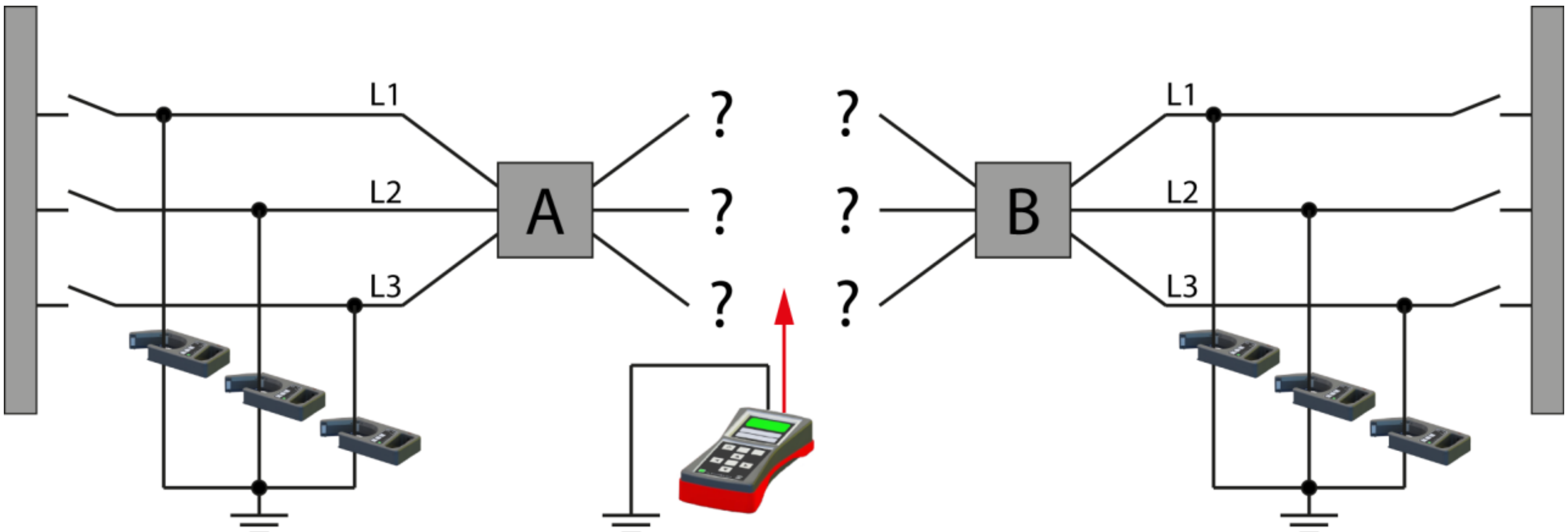


Safety requirement for **permanent grounding of all cores**

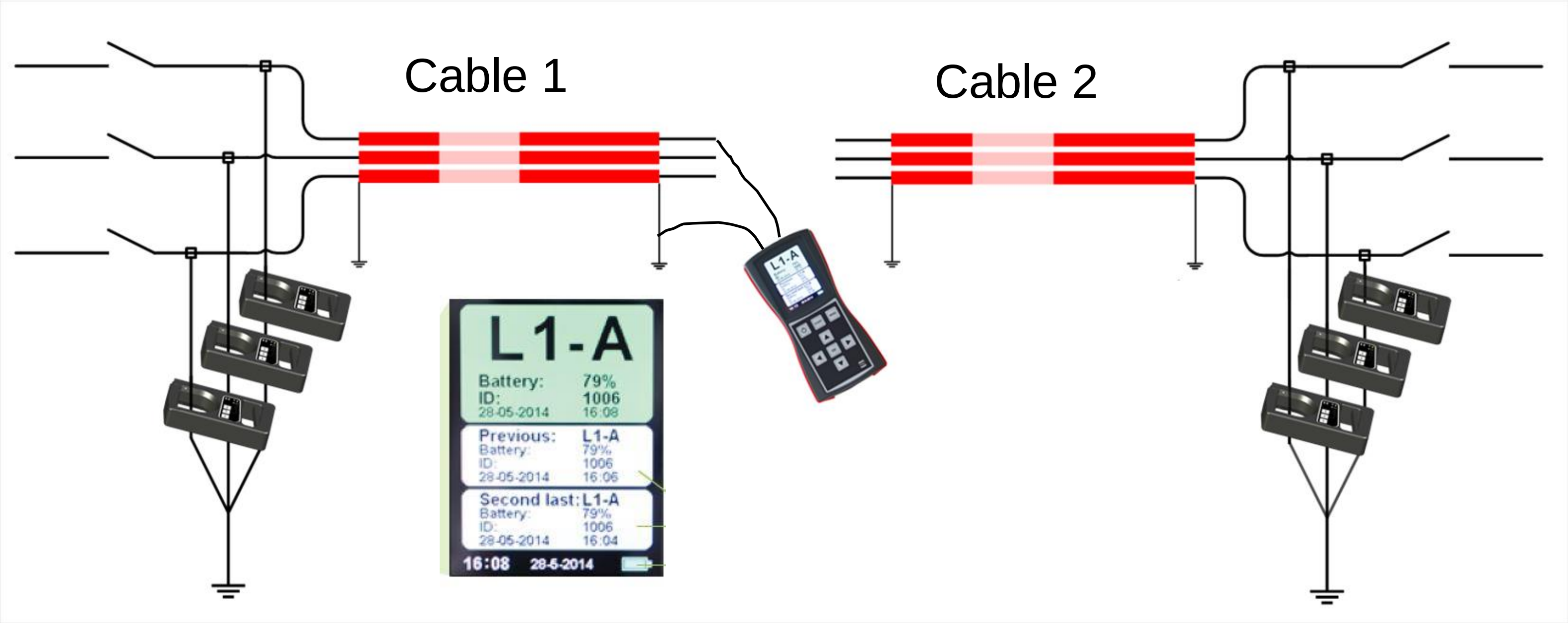
Phase Identifier >Paula< allows simultaneous identification of up 10 cables
Active transmitter can be added on both side to allow fast and safe phase identification on cable length up to 40km
Applicable on **single core** and **multicore** cable design

paula connection diagram

Safe phase determination with grounded cables
according to DIN EN 50110



Paula – phase identification



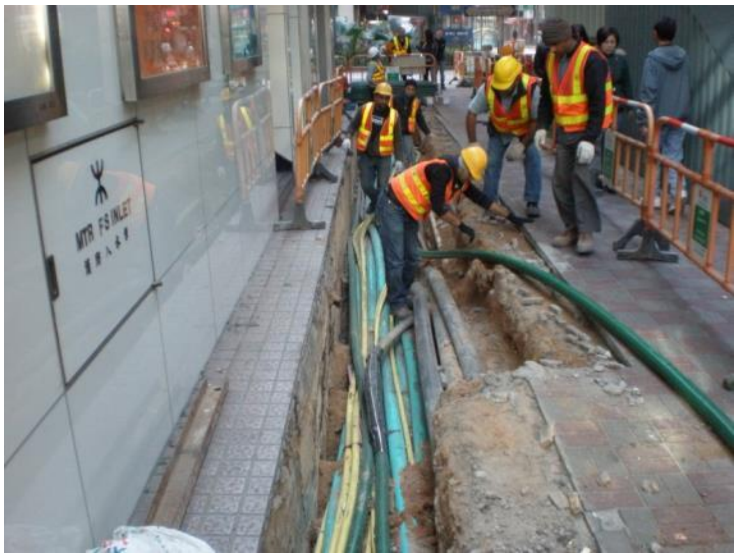
Safety: Permanent grounding of all conductors

With the active transmitters easy and reliable phase selection will be made on cable distances of up to 40km in length!

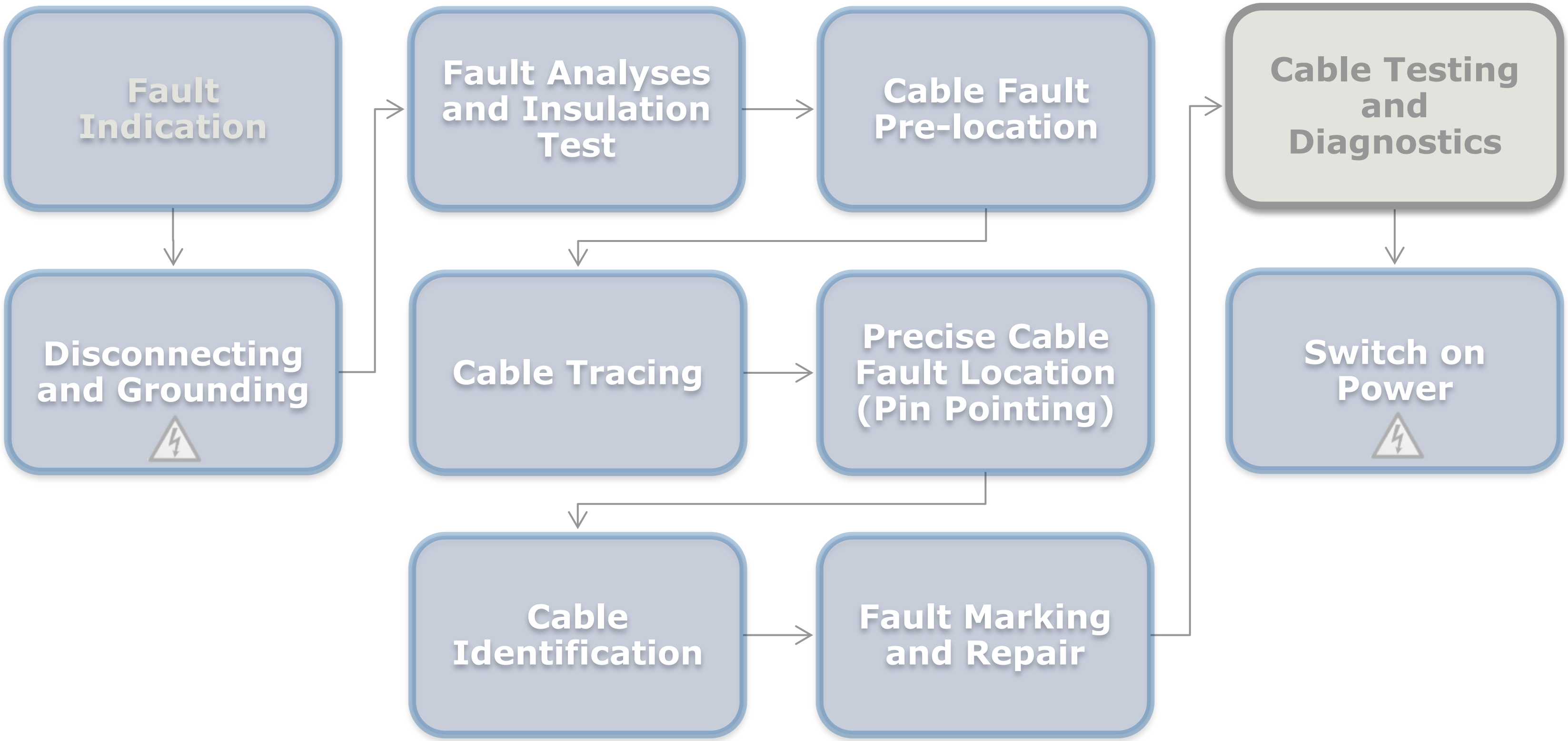
Application for single and multi-conductor cable

7th step: fault marking and repair

Cable repair



8th step
Cable testing and diagnostics



Application Cable Testing and Diagnostics:

New installations

- Installation test
- Quality and warranty
- Safety

Repairs

- After repairs
- Quality and warranty
- Safety

Periodically review

- Condition based maintenace
- Trend analysis

Standards overview – most important standards for cable testing and diagnostics

<u>Summary:</u>

IEC 60502-2014:

- No DC testing anymore
- Monitored PD and / or tan-delta reccomended

CENELEC HD 620 / HD 621-1996:

- VLF with 3*Uo / 1h

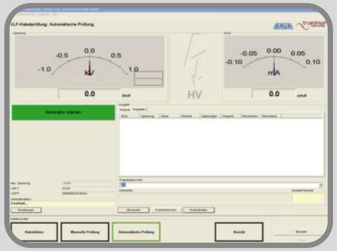
IEEE 400 – 2012

- No DC testing anymore
- Tan-delta and VLF Sinus MWT as „useful“

IEEE 400.2 – 2013

- VLF Sinus MWT – reduction of testing time
- Tan-delta limits for different
  - Types of cables
  - tan-delta parameters
  - Regions
- Reference – book: Lots of application information!

8th step: cable testing and diagnostics
VLF testing and diagnostic

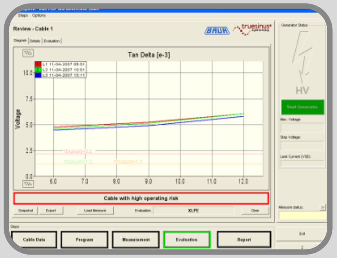


Cable testing (VLF)

cable OK | cable faulty

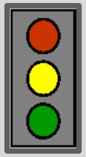
- Isolation Test („classic")
- Up to 3 x U_0 (3 times operating voltage)
- **Pass / fail statement** (yes / no)

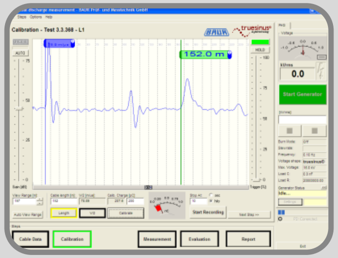
Destructive



Loss factor measurement (tan 6)

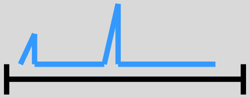
- Global isolation ranking
- Up to max. 2 x U_0 (2 times operating voltage)
- Information about **aging of the isolation**





Partial discharge (PD)

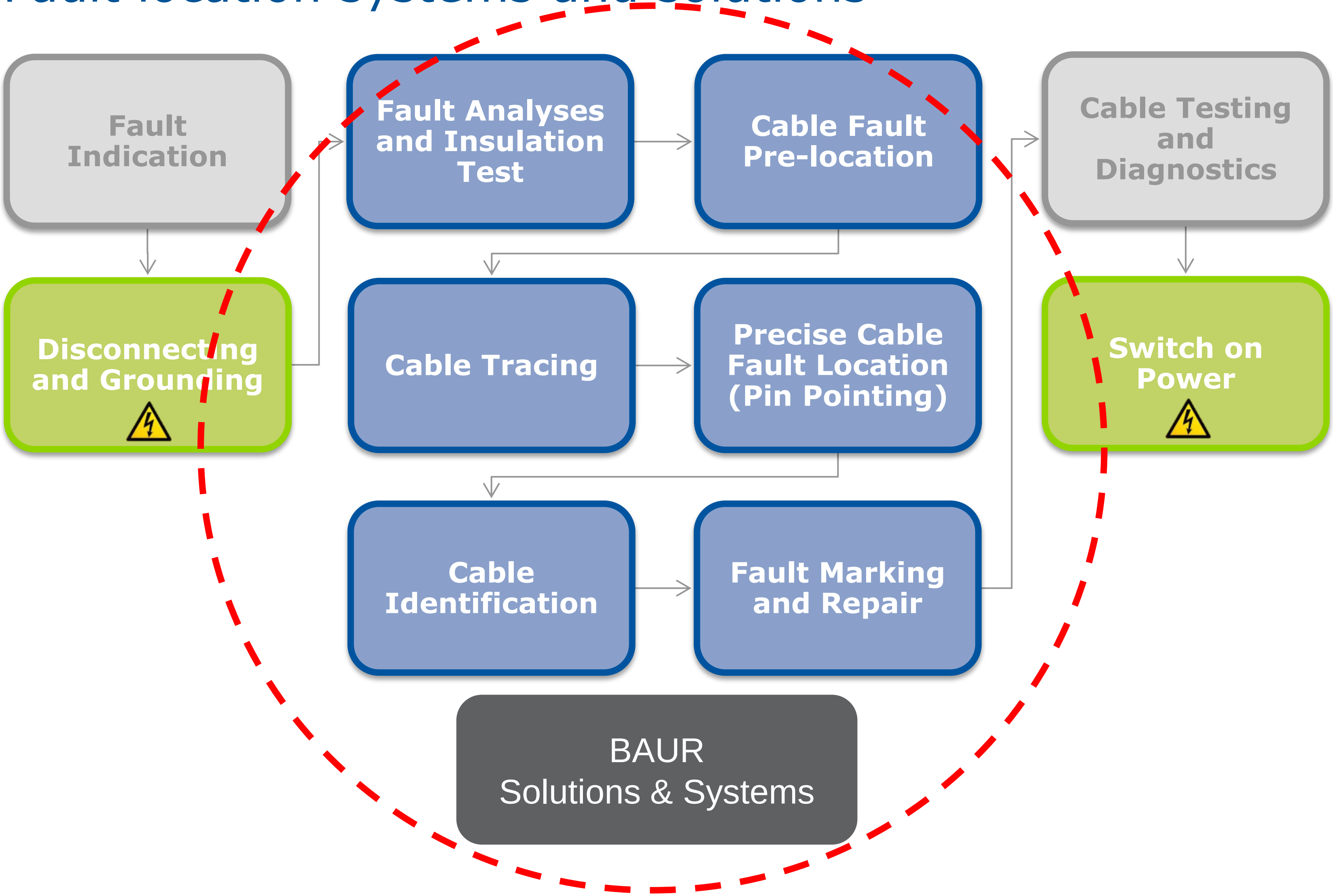
- Measurement of the PD activity
- PD capture and localisation
- Information about **installation failures**

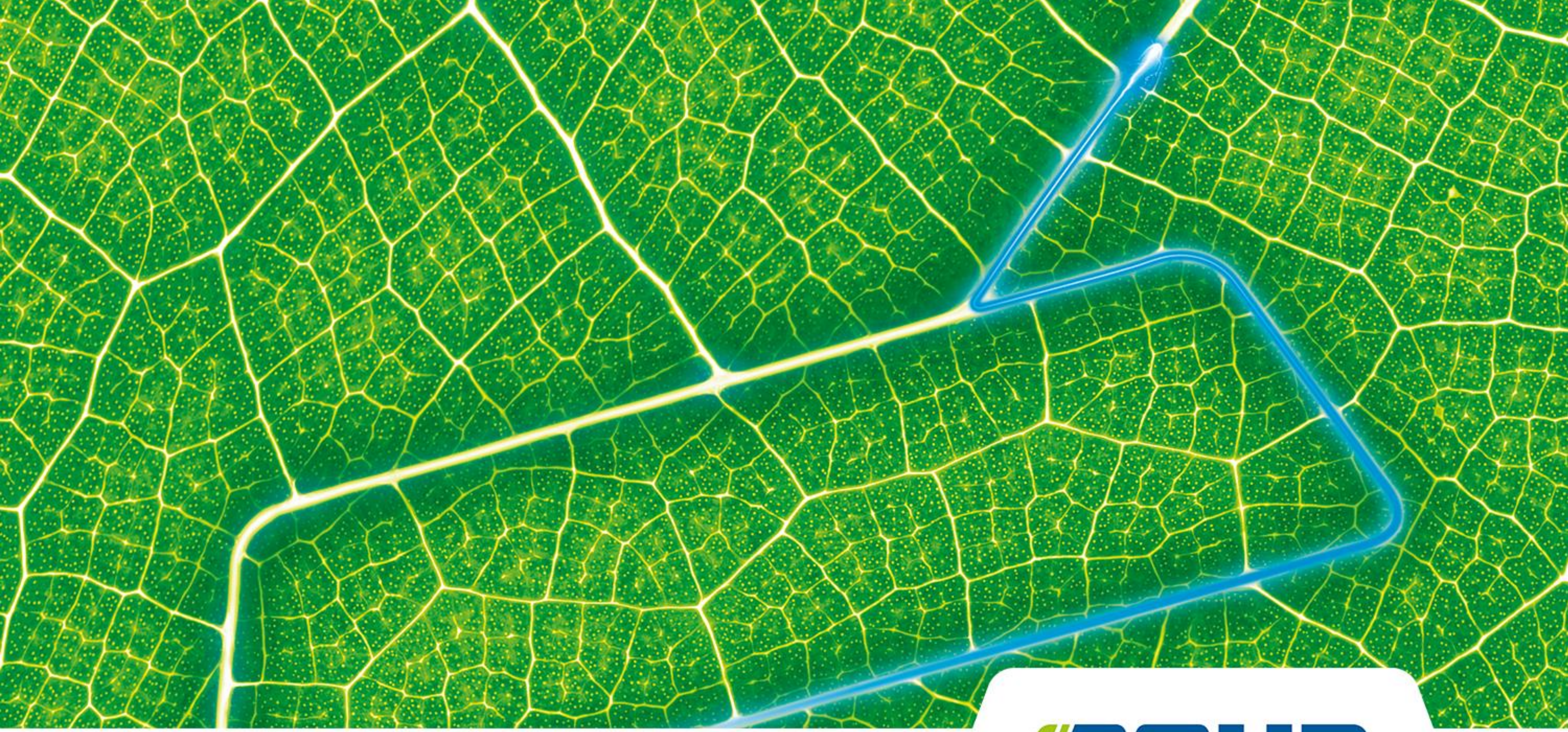


Non-destructive

Cable fault location procedure

Fault location systems and solutions





BAUR
Cable fault location equipment - overview

Fault location systems and solutions

Hand Held Devices – paula, TDR500/510

- Clear phase determination possible in cable lengths up to 40 km
- Highest level of safety when used on earthed and shorted
- cables in compliance with EN 50110-1 (DIN VDE 0105-100)
- Suitable for all switchgear constructions Ready for operation for up to 2 weeks

- Fault location in low voltage, coaxial, control and data cables as well as communication and CCTV cables
- Detection of all faults altering the impedance, such as short-circuits, cable interruptions, wiring faults, etc.
- Joint location
- Location and identification of cable pairs

Fault location systems and solutions

Low voltage networks

STG 600 with locator set
Cable testing, pre-location and pin-pointing
Test voltage up to 5 kV
Pulse voltage up to 4 kV
Energy up to 1000 J

Shirla
Cable sheath testing and fault location system
Cable sheath test up to 10 kV
Fault pre-location up to 10 kV
Sheath fault pin pointing up to 10 kV

Fault location systems and solutions

Medium voltage networks

Low voltage method

- Pulse reflection method (TDR) for:
    - o Low resistive faults
    - o measurement of the cable length

High voltage methods

- Secondary impulse method **SIM** < 32 kV, 80 – 90 %
- Impulse current method **ICM** < 32 kV
- Decay method > 32 kV, up to 150 kV
    - o high resistive faults
    - o breakdown / intermittent faults

Bridge method (Murray, Glaser)

- o low and high resistive cable & sheath faults
- o core to core faults in unshielded cables
- o faults in pilot cables and signal lines

Fault location systems and solutions
Medium voltage networks

Syscompact 2000

Cable testing, pre-location and pin-pointing

Voltage range 8/16/32 kV step less adjustable

Energy up to 3000 J

IRG 2000

Syscompact 4000

Cable testing, pre-location and pin-pointing

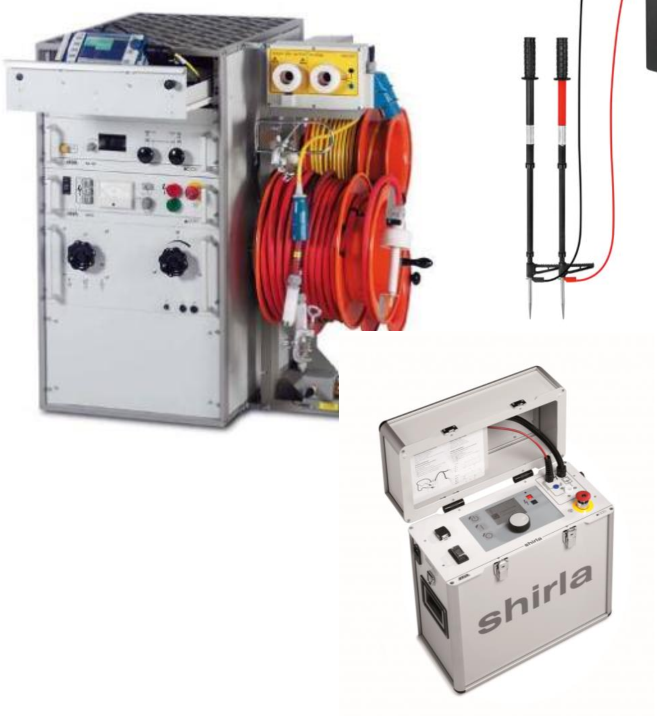
Voltage range 8/16/32 kV step less adjustable

Energy up to 2100 J

IRG 3000

Fault location systems and solutions

Medium voltage networks – combinations



Cable fault location

Cable fault location + VLF testing and TD + PD diagnostics

Fault location systems and solutions
LV, MV, HV Network - combinations

Fault location systems and solutions

LV, MV, HV Network - Test van solutions

Thank you for your kind attention!

If you have any questions, please feel free to ask…