

Practical Training of Fault Exploration for Underground Line

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1. Underground vs. Overhead

There are two methods of installing the power lines that carry electricity to users, overhead and underground. Trainees sometimes ask why they use one versus the other, or more to the point, why all power lines are not installed using the underground construction method. Isn't one method better than the other? These are great questions, and the answer is that each method has its place.

There are some advantages and disadvantages of each construction method.

1.1 Overhead lines

Overhead line construction starts with the setting of utility poles. Poles can be set in nearly any type of terrain, even rocky. In the case of heavy rock, special equipment is used to auger out the hole. If placement occurs in boggy or wet terrain, many techniques are available to set poles securely. Once the poles are in place, wires can be strung, and then the equipment—like transformers, fuses and reclosers—is installed.

Advantages:

- Lower cost. Overhead power lines are a less expensive way to get power to users. They are also less expensive to repair and upgrade.
- Quicker construction. Overhead lines can be installed relatively quickly, since there's no need to trench.
- Easier to spot damage and faults. Disco's linemen can see the entire line when placed overhead, facilitating the spotting of outage causes or other potential problem areas.
- Can be built anywhere.
- Any voltage can be placed overhead.

Disadvantages:

- More susceptible to bad weather, such as high winds.
- More vulnerable to damage from trees and vegetation, requiring right of way trimming.
- Vulnerable to blinks when animals and branches come into contact with the lines.
- Susceptible to damage from vehicle collisions.
- Less attractive, lower visual appeal

1.2 Underground lines

Underground line construction requires digging a trench that is deep enough to keep the lines well away from activities on the surface. Where the terrain is extremely rocky, underground lines may not be an option. Next, wires are laid in the trench directly or placed in conduits for protection. The trench is filled in, and the surface is restored to its original condition.

Padmount transformers and additional equipment are installed as needed.

Advantages:

- Not vulnerable to damage from tree branches; no right of way trimming required.
- Less susceptible to damage from vehicle collisions.
- Not impacted by wind.
- Less vulnerable to blinks when animals and branches come into contact with the lines.
- More attractive. Some people choose to install underground power lines so the infrastructure doesn't obstruct views.

Disadvantages:

- More expensive to build and repair.
- Fed by overhead lines. At some point, all underground power lines are connected to overhead lines, which makes them vulnerable to outages.
- Susceptible to flooding.
- Difficult to locate faults.
- Limitations on voltages that can be buried underground.
- Can be vulnerable to digging. Must ensure Disco always gets approval from the road authority and locate underground utilities before digging.

1.3 Underground vs. Overhead

Determining if power lines should be overhead or underground boils down to what is best for the situation on site. Underground lines might be ideal in cases where there is a desire to keep poles and wires out of sight, such as in residential neighborhoods, parks or historical areas. There are many cities and towns that construct only underground lines for a variety of reasons.

Overhead systems work well when appearance is not a major concern. Examples include extremely long transmission line distances across country, and where voltages are higher than the limitations set for underground lines.

The ultimate mix of underground and overhead construction used by Disco provides users with the highest possible quality of service at the lowest possible price. Cost, appearance, reliability, maintenance and future upgrades will indicate the better approach (overhead or underground).

2. Brief history of power cables

The earliest use of recognizable electrical cable was probably the early commercialized Telegraph lines such as that strung between Washington, D.C, to Baltimore, Maryland in the USA in 1844. These early cables were made of iron and were difficult to produce. In order to improve production by lubricating the iron surface of the wires, copper sulphate was used to apply a thin copper coating. The superior conductive property of the copper was soon realized and copper eventually replaced these early iron conductors. By 1913 the IEC (International Electrotechnical Commission) established IACS (International Copper Standard) as a benchmark for the resistivity of copper as being equal to 100 percent conductivity.

- In the 1880's the first insulated cables were insulated with gutta percha, a natural latex material produced from the sap of gutta percha trees. This insulation needed to be kept constantly wet, otherwise it would dry out and fail to insulate the conductors. This material was largely replaced by rubber and vulcanized bitumen.
- By the 1890's, mass impregnated paper insulation was being used on cables and voltages as high as 10kV.
- In 1906, armoured cables were introduced, which had flexible sheathing and two cloth covered, rubber insulated conductors.
- In the 1930's, the first trials with PVC insulations were being made in Germany, and by the end of the second world war, there were significant varieties of synthetic rubbers and polyethylene.
- By the 1950's, PVC was commercially viable and replaced rubber cables in many areas particularly in domestic wiring. Aluminum was also starting to be used widely as an alternative conductor.
- The 1970's heralded XLPE insulations replacing paper insulated cables in medium voltage applications.
- In the 1980's, optical fibers were being introduced in overhead lines for data transmission and condition monitoring, and further use of XLPE in high voltage transmission lines between 66 and 240kV. Also high temperature super conductivity materials were discovered. PVC alternatives (LSZH cables) which were safer in fires were being developed in response to a number of tragic public fires which demonstrated the dangers of smoke and toxic gases from various materials including PVC's.
- By the 1990's polymers were being extended to use in EHV, extra high voltage, applications and the use of optical fibers in overhead lines was becoming widespread.

3. Power lines in cables

The use of underground cables is the best solution from the perspective of visuals, even if it has negative impacts in laying and maintenance processes because trenches have to be opened, with consequential disturbances to the surrounding environment. The underground cable issued in urban areas for low-voltage lines, and has also been adopted outside urban centers. There are particular reasons or constraints that necessitate the burying of the line. In the case of high voltage lines the technical, economic and environmental difficulties increase enormously; for these reasons, the lines at 132-150 kV are carried in cables only in urban crossings to reach the primary substation. For higher voltage lines (380 kV) the technical problems, the environmental impact and costs are such that the buried cable cannot be a solution. No country in the world in fact is using underground cables for transmission at 380 kV, unless for very short connections and in particular circumstances. Underground utility lines are made up of three phase triplets with various geometries placed in a special underground trench.

3.1 Functional characteristics of the cables

A distinction can be made based on the number of cores: single-core cables, three-pole cables and multipole cables. This classification depends on the presence or absence of the protective conductor. Moreover, depending on the type of insulation, the cables are distinguished as follows:

(1) Insulated cables with impregnated paper: insulation made from thin layers of pure cellulose paper, impregnated with thick oil or appropriate mixture of oil-resin, wrapped around the conductor. They can be used for low voltages up to 60 kV.

(2) Cables with solid insulator: consisting of thermoplastic resins or elastomeric material, mixtures based on natural or synthetic rubber and silicone rubber such as ethylene propylene resin (EPR). Insulation is arranged in uniform and compact around the conductor, by means of the extrusion process. There are butyl rubber cables for voltages up to 20 kV, cross-linked polyethylene and EPR cables for voltages up to 132 kV.

(3) Oil fluid cables: cables are of a mixture type that replace the dense oil of cables with impregnated paper and oil fluid at low or high pressure, while the insulator is still consisting of layers of paper; cables are used for high voltages up to 380 kV.

This technology has been gradually abandoned due to the complexity, laying cost and operation conditions.

The insulation is a key part of the cable; from its characteristics depending largely on the

performance of the cable in terms of isolation voltages, current transmitted, and thermal behavior. In multi core cables of high section, a filling material is present, generally consisting of textile fibers which serve to fill the interstices between the cores, giving the cable its round shape.

For cables with a rated voltage of ground insulation greater than 3.6 kV, a screen is required. This screen consists of a thin copper strip that is coiled and applied either around each core individually or around the insulation of core. The shield serves to modify the lines of force of the electric field that are formed within the cable, in order to decrease the stresses on the insulation dielectric and confine the field itself between conductor and screen.

As a matter of fact, the conductor and the screen can be seen as the two plates of a cylindrical capacitor:

- The lines of force of the electric field will develop in the radial direction. The presence of unwelcome tangential components for the insulator is thereby avoided; a cable of this type is called a radial field.
- The outer insulation (belt), the metal armor and the outer jacket have the task of protecting the cable from environmental agents, mechanical influences and interference. The wires are generally copper or aluminum, with a prevalence of the first; may be either single wire or string. The copper conductors may be bare or coated: the coating consists of a thin layer of suitable metal, such as tin, tin alloy or lead alloy.

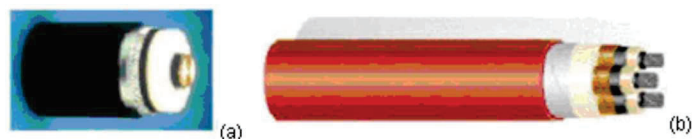


Fig. 1 a) Single core cable - b) Three-core cable for underground MV lines

Rated voltages: when a cable is used it is necessary to choose a level of insulation suitable for the voltage of the electrical system in which it is to be used.

The reference voltages for which the insulation is provided are:

- rated insulation voltage to ground, i.e. between conductor and ground;
- rated insulation voltage between phases cannot be assessed in the case of single core cables.

As the value of the nominal operating voltage increases, it is necessary to choose cables with higher isolation voltages. Another key feature for the choice of cables is the flow: the

flow rate is the maximum intensity of current that can flow in each conductor, under certain conditions of installation and service life, without the temperature exceeding insulation limits. The permissible temperature is also a characteristic of the cable, established by the regulation based on the type of insulation.

3.2 Type of laying

The laying conditions are of crucial importance in the design of a cable, especially with regards to both the determination of the scope of the cable itself, and the protection from external stresses. It is possible to perform the following types of installation:

- Direct laying
- Draw-in system
- Solid system

(1) Direct laying

This method of laying underground cables is simple and cheap and is much favored in modern practice. In this method, a trench of about 1.5 meters deep and 45 cm wide is dug. The trench is covered with a layer of fine sand (of about 10 cm thickness) and the cable is laid over this sand bed. The sand prevents entry of moisture from the ground and thus protects the cable from decay. After the cable has been laid in the trench, it is covered with another layer of sand of about 10 cm in thickness. The trench is then covered with bricks and other materials in order to protect the cable from mechanical injury. When more than one cable is to be laid in the same trench, a horizontal or vertical inter-axial spacing of at least 30 cm is provided in order to reduce the effect of mutual heating, and also to ensure that a fault occurring on one cable does not damage the adjacent cable. Cables to be laid in this manner must have a serving of bituminized paper and hessian tape to provide protection against corrosion and electrolysis.

The cables can be laid directly in the ground in the trenches, linearly arranged on the same plane (flat triad available) or in other configurations of installation, such as the triangle arrangement (available in clover).

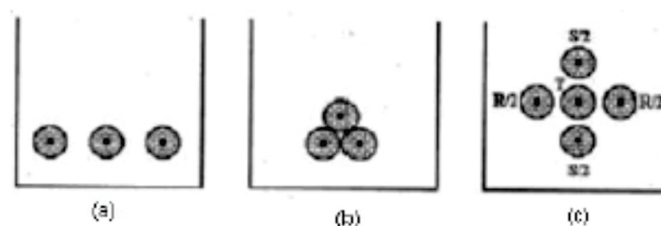


Fig. 2 Laying cables: a) flat triad b) clover c) with phase separation

Advantages:

- Simple and less costly.
- Creates ideal conditions for dissipating heat generated in the cables.
- It is a clean and safe method as the cable is invisible and free from external disturbances.

Disadvantages:

- Load extension is possible only by completing new excavation work which may cost as much as the original work.
- The alterations in the cable network cannot be made easily.
- Very high maintenance costs.
- Localization of fault is difficult.
- Cannot be used in congested areas where excavation is expensive and inconvenient.

(2) Draw-in system

In this system, conduit or duct of glazed stone, cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route. The cables are then pulled into position from manholes. Fig. 3 shows the four-way underground duct line.

Three of the ducts carry transmission cables and the fourth duct carries a relay protection connection, pilot wires. Care must be taken where the duct line changes direction; depths, dips and offsets should be made with a very long radius, otherwise it will be difficult to pull a large cable between the manholes. The distance between the manholes should not be too long, to facilitate the pull-in of the cables. The cables to be laid in this manner need not be armored but must be provided with a serving of hessian and jute in order to protect them when being pulled into the ducts.

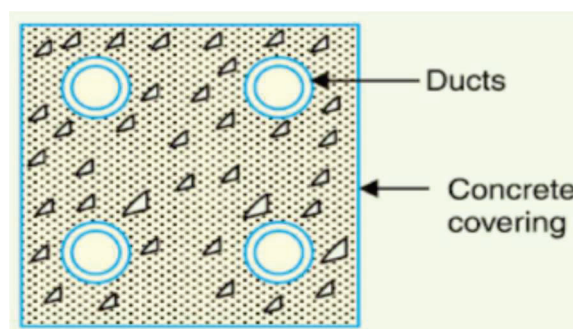


Fig. 3 Four-way underground duct line

Advantages:

- Repairs, alteration or additions to the cable network can be made without opening the ground.
- Since the cables are not armored, joints become simpler and maintenance cost is

significantly reduced.

- There are fewer fault occurrences due to stronger mechanical protection provided by the system.

Disadvantages:

- The initial cost is very high.
- The current carrying capacity of the cables is reduced due to the close grouping of cables and favorable conditions for dissipation of heat.

This method of cable laying is suitable for congested areas where excavation is expensive and inconvenient, for once the conduits have been laid, repairs or alterations can be made without opening the ground.

Moreover, the method is generally used for short length cable routes such as in workshops and road crossings where frequent digging is costlier or impossible.

(3) Solid system

In this method of laying cables, open pipes or troughs are dug out in the ground along the cable route. The troughing is of cast iron, stoneware, asphalt or treated wood. After the cable is laid in position, the troughing is filled with a bituminous or asphaltic compound and then covered. Cables laid in this manner are usually plain lead covered because troughing affords good mechanical protection.

Disadvantages:

- More expensive than direct laid system.
- Requires skilled labor and favorable weather conditions.
- Due to poor heat dissipation facilities, the current carrying capacity of the cable is reduced.

Nowadays, given these disadvantages, this method of laying underground cables is rarely used.

4. Common underground infrastructure

Underground cable can serve as a distribution main feeder. A main feeder is that portion of a distribution circuit between the substation and the first in-line overcurrent protective device. The protective device in the substation clears a fault on a main feeder. Therefore, a main feeder fault causes an outage to the entire circuit. Because most faults on an underground main feeder are cable failures and are permanent, power to the circuit may remain off until the cable is repaired. Disco engineer must consider this characteristic when designing a main feeder, particularly when deciding between a radial or open-loop feeder.

4.1 Radial main feeder

The radial main feeder has one source and delivers power to a load area along a single path. This feeder can also serve several load areas by using a junction box or sectionalizing switch with fused taps. This type of arrangement is shown in Fig. 4 and may have the following components:

- Underground primary-voltage cable,
- Cable terminations,
- Pad-mounted junction box or sectionalizing switch,
- Surge arresters, and
- Grounding electrodes.

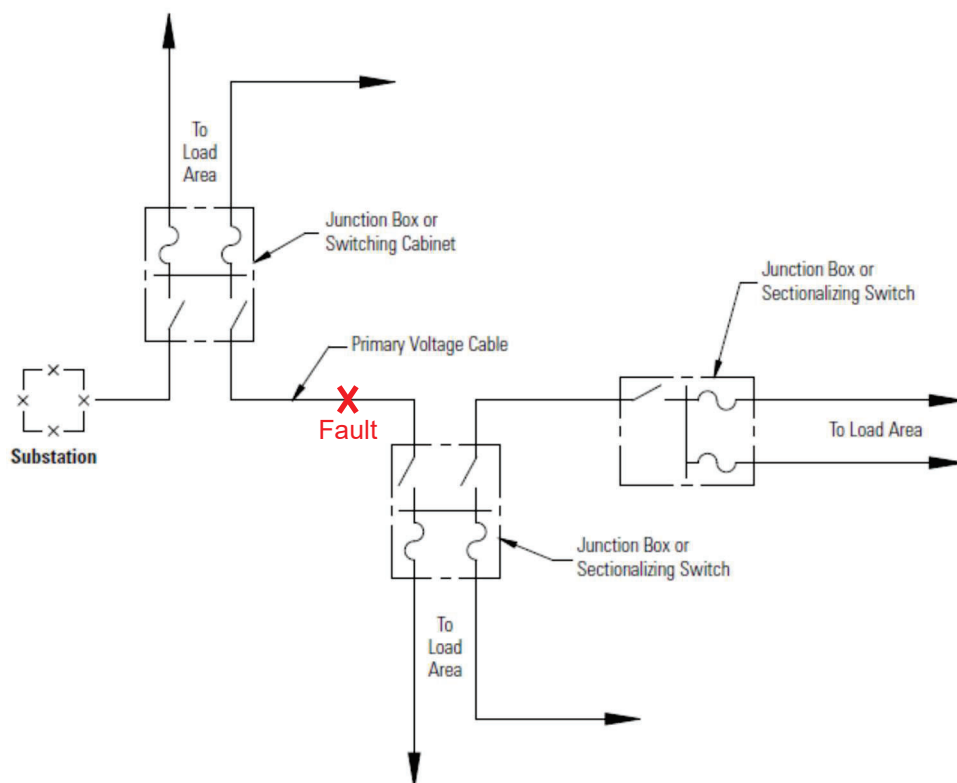


Fig. 4 Radial main feeder

The junction box or sectionalizing switch sectionalize the main feeder. For instance, consider a fault in the second line section as shown in Fig. 4 (in red). This fault trips the protective device at the substation and interrupts power to all consumers on the faulted circuit. Disco can restore power to the first load area by placing the faulted cable(s) in a parking stand, or by opening the load-side switch on the first sectionalizing switch to isolate the faulted cable. Fig. 4 shows this option. Because the radial feeder has no alternative source or path, Disco

cannot restore power to the other consumers until crews repair the cable fault.

It is possible to improve the reliability of a radial system by installing the cable in a concrete-encased duct bank or in a conduit system, or by installing a spare cable or conduit in the trench. A concrete-encased duct bank provides substantial mechanical protection from digging and should be considered in areas congested with other underground utilities. A conduit system provides limited mechanical protection. However, it does decrease outage time by allowing Disco to replace a section of faulted cable without disturbing the earth surface. This saves substantial time, particularly when the main feeder is located beneath a roadway. The spare cable or conduit provides no mechanical protection but does decrease restoration time if only one cable is faulted. Because the costs of these installation methods vary significantly, each Disco must weigh the advantages of these more expensive installations against their costs.

Under any circumstance, the simple radial does have limited operational flexibility and should not be used to serve a large number of consumers.

4.2 Open-loop feeder

In dense load areas, an underground main feeder may tie together two substations. A main feeder may also tie two circuits from the same substation. This type of arrangement would operate as an open-loop system. The components of this system are the same as those of a radial system. However, the open-loop feeder has two sources, unlike the radial feeder that has only one source. Each source provides power along a single path to the designated open point in a junction box or a sectionalizing switch. In a junction box, the open point results from placing one set of cables in a parking stand. In a sectionalizing switch, leaving one of the switches open creates an open point.

The open-loop feeder (Fig. 5) provides much higher system availability than the radial system. With an open-loop system, utility crews can isolate a faulted cable section and restore power to all consumers. A cable fault in the second line section interrupts power to all consumers on that circuit. After isolating the faulted cable section, as shown in Fig. 5 (in red), crews can feed the first section from Substation No. 1 and remaining line sections from Substation No.2. Since crews can restore power to all load areas before repairing the cable fault, the outage time is much shorter than with a radial feeder. As a result, it is not critical to install the cable in a concrete-encased duct bank or conduit. However, as already noted, in areas congested with underground utilities, the concrete-encased duct bank will help protect cables from diggings. Again, it is important to judge the benefits of installing duct bank or conduit against the additional cost. An open-loop feeder also requires that the designer consider the ampacity of the feeder cables while serving all possible loop segments, which may dictate the use of

a larger cable size than otherwise needed.

Open-loop feeders provide much more operating flexibility than the simple radial feeders.

System reliability considerations make them the preferred design.

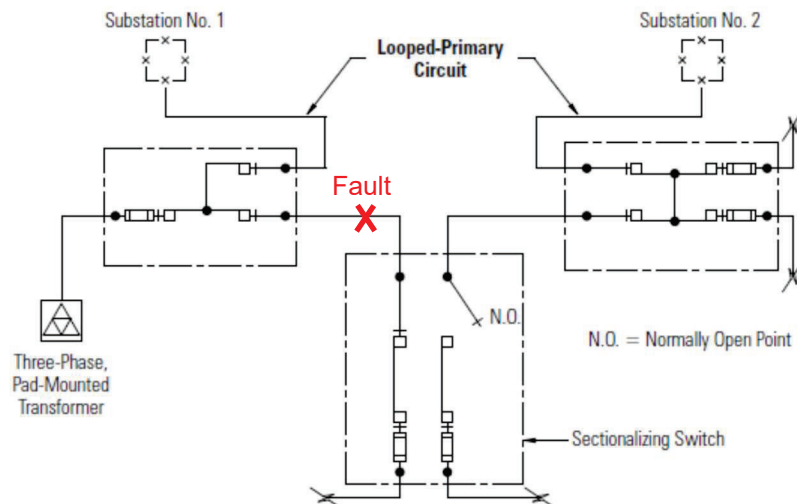


Fig. 5 Open-loop feeder

5. Cable fault/failure mechanisms

5.1 Overview of faults

The *IEEE Standard Dictionary of Electrical and Electronics Terms* (2000) lists several different definitions of the word *fault*. The first two definitions listed are relevant here:

- A wire or cable fault is a partial or total local failure in the insulation or continuity of a conductor.
- A component fault is the physical condition that causes a device, a component, or an element to fail to perform in a required manner; for example, a short circuit, a broken wire, or an intermittent connection.

All faults within these two definitions fall within one of two major categories: an open circuit or a short circuit. An open circuit is any circuit in which the normal continuity of the circuit is interrupted. The IEEE dictionary defines a short circuit as “an abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of a different potential.” Within the same definition, there is a note that the term *fault* or *short-circuit fault* is used to describe a short circuit.

Open circuit typically do not lead to damage to the electrical system. In addition, normally available protective sectionalizing devices used on electrical distribution systems do not

typically detect open circuits.

Some of the phenomena associated with a fault are listed below.

- Very little current flows past a fault point, leading to loss of service to loads beyond the fault.
- Voltage at the fault and beyond decreases significantly. The voltage between the generation source and the fault decreases proportionally to the inverse of the line impedance.
- Faults typically lead to current levels that exceed the thermal rating of the conductor and other system components, causing damage within a fraction of a second.
- The abnormally low-impedance path can include nonutility property or human beings, causing damage, injury, and even fatalities.

5.2 Description of cable faults

Cables are generally laid directly in the ground or in ducts in the underground distribution system. For this reason, chances of faults in underground cables are low. However, if a fault does occur, it is difficult to locate and repair because conductors are not visible. Nevertheless, the following are the faults most likely to occur in underground cables:

- Open-circuit fault
- Short-circuit fault
- Earth fault

(1) Open-circuit fault

- When there is a break in the conductor of a cable, it is called open circuit fault.
- The open-circuit fault can be checked with a megger.
- For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed.
- Resistance between each conductor and earth is measured by a megger.
- The megger will indicate zero resistance in the circuit of the conductor that is not broken.
- However, if the conductor is broken, the megger will indicate infinite resistance in its circuit.

(2) Short-circuit fault

- When two conductors of a multi-core cable come in electrical contact with each other due to insulation failure, it is called a short-circuit fault.
- Again, we can seek the help of a megger to check this fault.
- For this purpose, the two terminals of the megger are connected to any two conductors.

- If the megger gives a zero reading, it indicates a short circuit fault between these conductors.
- The same step is repeated for other conductors connecting two at a time.

(3) Earth fault

- When the conductor of a cable comes in contact with earth, it is called earth fault or ground fault.
- To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth.
- If the megger indicates a zero reading, it means the conductor is earthed.
- The same procedure is repeated with other conductors of the cable.

5.3 Cause of faults

Causes of common mechanical failures of underground cables are digging, rodent damage, and improper handling and installation. This last cause includes sharp bending of cable, excessive pulling force during installation, driving vehicles over laid cable, walking on the cable in a trench, placing or leaving rocks in a position to cause future cable damage, and allowing nails in reels to damage the cable. Principal causes of electrical faults to underground systems include lightning, insulation treeing, and thermal insulation failure caused by overloading.

In addition, during single-phase faults on three-phase circuits, the phase-to-neutral voltage on the two unfaulted phases can sometimes increase to a level that can approach the normal phase-to-phase voltage. This increased voltage on the unfaulted phases stresses the insulation and can lead to failure. Failure of splices and elbows is also either an electrical or mechanical failure, depending on the cause.

For a comparison of the sectionalizing of overhead and underground systems, it is useful to examine the many causes of faults on overhead distribution lines. Some of the more common causes are:

- Lightning,
- Squirrels or large birds,
- Extreme weather conditions,
- Tree limbs or trees falling on the lines, and
- Vehicular damage

Although the intent of this section is to focus on the protection of underground systems, overhead lines in many instances are connected either on the source side or, less frequently, on the load side of underground lines. In these cases, the protective devices often protect

mixed line sections. Also, underground devices on systems served by overhead feeders must coordinate with those devices protecting the overhead portions of the system.

(Refer to Attachment-1: The causes of cable failure)

5.4 Protection methods on underground lines

It is normally desirable to place sectionalizing devices at the beginning of underground cables, that is, any location where a transition from overhead to underground cable takes place or in a substation or step-down transformer where the underground circuit originates. Doing so will minimize restoration time and help distinguish between overhead and underground faults. Faults on overhead lines are usually temporary and are best protected by reclosing devices such as breakers or reclosers. Since faults on underground lines are usually permanent; they are best protected by nonreclosing devices such as fuses.

(1) Fuses

The main advantages of fuses are that they are:

- Inexpensive,
- Compact,
- Require little maintenance, and
- Are easy to replace.

Moreover, a current-limiting fuse is the only readily available device that effectively limits fault current and, thus, reduces the destructive failure of transformers and capacitors.

Disadvantages:

- The number of sizes and types is limited.
- The total clear curves and minimum melt curves overlap at high fault current levels for fuses with current ratings that are close to each other.
- The maximum current-interrupting rating is limited, especially with expulsion fuses.
- Expulsion fuses produce hot gases and by-products.
- Fuses do not have any reclosing capability.
- Fuses have no ability to sense low-level ground faults.
- Fuses cause "single-phasing" on three-phase circuits.
- Fuses cannot be controlled or monitored by Supervisory Control and Data Acquisition (SCADA) systems.

In general, the main application for fuses is on radial taps that do not require simultaneous three-phase protection and that are not subject to frequent temporary faults. Fuses particularly lend themselves to protecting underground circuits. The inability of fuses to reclose is not a limitation on underground circuits and transformers, because faults on this

type of system simply increases the amount of fault damage. Using current-limiting fuses on pad-mounted transformers is very beneficial when the maximum fault level is enough to cause destructive failure of the transformer for internal faults. The primary conditions that limit the use of expulsion fuses at certain locations are following:

- Where the maximum fault current exceeds the fault-interrupting capability of commonly available expulsion fuses, and
- Where the maximum load current exceeds current ratings of expulsion fuses (typically 200 amperes).

Another shortcoming of fuses is that their curves do not always coordinate well with upstream breakers or reclosers. For this reason, at certain locations, particularly on heavily loaded feeders, a breaker or recloser rather than fuses may be needed to coordinate with substation breakers or reclosers.

(2) Circuit Breakers

Most circuit breakers on underground distribution systems are found in substations, although it is possible to install breakers on platforms on overhead portions of the system or in metal or fiberglass enclosures.

Advantages:

- The types of relays that may be used to control the breakers are available in a wide variety of characteristics.
- The relays (typically inverse overcurrents on a distribution circuit) may be varied over a wide range of time dial settings and pickup levels to accommodate most system conditions and to allow changes as the load increases over time. In addition to overcurrent functions, many of the electronic relays provide almost any known relay function within one relay. Some of these functions include over/under voltage, over/under frequency, sensitive earth, directional power and/or current, impedance, negative sequence, reclosing, and sync check. Other features may include fault location, a wide variety of metering functions, event recording, and communications. Programmable logic functions can be used to define the sequence of responses to almost any type of event.
- Reclosing relays are available where breakers protect portions of overhead line; instantaneous relays are available to provide high-speed operation during high fault levels.
- Breakers can be purchased with maximum interrupting capability exceeding the capacity in most reclosers.
- Breakers are rated for more operations between maintenance works than are reclosers.
- Breakers interrupt all three phases simultaneously.

- Breakers are available with ground trip protection.

Disadvantages:

- They require separate relays that add to total expenses.
- They require much more space than fuses.
- They require an outside power source (typically a battery).
- Their relays must be calibrated initially and periodically.
- They are harder to operate and maintain than reclosers and, particularly, fuses.
- They are significantly more expensive than other available devices.

(3) Reclosers

Reclosers are available in both single-phase and three-phase versions. The single-phase series-trip versions do not require an outside power source and are frequently used on distribution lines, although they are seen more frequently on overhead systems than on underground systems. The interrupting rating of most single-phase reclosers is typically less than or equal to that of most distribution fuses. The main advantage of a recloser is that it does reclose; however, as indicated earlier, this is not considered an advantage on an underground system.

Three-phase reclosers can be supplied with a ground-fault-sensing unit, which is an advantage. This is a particular advantage on circuits with a large load where the minimum phase-to-ground fault may be on the same order of magnitude as the maximum load current. Three-phase electronically controlled reclosers are also easily changeable in pickup level and operating curves.

Three-phase reclosers with electronic control are available with a wide range of SCADA accessories. Reclosers are usually less expensive than breakers and come with all controls included. The electronic reclosers do require an outside power source. Reclosers are typically used as a circuit protective device inside a substation and on main three-phase lines where the following apply:

- The load current exceeds the rating of typical fuses.
- Three-phase protection is desired.
- Ground fault protection is desired.
- It is advantageous to use SCADA for both control and status reporting of reclosers.

Where three-phase or single-phase reclosers are used on underground circuits, it is simple to disable the reclosing feature and have one-shot operation of the recloser.

6. Cable testing and diagnostics of MV cables

MV cables have three distinct phases to their lifecycle: (1) new—just manufactured, still in the factory; (2) installed—ready for commissioning but not yet energized; and (3) aged—in-service for some period of time. These different periods of their life provide opportunities for condition assessment.

Very low frequency AC high voltage testing can meet the needs of laminated paper cables such as PILC and newly installed solid dielectric cables such as XLPE. Tan delta and partial discharge testing are excellent indicators of insulation health and can be applied in all phases of a cable's life. Tan delta provides an overall average condition assessment, whereas partial discharge testing can indicate weak spots that might not appear in tan delta results.

6.1 Very low frequency AC high voltage testing

VLF operation reduces the power required to load cables which present a capacitive load. Test sets typically operate at 0.1Hz. The length of cable that can be tested at given power increases by a factor of 5,000 compared to 50Hz with consequent weight and cost savings. There are several VLF waveforms available and included within the IEEE 400 guidelines. Sinewave testing has some advantages. Research shows that the faster growth rate of any existing electrical tree with a sinewave waveform gives a higher probability of finding the defect.

Three types of tests are listed in the IEEE 400.2 Guide for Field Testing Cables using VLF.

- Installation test: conducted before the installation of accessories such as splices and terminations.
- Acceptance test: performed after the installation of the accessories before service energization.
- Subsequent maintenance tests: to assess aging and/or serviceability of the cable system.

The IEEE 400.2 cable testing guide in table 1 below shows the recommended VLF voltage testing levels for various cable ratings.

Table 1 IEEE 400.2 VLF Test Voltage Levels

Cable Rating phase to phase (RMS)	Installation Test phase to ground	Acceptance Test phase to ground	Maintenance Test phase to ground
kV RMS	kV RMS (or peak)	kV RMS (or peak)	kV RMS (or peak)
5	9 (13)	10 (14)	7 (10)
8	11 (16)	13 (18)	10 (14)
15	18 (25)	20 (28)	16 (22)
25	27 (38)	31 (44)	23 (33)
35	39 (55)	44 (62)	33 (47)

The current IEEE recommendation for the duration of a VLF test is from 15 to 60 minutes. Industry experience justifies a minimum time of 30 minutes. The most common European recommendation is one hour.

The industry default standard VLF test frequency is 0.1Hz. However high capacitive loads as encountered with very long cable runs may require a lower frequency for the correct operation of test sets. Lowering the VLF frequency needlessly is to be avoided given that it reduces the effectiveness of the test and can introduce some space charge effects.

The VLF test instrument should be solidly grounded before connecting any cables. The HV test lead outside shield conductor is connected to the concentric neutral ground point of the cable under test. The main conductor of the HV test lead is then connected to the conductor of the cable under test. The other phases are grounded. It is possible to reduce the testing time by connecting all three phases together, except for a belted cable, or if the individual phases are unshielded. In such cases, each phase should be tested independently, grounding the other two phases in order to detect phase to phase faults. (Fig. 6)

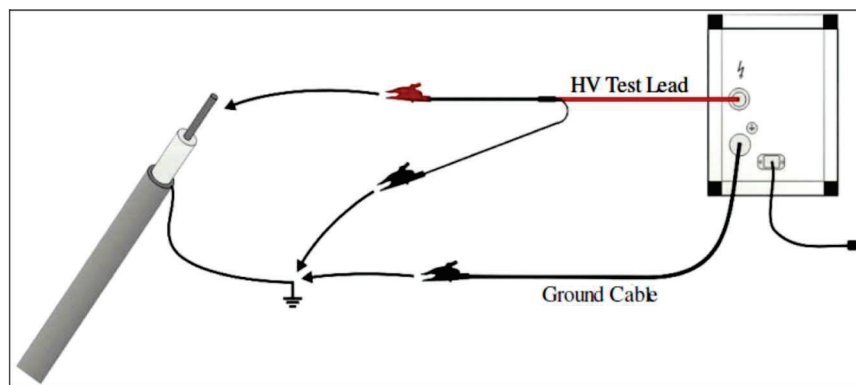


Fig. 6 VLF test connections

Regular routine maintenance testing of aged cables has been demonstrated to reduce the chance of unscheduled failure to approximately 10% of the failure rate that might be encountered without such testing. Approximately 12% of cables fail during the test and cable repair can then be done in a planned manner. Alternative cable diagnostic techniques may be preferred, however this may not be viable on circuits with combinations of different types of cables, very long cable runs, and network cables with multiple taps.

Fault location usually involves the use of a DC thumper with consideration stress on what may be an aged cable. Preconditioning using VLF tester can reduce the thumper voltage required by ionizing carbonizing the insulation at the fault location. It may also enable fault location with a low voltage TDR.

6.2 Tan delta diagnostics

An ideal cable insulation system will be entirely capacitive in nature. The only current flowing through the insulation is a result of the reactive impedance at the power line frequency. This current will be 90 degrees out of phase with the voltage and is given by the following formula:

$$I_C = V / (2 * \pi * f * C)$$

In the real world, a resistive current results from impurities in the insulation and is increased by aging effects such as water trees. This current is in phase with the voltage and is given by the following formula:

$$I_R = V / R$$

Combining these two phasor currents, you can see the relationship and resultant leakage current (Fig. 7).

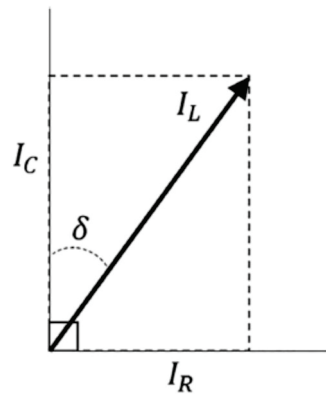


Fig. 7 Relationship between Capacitive and Resistive Currents

The ratio of the two currents (I_R/I_C) is the tangent of the angle δ (delta) or tan delta, for short. It is also known as dissipation factor or loss angle. As can be seen from the previous formulas, the capacitive current is a function of frequency, so the result is also a function of frequency. Therefore, not only do you need to know tan delta, you also need to know the frequency used for testing. Very low frequencies are typically used to limit the amount of power required to run the test.

For a given frequency and voltage, tan delta increases as the resistive current increases (while the resistance in the insulation decreases). This provides a measurable way to see how aging and impurities have affected a given cable. As this measure applies to the entire cable, a measure of the average condition over the length of the cable can be determined. As a cable ages, its tan delta figure becomes more voltage dependent. Water trees exhibit a capacitance that increases with voltage, so the tan delta measurements taken at higher

voltage increase. This plays an important part in analyzing cable condition.

Tan delta testing requires isolation from equipment not under test, and therefore, must be done off-line. A high-quality, low-frequency voltage supply is typically used. The supply is attached to the cable under test and a tan delta analyzer is connected to measure the current and its phase angle relative to the voltage (Fig. 8).

The measurement is relatively quick and is taken at several voltages. Getting the outage, switching the load, disconnecting attached equipment, setting up the test equipment, and taking high-voltage safety precautions take much longer than actually running the test.

When looking at the results of a tan delta test, two characteristics are significant. Whenever possible, comparing to a baseline measurement done at commissioning can show deterioration by a shift in the leakage current amplitude. If a baseline measurement is not available, the value versus voltage is an excellent indicator of water intrusion. The more water tree damage is present, the greater the influence of voltage on tan delta amplitude. A rising trend in tan delta amplitude indicates damage or aging.

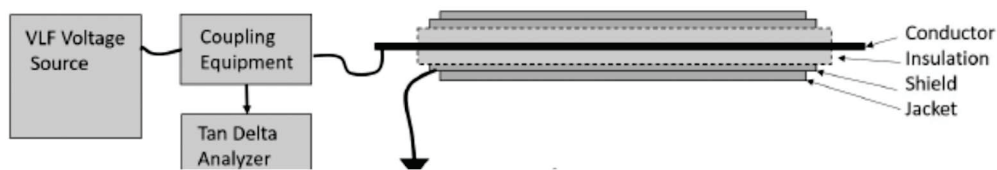


Fig. 8 Typical Tan Delta Test Connections

6.3 Partial discharge diagnostics

Partial discharge is best described as a failure of part of an insulation system to withstand the electrical field applied to it. This can be a result of poor design, poor workmanship, defective materials, contamination, or aging. The result of this failure is a high-frequency, unipolar discharge and accompanying current that flows through and on the insulation from the conductor to ground. This current pulse is low energy due to its short (microsecond) duration, but it can negatively affect the insulation and eventually cause catastrophic failure. The discharge spark erodes the insulation from within through its heat and ionization. If occurring on the surface, the discharge also causes the breakdown of air molecules into oxygen (ozone) and nitrogen (nitric oxide). The nitric oxide forms nitric acid, which erodes the insulation from the outside.

As any erosion of the insulation causes an increase in discharge — and therefore more erosion — the effects are exponential until catastrophic failure occurs.

Partial discharge cable testing involves applying a voltage conducive to partial discharge

and then directly or indirectly measuring the discharge current pulses.

(1) Offline partial discharge testing

Offline partial discharge testing uses a similar setup to tan delta testing in that the cable should be disconnected from external equipment and connected to a high-quality, low-discharge voltage source. Additional precautions must be made because any discharge in the test equipment or setup will render the results meaningless.

Below is a typical offline PD test setup (Fig. 9). While the goal is to measure the PD current pulse, it is not measured directly. Instead, it is inferred from the voltage drop when the discharge occurs. For this reason, a known pulse generator is typically required to calibrate the system by relating a measured voltage drop to a Pico-Coulomb amount. Test procedures and general evaluation guidelines are given in the relevant IEEE 400 series standards.

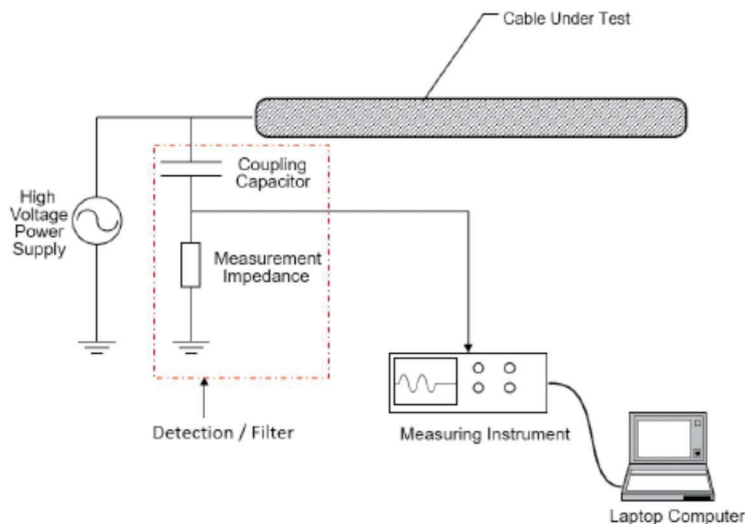


Fig. 9 Typical Offline PD Test Connections

(2) Online partial discharge testing

Online partial discharge testing makes use of the power system voltage and only requires a monitoring circuit. While it is possible to attach a monitoring circuit to the conductor, it is also possible to connect to the ground strap of the conductor since the discharge must travel down the circuit to ground. This ground connection is preferable due to its increased safety and the fact that the connection will not adversely affect the electric field at the conductor. By connecting via a high-frequency current transformer (HFCT), a direct measurement can be made, eliminating the need for a calibrator (Fig. 10). Tests can be done in a few minutes, as a periodic survey or as continuous monitoring.

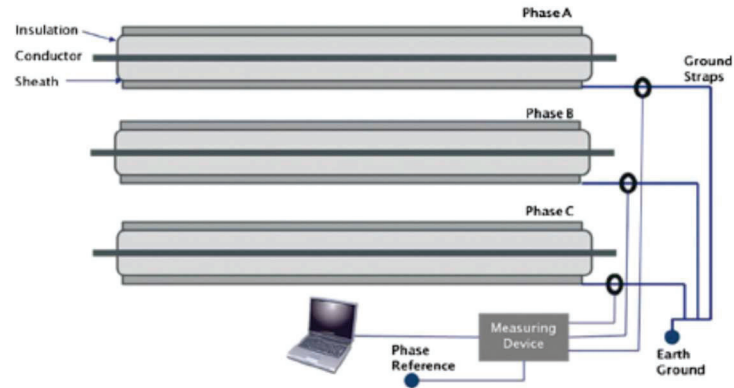


Fig. 10 Typical Online PD Test Connections

(3) Online PD vs. offline PD

Both of these tests have advantages and disadvantages, and both should be applied in the right circumstance. Table 2 shows that offline testing provides more detailed results, but is much more of a commitment to perform. Some of that commitment is lessened if done at commissioning. Online testing provides less detail but is economically feasible to perform on larger cable populations.

Table 2 Comparison of Offline and Online PD Test

Criteria	Offline Partial Discharge	Online Partial Discharge
Outage Required?	Yes	No
Cost of Test Equipment	High	Medium
Skill required to run test	High	Low
Time per test	Long (>2 hours)	Short (<10 minutes)
Test qualities		
Partial discharge presence	Yes	Yes
Partial discharge severity	Yes	Yes
Partial discharge location	Yes	Sometimes
Inception / extinction voltage	Yes	No

7. Introduction to cable fault location

Cable fault location can be quite challenging even though there is a number of fault locating techniques and quite a few tools to help out with underground cable faults. Most of these issues are due to technicians not properly interpreting the test results and then selecting the wrong tool for the task at hand, and ultimately a lot of wasted time is due to taking a shortcut in the process.

The challenges of underground fault location may be minimized significantly by understanding the equipment and techniques available. Education and experience in cable fault locating will help correct and make improvements in interpreting of the results and definitely will help correct and make improvements in the selection of which equipment and technique is most appropriate for a particular task. However, only a high level of awareness is going to correct wasted time that is afforded through taking shortcuts.

7.1 Thumping a cable

One of the oldest and most popular techniques out there is a technique called the capacitor discharge technique or thumping a cable. In application this technique is actually very straightforward and simple. In essence, a device called the thumper, or surge wave generator, creates a high voltage surge which is launched out onto the faulted cable. This surge of energy will travel along the cable conductor. If it reaches an area of dielectric breakdown or a failure in the insulating material, the transmitted energy will discharge through the gap at the fault and discharge all of the energy through the faulted insulation. All the fault current will then come back through the neutral or shield on the cable, back into the surge wave generator, and then will be dissipated safely to earth potential.

If a several thousand volt surge is sent into the cable, and all that energy is discharged through the gap or fault, it is going to cause a small explosion. Buried in the ground, this small explosion will cause a percussion and sound wave to travel up through the layers of earth. As a result, a thumping sound can be heard on the surface of the ground. To locate the defect in the underground cable, a repair crew has to walk along the surface of the ground listening for this thumping sound. Once the fault is pinpointed, the crew digs a hole and repairs the faulted cable.

The advantages of the capacitor discharge technique are that it is very accurate to do pinpointing and is easy to learn. This technique requires fairly minimum training, in particular, some safety training on how to properly handle the instrument, how to properly make connections, and how to set the various controls.

The weak point of this technique is that it is extremely time consuming and potentially harmful if misused. In some cases it may take hours or even days to walk the cable and definitely locate the fault. During that time the cable is exposed to high voltage surges, leading to a higher rate of repeat failures on the service age polyethylene cables. Repetitive thumping could be accelerating the vented tree channel growth of other water trees that under natural aging may have lasted several more years of service life. In essence, the cable is being set up for a future fault in the process of trying to find the current fault. Thus, this technique, if used all by itself, can be potentially harmful. The same is not necessarily true for the paper insulated lead-covered cables, where typically higher voltages and more energy is required to locate faults, with no noticeable damage to the cable.

Also this technique will not find faults that do not arc over. So, for instance, if there is a dead short, what is called a bolted fault, where basically the conductor and neutral have come together and bonded, if there is no gap, there is no sound no matter how much energy and voltage is discharged into the circuit. There is no energy being discharged or jumped across, there is just basically a constant current loop. So, since there will not be an acoustic event, it will not be possible to pinpoint a bolted fault, or a dead short. Again, in order to have sound, there needs to be a gap, and there needs to be air.

Another challenge for the capacitor discharge technique is a gap that is too large. For instance, the cable blows apart, and in the process of blowing apart the conductor had burned back into the dielectric material, or the neutral had burned back, causing a sizable distance in that gap. No matter how much voltage is applied to it, the gap is physically too large to actually arc across. The choice here may be the burn down technique, with the insulation resistance burnt away to reduce the gap size in order to get the thumper to discharge an arc across properly. But, again, this is going to come with stress to the cable.

To reduce the amount of stress applied to the cables under test, the surge or thumping technique is combined with pulse echo.

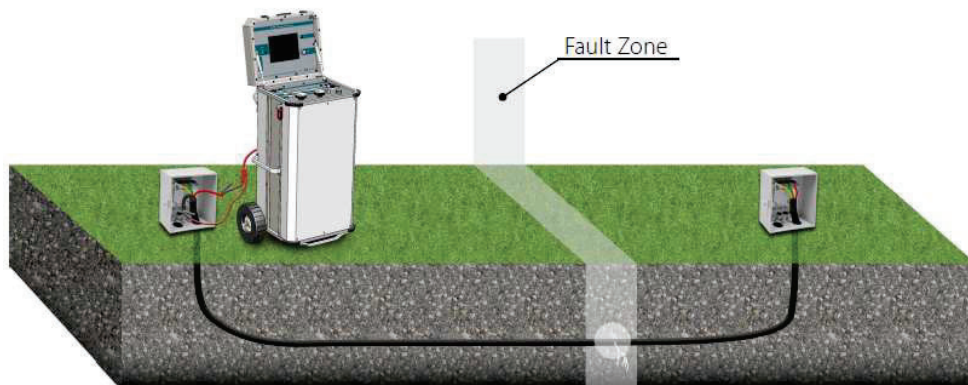


Fig. 11 Capacitive discharge (Thumping)

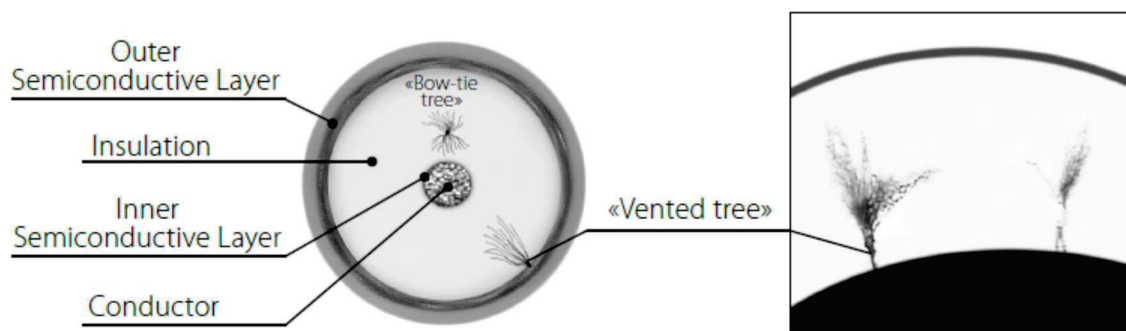


Fig. 12 Water tree sample

7.2 Time domain reflectometry (TDR)

Another time-proven cable fault locating method is time domain reflectometry (TDR), which has some variations, including the pulse echo, arc reflection, and impulse current. This section will focus on the pulse echo method, its principle, benefits and associated issues.

The pulse echo technique is performed with a time domain reflectometer (TDR), which combines a transmitter and a receiver. The transmitter sends out a low voltage high frequency pulse of a short duration onto a cable. This pulse of energy travels along the surface of the cable until it encounters some type of disruption manifested in a change within the characteristic impedance of the cable; these mismatches in the characteristic impedance of the cable may be caused by the start of the cable, splices in the cable, transformers, faults, etc. Depending upon the magnitude of the impedance change, either part or all of the transmitted energy reflects and travels back to the time domain reflectometer. In essence, this technique creates an electronic or a graphical roadmap of the underground cable showing different events along that path.

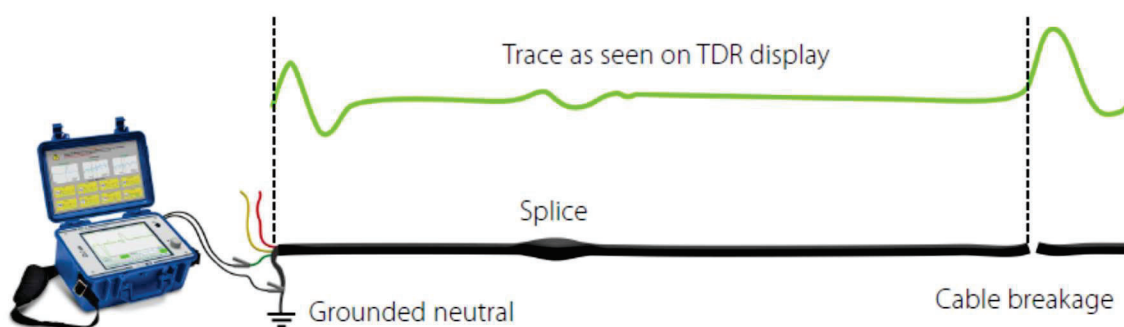


Fig. 13 TDR Return Cable End

The elapsed time of a transmitted pulse traveling the entire length of a cable and the pulse reflections produced by deviations from the harmonious structure of the cable are shown on a screen. These reflections are then shown in a time sequence.

So, on the graphic display of a time domain reflectometer, the first event is the pulse or the start of the cable and then the first mismatch impedance, second mismatch impedance, etc. Everything is shown in a time domain format. Thus, time domain reflectometers make it possible to see into a cable, visualizing different cable landmarks such as splices, transformers, cable transition areas, the start and end of a cable, etc. In addition to this, TDR also provides the ability to take measurements of the cable length and relatively easily locate faults that are in series with the cable transmission path, such as a broken or open conductor, neutral or severe corrosion building up on a concentric neutral, separated splices or sealed off cable ends, etc. To a lesser extent the pulse echo technique can be used to locate a shunt cable fault or faults in the dielectric material in the cable, provided that the resistance of the insulation fault is of value less than 10 times the characteristic impedance of the cable being viewed.

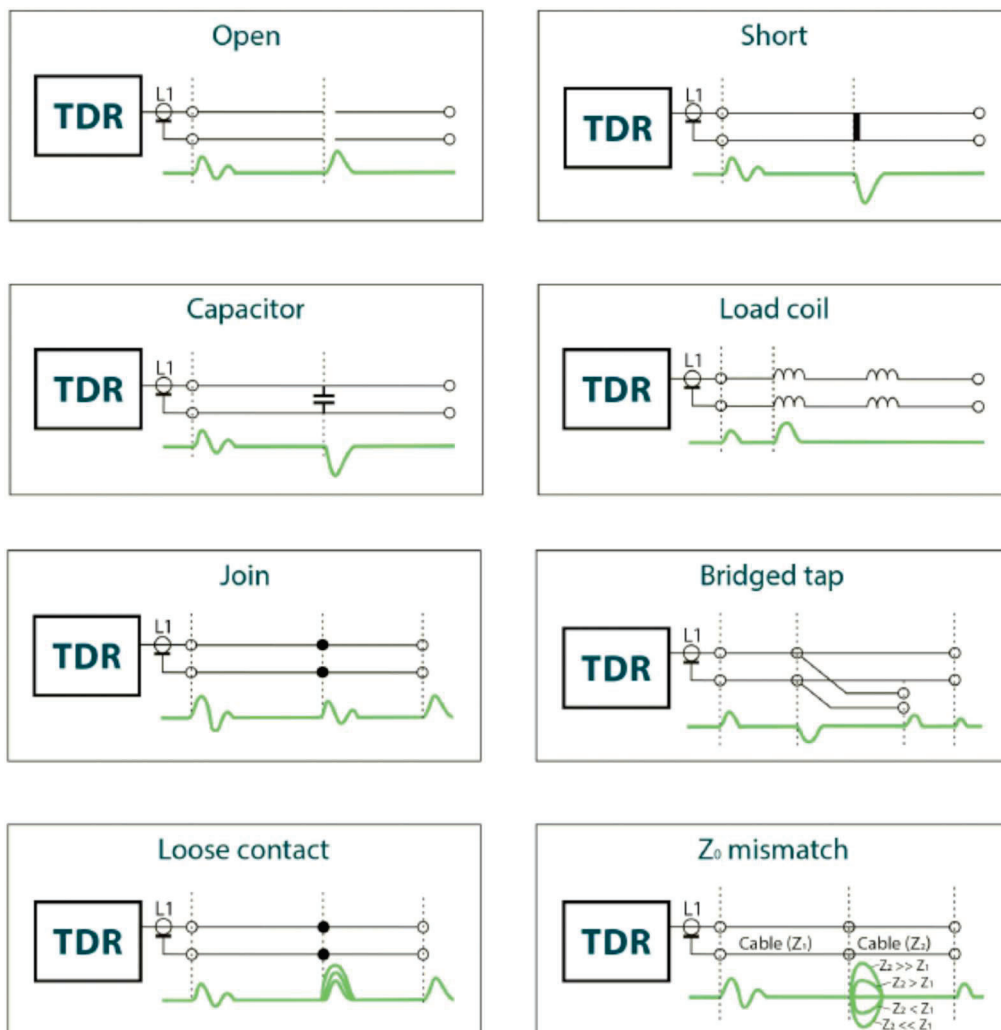


Fig. 14 Typical Waveforms

Measurements on a time domain reflectometer are made by measuring time. The TDR actually measures the amount of time it takes a pulse to launch out onto a cable, and then it starts to measure the elapsed time to when those reflections start to come back in. To find out the distance to where the pulse traveled, the TDR automatically takes the total amount of time that a pulse takes to leave and to return, divides that by half and then multiplies that by the speed at which the pulse is traveling.

A very important setting on the time domain reflectometer is velocity of propagation. Velocity of propagation is the speed at which high frequency pulses are traveling on a given cable and the speed at which these pulses travel will be influenced by the type of dielectric material and the thickness of the cross-sectional geometry of the cable.

Yet, even not knowing the details of the given cable, like its velocity, total length, and not knowing the particularities of the circuit, it is still possible to get very accurate results using a time domain reflectometer by simply taking advantage of the fact that the cable has two ends. To find a cable disruption in this case, it is necessary to measure the distance to the fault from both ends with the same velocity value; even if the velocity value is wrong, the fault will be pinpointed accurately.

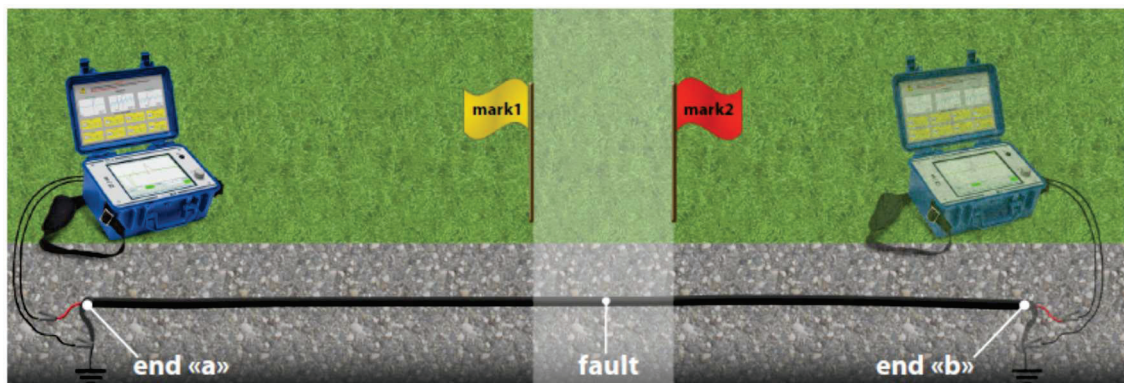


Fig. 15 If Velocity of Propagation is not known

To locate the fault, the distance should be first measured from end “a” and then marked on the ground. After that, the distance to the fault should be measured from end “b” and marked on the ground as well. In result, if the velocity was set too low, the fault will be undershot from both sides, with the true fault location being between the two markers. Naturally, if the velocity was set too high, the fault is going to be overshoot from both sides, with the true fault location still being between the markers. Hence, even with very little information about the cable and no knowledge of the right velocity value, accurate results can be received by simply doing

bidirectional measurements. When measurements are made on a longer cable, the total cable length can be divided into smaller sections.

The strong point of the pulse echo technique is that it enables relatively easy and fast faultfinding. All the results are shown on the TDR screen, which means there is no need to walk along the cable path tracking the fault. Another important advantage is that this approach uses safe low voltage pulses, preventing stress to the cable and making the process safe for technicians. The time domain reflectometer can be used on various cables all the way up through a low voltage, medium voltage and high voltage on electrical power cables. The obtained pulse echo signatures can be used for diagnostic values. For instance, to examine the splices within a three phase circuit, it is possible to capture all three phases, overlay them together and examine some of the issues that may be occurring on one phase and not occurring on another phase.

One of the drawbacks of the pulse echo technique is that traces that result from complex circuits can be difficult to interpret. For example, in a circuit with several “T” or “Y” connections, when the reflections from them are overlaid, it can result in a very complicated wave form. This means that it may be very difficult to make meaning of all these reflections. The recommended practice in this situation is to use differential pulse echo: basically, a picture of a good cable phase is taken, and then a picture of the faulted cable phase is made. Everything that is common, all the areas where they share common “T” and “Y” connections, transitions, etc., all these images will be the same. So, the two common data points from these two waveforms are subtracted, which will display the points of difference or potential fault on the bad phase.



Trace description:

1. Positive reflection at the cable end
healthy core
2. Negative reflection at the faulty point (short circuit)
faulty core

Fig. 16 Comparison Method

Another problem is that it is impossible to locate with pulse echo alone a dielectric fault or insulation fault where the resistance value is ten times or greater the characteristic impedance of the cable being viewed. In this case the recommended technique is arc reflection, and it will be discussed below.

7.3 Arc reflection technique (ARC)

The technique of Arc Reflection (ARC) combines the surge wave generator (thumper) and the pulse echo technique (TDR) for the purpose of locating high resistance shunt faults and intermittent shunt faults.

Although the pulse echo technique is a very good tool for a low voltage cable application, a problem occurs when this method is used on medium voltage electrical power cables.

To locate vented trees, which basically form a hole in the insulation, a breakdown voltage is typically required. The pulse echo tool by itself is very low voltage in nature. So, if the fault requires some level of breakdown voltage, the low voltage pulse echo energy will travel straight past the fault never seeing it. The TDR will just show the reflection of energy off the terminating event or the end of the cable.

Yet, if a high voltage breakdown surge is applied at the same time that the pulse echo pulses are sent, when the fault breaks down due to the high voltage surge and the arc jumps through the faulty insulation, the pulse echo wave will reflect off that arc.

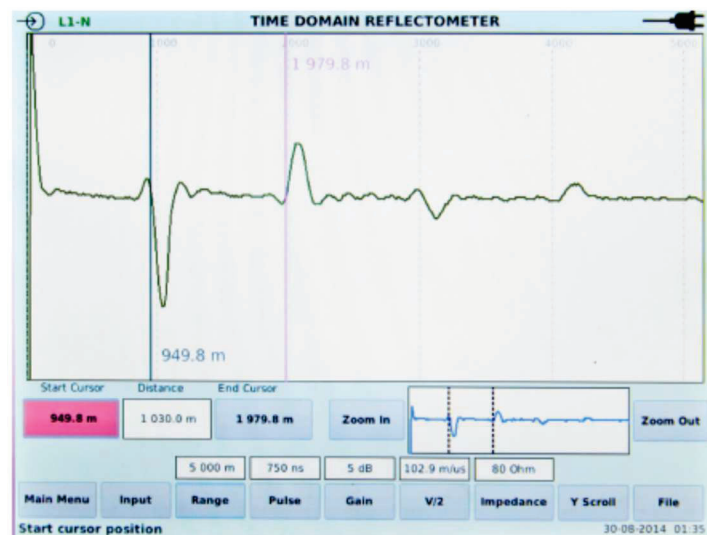


Fig. 17 Arc Reflection

For the ARC, a coupling device (a filter, or a power separation unit) is introduced into the circuit allowing the high voltage surge generator and low voltage time domain reflectometer to be combined simultaneously to the faulted cable. The function of the surge generator is

simply to transmit a high voltage surge into the faulted cable. This surge momentarily reduces the resistance of the shunt fault. During the high voltage impulse time interval the pulse echo technique is applied.

In other words, the momentary reduction in the shunt resistance established by the high voltage impulse, or arc created at the fault will create a point of reflection for the low voltage pulse transmitted by the time domain reflectometer and help to identify the fault.

The strong point of the ARC is that it helps localize any fault that will sustain an arc during the thumper pulse. Even though a surge wave generator is used, this method significantly reduces the amount of stress that is traditionally associated with the thumping technique because only one or two surges into the cable are needed in order for the pulse echo to be able to find the fault, display that image and measure the distance.

So, the amount of stress to the cable is considerably decreased by reducing the number of surges it's going to take to find this overall fault, and the output voltage is regulated by the reflection filter or power separation unit.

One disadvantage of this method is that long cables with very highly attenuated dielectrics or a lot of corrosion on the neutrals can very quickly absorb the reflected pulses of the pulse echo technique. Thus, if the TDR does not have enough transmitted pulse energy to overcome these very long cables or high corrosion is bleeding down the signal, it may not be possible to see the end of the cable or the actual fault event just because the signals attenuate before they get back to the receiver.

Also, if it's a complex circuit with many branches and therefore a lot of reflections, the waveform can be difficult to interpret. In this case, a differential technique called differential arc reflection can be applied.

The first step is to get a standard low voltage pulse echo waveform and then capture that image. Then, the high voltage surge is applied to the cable, the arc or flashover is created and the time domain reflectometer displays a new waveform showing the reflection from the arc.

Since the result is two wave forms which are really just an accumulation of data points, the computer or the analyzer will cancel everything common, getting rid of all the unwanted reflections. This will clearly show points of difference where the arc took place, allowing to very quickly visualize and measure the distance to the flash point, or reflection point of the arc.

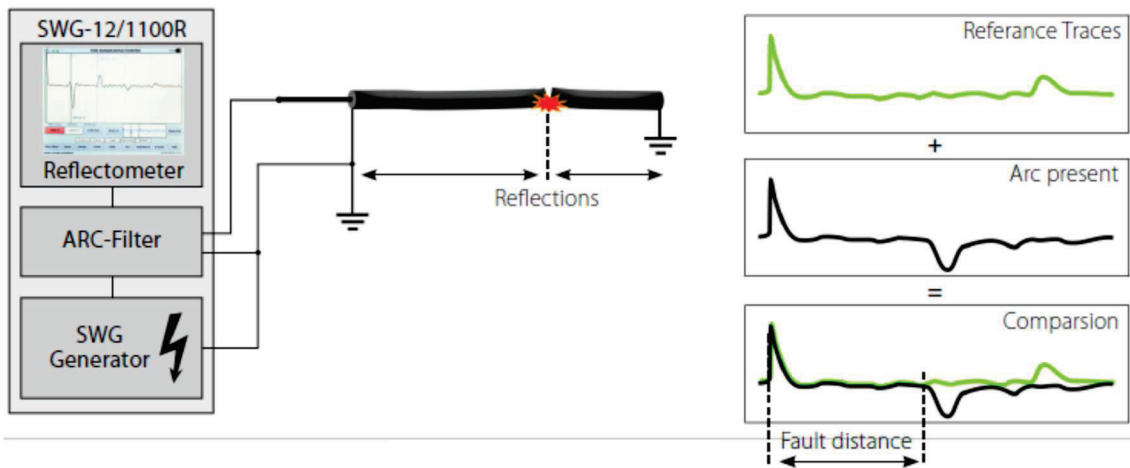


Fig. 18 Typical Traces

8. Hands-on/Practical training

8.1 Functions of Cable Fault Locator STX 40 (Megger)

(Refer to **Attachment-2: STX 40 Portable Fault Location System USER GUIDE** by Megger)

(1) Schema of cable fault location

Schema The following schema illustrates the typical approach for detection, classification and location of cable faults using the methods of measurement available in STX 40:

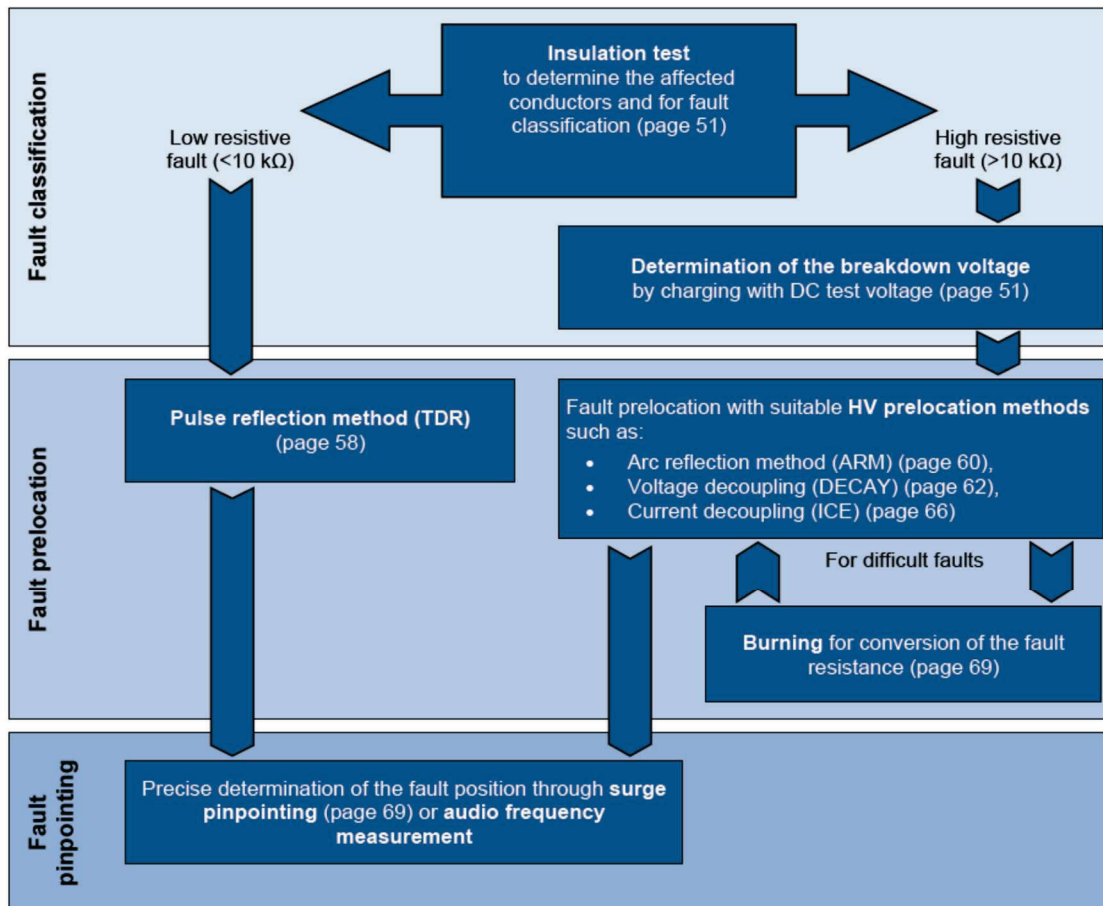


Fig. 19 Schema of cable fault location for low resistance fault and high resistance fault

(2) Insulation test

A basic fault classification can often be carried out in advance by measuring the ohmic insulation resistance.

(3) DC voltage test / breakdown detection

A DC voltage test not only allows the dielectric strength of the connected test object to be checked, but also the breakdown voltage of the fault location to be reliably determined in the

event of insulation problems.

(4) Pulse reflection method (TDR)

(Refer to **Attachment-3: Cable Fault Prelocation Basics of TDR (Time Domain Reflectometry)** by Megger)

Low-resistance cable faults can be localized using the tried-and-tested and widely-used pulse reflection measurements. This method is based on radar principle and makes use of the fact that any sudden deviations in the characteristic impedance of a cable reflect part of the energy transmitted into the cable. The degree of reflection is dependent on the magnitude of the deviation in the characteristic impedance, the number of reflections, the cable length and distance to the fault position.

(5) Surge pinpointing

(Refer to **Attachment-4: Cable Fault Pinpointing Acoustic Method with Surge wave Generator (SWG)** by Megger)

Surge pinpointing is the preferred method for precise location. It can be used for about 90% of all cable faults.

Using an abrupt discharge of the surge capacitor, surge voltage pulses are continuously fed into the defective cable, causing voltage arc-overs at the fault location. The resulting flashover noise propagates in ground and can be recorded with a ground noise sensor on the surface (acoustic location). The distance to the fault can be calculated using either the volume of the flashover noise or the time difference between the arrival of the magnetic pulse and the flashover noise.

(6) Arc reflection measurement (ARM)

(Refer to **Attachment-5: Cable Fault Prelocation HV – Methods for high resistance Faults** by Megger)

The ARM method suited for the pre-location of high-resistance cable faults on power cables with a total length of up to 10 km. For faults with low ignition voltage (<32 kV), pre-location should be started with this method.

When locating the fault position a reflectogram is taken first under normal conditions (reference trace). The charged surge capacitor is then discharged suddenly into the cable and 32 reflection measurements are carried out in the static arc caused by faulty ignition. The user can then select the most suitable fault pattern from the 32 recorded patterns.

The direct comparison of reference and fault pattern usually makes possible immediate, clear identification of the fault location, because, due to the reflection at the burning arc, the fault

pattern displays a significantly negative reflection at the fault location compared to the functional image.

(7) Voltage decoupling (DECAY)

(Refer to **Attachment-5: Cable Fault Prelocation HV – Methods for high resistance Faults** by Megger)

The decay method is used to pre-locate high-resistance cable faults using a high fault ignition voltage in rechargeable cables.

To this end, the cable is charged with a DC voltage until the voltage exceeds the fault's breakdown voltage. The energy stored in the cable capacitance discharges through the fault and generates a travelling wave, which is recorded and displayed by the system as an attenuated oscillation. The period of this oscillation can be used along with the following formula to determine the actual fault distance.

$$\text{Fault distance} = \frac{\text{Full period distance}}{2} - \text{Length of HV connection cable}$$

(8) Current decoupling (ICE)

(Refer to **Attachment-5: Cable Fault Prelocation HV – Methods for high resistance Faults** by Megger)

Prelocation using current decoupling has established itself, particularly with regard to faults in the lower kOhm range and for extremely large fault distances, in which the ARM-method often fails to achieve any results.

As with the ARM method, an abrupt discharge of the surge capacitor triggers a breakdown in the fault. Consequently, an attenuated transient wave moves back and forth between the fault location and the measurement system. Inductively decoupling the current causes the display of an oscillation, which has a period equivalent to a single fault distance. However, the length of the pre-measuring cable still needs to be deducted from this distance.

(9) Connection

Fig. 20 shows the simplified connection diagram of the fault location system for cable testing and cable fault location.

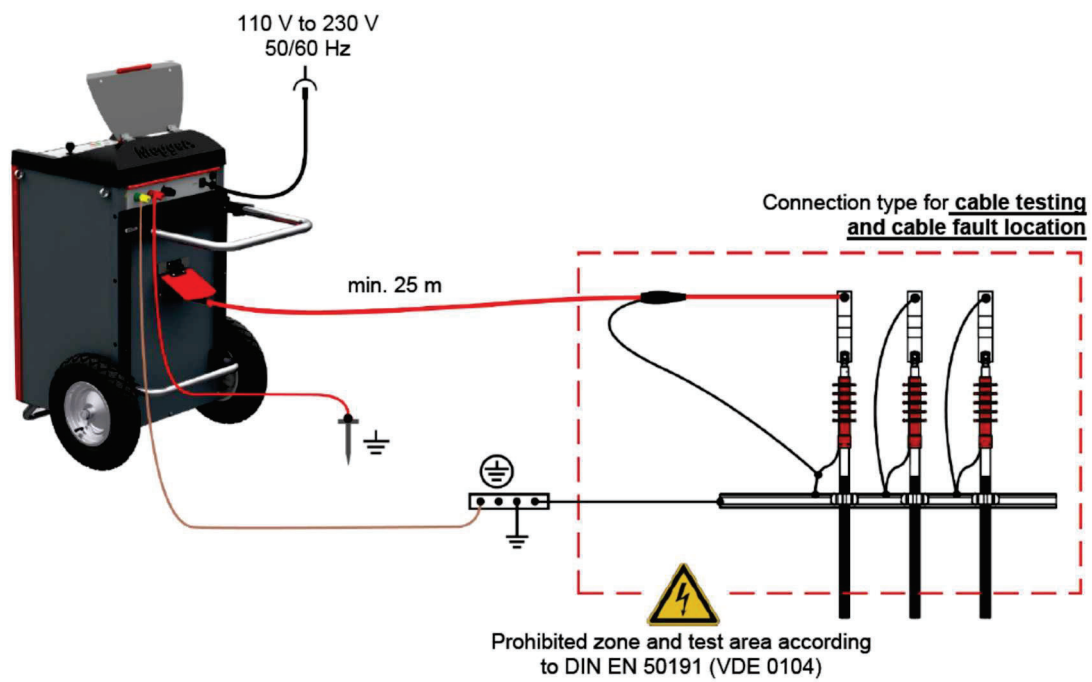


Fig. 20 Connection diagram of the fault location system

8.2 Preparation of equipment, materials, gears & tools

- Cable Fault Locator
- Generator
- Safety belt
- Insulated globe
- Ladder
- Binding wire

8.3 Procedure of cable fault location

(1) Open end, faultless

Conduct tests and measurement below on Cable-1 or Cable-2 at A, B or C Phase.

- Insulation test
- DC voltage test / breakdown detection
- Pulse reflection measurement (TDR)

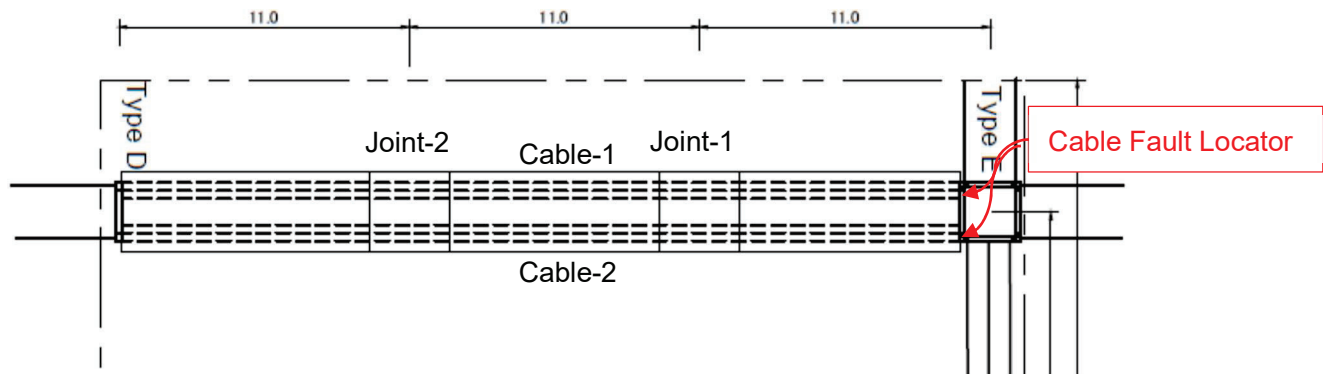


Fig. 21 Underground cable of the training facility (open end, faultless)

(2) Low resistance fault (<10 Ω)

Make a low resistance fault on Cable-1 or Cable-2.

Conduct tests and measurements below on the faulty cable.

- Insulation test
- DC voltage test / breakdown detection
- Pulse reflection measurement (TDR)
- Surge pinpointing

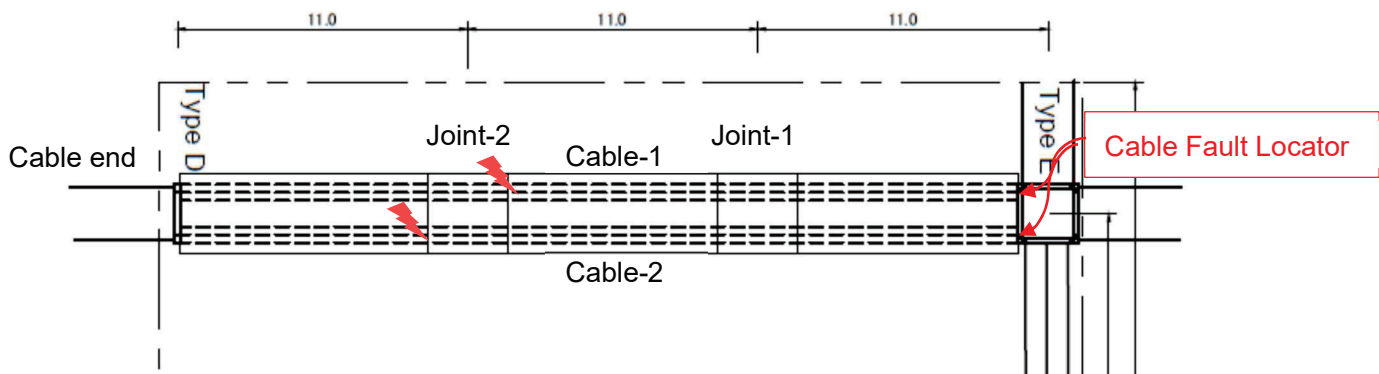


Fig. 22 Underground cable of the training facility (low resistance fault)

(3) High resistance fault ($>10\ \Omega$)

Make a high resistance fault on Cable-1 or Cable-2.

Conduct tests and measurements below on the faulty cable.

- Insulation test
- DC voltage test / breakdown detection
- Arc reflection measurement (ARM)
- Voltage decoupling (DECAY)
- Current decoupling (ICE)
- Surge pinpointing

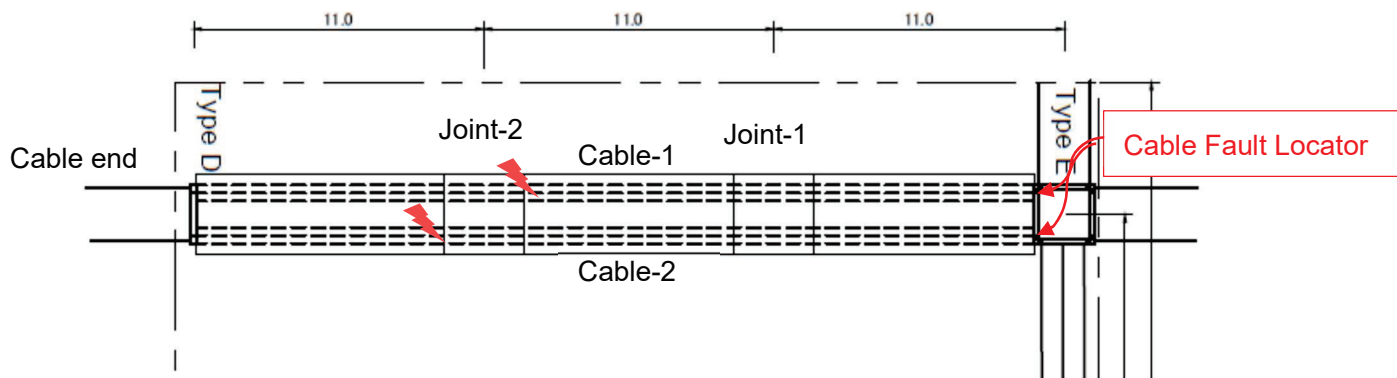


Fig. 23 Underground cable of the training facility (high resistance fault)

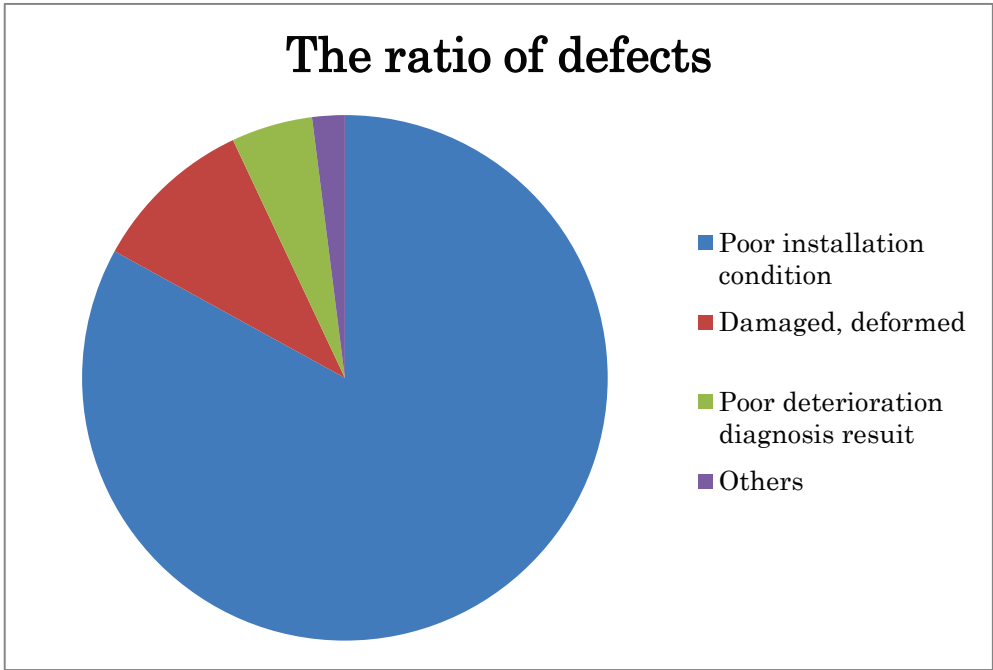
【 The causes of cable failure 】



- Cause 1. Outside damage while installing the cable
- Cause 2. Lack of quality control of the joint and the cable head
- Cause 3. Outside damage by traffic accident
- Cause 4. Outside damage by road digging construction
- Cause 5. Accident by the third party (including animals, birds and bees)
- Cause 6. Others

The cable

The ratio of defect according to the aspect of discovery



Poor installation condition

This defect is mainly caused by increase of stretching volume of cable, others are contact to other facilities, floating up, lack of bend radius and slip down. The factors are surfing phenomenon and thermal behavior.



“Damaged, deformed”

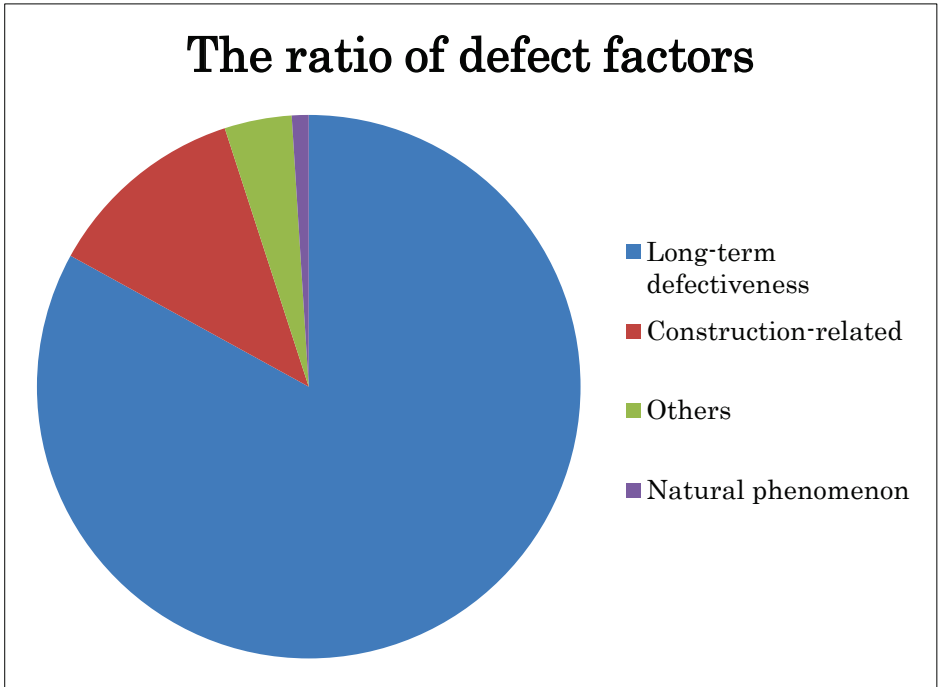
This defect is mainly caused by construction-related or aging damage of corrosion-resistant layer. There is also natural deterioration of waterproof tape. The damage of corrosion-resistant layer is estimated some kind of external factor.



“Poor deterioration diagnosis result”

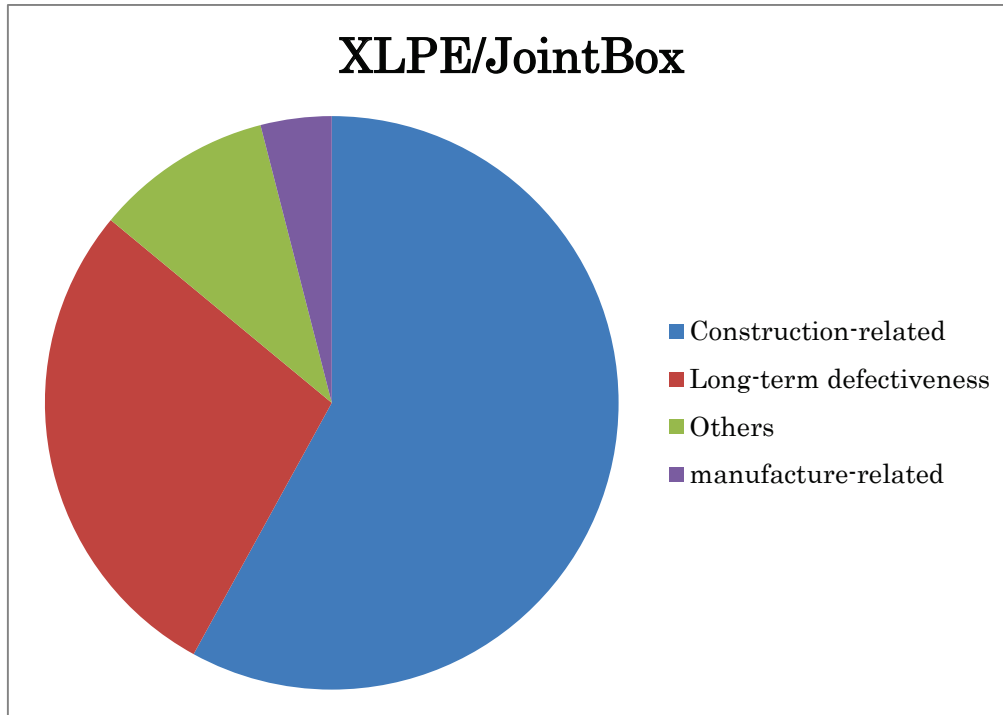
In case of judgment of poor water tree deterioration diagnosis.

The ratio of defect factor



The joint box

The ratio of defect factor of the joint box.



”Construction-related”

- Inner and outer semi-conductive layer nick
- Finishing defects of insulator surface
- Dirt of insulator surface
- Poor connection of ground wire
- Poor processing of Waterproof tape



”Aging damage”

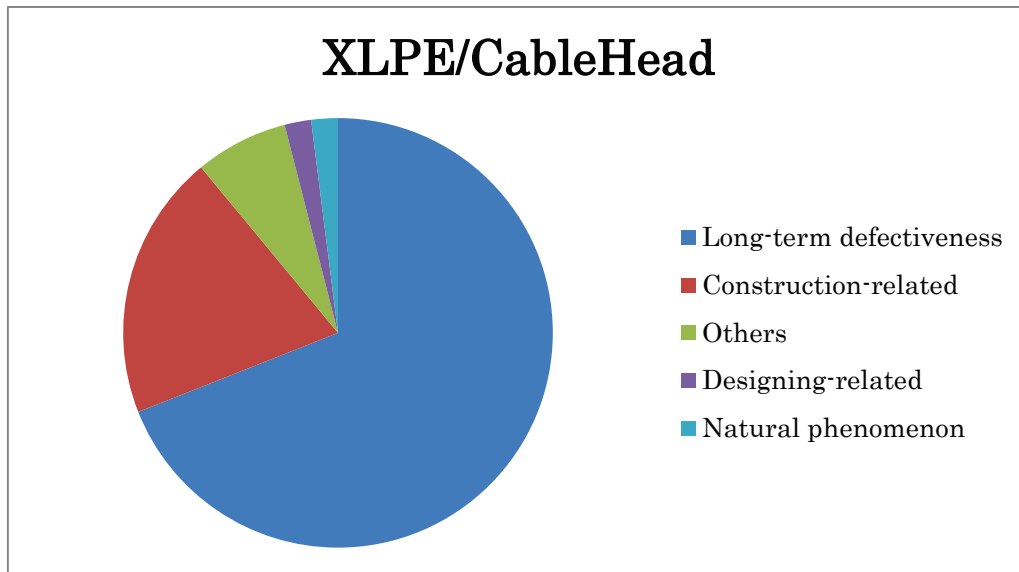
- Deformation of junction

- Inside deformation by thermal behavior
- Deterioration of waterproof tape
- Infiltration of moisture



The cable head

The ratio of defect factor of the cable head



”Long-term defectiveness”

- Separation and deformation of waterproof tape
- Corrosion of connection terminal and ground terminal
- Slack of connection terminal

”Construction-related”

- Failure of fixation of cable
- Failure of connection of ground wire
- Inner and outer semi-conductive layer nick
- Finishing defects of insulator surface
- Dirt of insulator surface
- Others



〈 Summary 〉

The cable

- The main defection of the CV cable is the move of the cable caused by surfing phenomenon and thermal contraction. It is necessary to control not to become less than prescribed cable permissible bend radius.
- It is necessary not to damage outside the cable during laying work and strong power is not added to the part.
- It is necessary to prevent water from getting in by using a cable cap while keeping.

The joint box

- As you can see from the graph there are many construction-related defects. We have to prevent the defect before occurring by thoroughly quality control of construction. Therefore, preparation of the necessary equipment, checking the necessary material and improvement of cable processing technology are necessary
- For the long-term preservation, certainly execute the winding treatment of waterproof tape to prevent infiltration of water from outside not to make tree factor and devising to tolerate the pressure from the upper part is necessary.
- We can detect the defect in its early stages by carrying out the present maintenance.
- At the time of road digging construction, we have to prevent the defects before occurring by allowing to confirm a place buried beforehand or to have the person in charge standby while digging.

The cable head

- Regular patrol is effective to prevent defect before occurring because according to the graph aging damage is the most major factor. Also tensile of lead wire is the one factor of deformation of terminal.
- Regular patrol can avoid separation and deformation of waterproof tape beforehand.
- Preparation of the necessary equipment, checking the necessary material and improvement of cable processing technology are necessary to prevent construction failure beforehand.



【 Cable accident examples 】

Form	Cause	Details
On the tower	Others	Electrical breakdown by rainwater intrusion to insulator from outside
Substation premises	Construction-related	Cable bending and too much shaving of outer semi-conductive layer
Substation premises	Construction-related	Insulator nick by electric works knife
Substation premises	Construction-related	Cable bending and contamination
On the street	Construction-related	Damaged the insulator by mistake while dismantle NJ using hammer
On the street	Public fault	Cable external injury by water-supply construction company
Substation premises	Construction-related	Partial discharge breakdown by the growth of void caused by the outer semi-conductive layer damage
Substation premises	Public fault	Damaged the cable with material by the footing assembling worker
On the street	Natural deterioration	Breakdown caused by water tree growth and progress by aging of cable
On the street	Public fault	Cable damage caused by the boring exploration by road company
Substation premises	Construction-related	Electrical breakdown caused by finishing defects of insulator surface
On the street	Natural phenomenon	Water tree progress caused by intrusion of water after insect damage by termite
On the street	Construction-related	False cutting by the error of the work line

【 From the cable laying situation 】

〈 Direct burial 〉

The place where a cable is laid.



The joint which was exposed where many people pass.



The joint which is kept under the asphalt



- 1 . Can't recognize the place where cable is laid.
- 2 . Many people pass by stepping on the joint.
- 3 . The weight of the asphalt and the soil is on the joint.
- 4 . There is few offset in the cable of right and left side of the joint.
- 5 . Others

Measures : 1

Bury an undergrounding plate on the place where the cable is laid.

Effects : 1

Can recognize the cable is laid right underneath.

It would be attention reminding when the digging construction by other companies.

Easy to find an accident point when cable was damaged.

Measures : 2

Lay the board right over the cable.

Others

Effects : 2

People do not step on the cable directly.

If by any chance the cable was damaged, it is hard to give a third party harm.

Backfill soil is hard to come off.

Measures : 3

Lay the board right over the joint box.

Effects : 3

Direct weight is not on the joint box.

In case of the digging construction by other companies, it is easy to find because the board strikes an excavator at first.

If by any chance the cable was damaged, it is easy to find.

Measures : 4

Make an offset for both sides of the joint box and backfill it

Effects : 4

Slight move become possible by thermal behavior.

If by any chance the cable was damaged, connection would be possible by using offset.

Example 1. The undergrounding plate



Example 1. The undergrounding tape



< Culvert >

S/S premises pit

1. Lower part of the cable at bending section is touching the corner.
2. It is laid inside the culvert but in disorder.
3. There are no circuit name board on cable.
4. Opening part is completely exposed to view.



Measures : 1

Wind the peeled vinyl sheath around the cable the place where the corner of the culvert is touching.

Effects : 1

Prevent the damage by protecting the cable not to touch directly by vinyl sheath.

Measures : 2

Put the existing cable in order before laying a new cable.

Effects : 2

Easy to confirm the working line and prevent false cut by putting in order.

Easy to work at renewal period.

Measures : 3

Put circuit name board on the surface of cable.

Effects : 3

Easy to confirm the working line and it can reduce the time.

If the cable was damaged, it is easy to confirm which circuit was damaged.

Measures : 4

Draw a line of demarcation not to approach the opening part.

Cover the opening part.

Effects : 4

Prevent falling from the opening part.

Prevent the cable damage by falling object.

Megger[®]



STX 40

Portable Fault Location System

USER GUIDE

Issue: H (11/2022) - EN
Article number: 86883



Consultation with Megger

The present system manual has been designed as an operating guide and for reference. It is meant to answer your questions and solve your problems in as fast and easy a way as possible. Please start with referring to this manual should any trouble occur.

In doing so, make use of the table of contents and read the relevant paragraph with great attention. Furthermore, check all terminals and connections of the instruments involved.

Should any question remain unanswered or should you need the help of an authorized service station, please contact:



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Terms of Warranty

Megger accept responsibility for a claim under warranty brought forward by a customer for a product sold by Megger under the terms stated below.

Megger warrant that at the time of delivery Megger products are free from manufacturing or material defects which might considerably reduce their value or usability. This warranty does not apply to faults in the software supplied. During the period of warranty, Megger agree to repair faulty parts or replace them with new parts or parts as new (with the same usability and life as new parts) according to their choice.

This warranty does not cover wear parts, lamps, fuses, batteries and accumulators.

Megger reject all further claims under warranty, in particular those from consequential damage. Each component and product replaced in accordance with this warranty becomes the property of Megger.

All warranty claims versus Megger are hereby limited to a period of 12 months from the date of delivery. Each component supplied by Megger within the context of warranty will also be covered by this warranty for the remaining period of time but for 90 days at least.

Each measure to remedy a claim under warranty shall exclusively be carried out by Megger or an authorized service station.

This warranty does not apply to any fault or damage caused by exposing a product to conditions not in accordance with this specification, by storing, transporting, or using it improperly, or having it serviced or installed by a workshop not authorized by Megger. All responsibility is disclaimed for damage due to wear, will of God, or connection to foreign components.

For damage resulting from a violation of their duty to repair or re-supply items, Megger can be made liable only in case of severe negligence or intention. Any liability for slight negligence is disclaimed.

Since some states do not allow the exclusion or limitation of an implied warranty or of consequential damage, the limitations of liability described above perhaps may not apply to you.

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1 Safety Instructions

1.1 General Notes

Safety precautions This manual contains basic instructions for the commissioning and operation of the device / system. For this reason, it is important to ensure that the manual is always available to the authorised and trained operator. He needs to read the manual thoroughly. The manufacturer is not liable for damage to material or humans due to non-observance of the instructions and safety advices provided by this manual.

Locally applying regulations have to be observed!

Labelling of safety instructions The following signal words and symbols are used in this manual and on the product itself:

Signal word / symbol	Description
DANGER	Indicates a potential hazard which <u>will result</u> in death or serious injury if not avoided.
WARNING	Indicates a potential hazard which <u>may result</u> in death or serious injury if not avoided.
CAUTION	Indicates a potential hazard which may result in moderate or minor injury if not avoided.
NOTICE	Indicates a potential hazard which may result in material damage if not avoided.
	Serves to highlight warnings and safety instructions. As a warning label on the product it is used to draw attention to potential hazards which have to be avoided by reading the manual.
	Serves to highlight warnings and safety instructions that explicitly indicate the risk of an electric shock.
	Serves to highlight important information and useful tips on the operation of the device/system. Failure to observe may lead to unusable measurement results.

Working with products from Megger It is important to observe the generally applicable electrical regulations of the country in which the device will be installed and operated, as well as the current national accident prevention regulations and internal company directives (work, operating and safety regulations).

After working on the system, it must be voltage-free and secured against reconnection as well as having been discharged, earthed and short-circuited.

Use genuine accessories to ensure system safety and reliable operation. The use of other parts is not permitted and invalidates the warranty.

Operating staff The system may only be installed and operated by an authorised electrician. DIN VDE 0104 (EN 50191), DIN VDE 0105 (EN 50110) and the German accident prevention regulations (UVV) define an electrician as someone whose knowledge, experience and familiarity with the applicable regulations enables him to recognise potential hazards.

Anyone else must be kept away!

Declaration of Conformity (CE) The product meets the following security requirements of the European Council Directives:

- EMV Directive (2014/30/EC)
- Low Voltage Directive (2014/35/EC)
- RoHS Directive (2011/65/EU)

1.2 General Safety Instructions and Warnings

Intended application The operating safety is only guaranteed if the delivered system is used as intended (see page 10). Incorrect use may result in danger to the operator, to the system and the connected equipment.

The thresholds listed in the technical data may not be exceeded under any circumstances.

Five safety rules

The five safety rules must always be followed when working with HV (High Voltage):

1. De-energise
2. Protect against re-energising
3. Confirm absence of voltage
4. Earth and short-circuit
5. Cover up or bar-off neighbouring energised parts



Using cardiac pacemaker / defibrillator

Physical processes during operation of high voltage may endanger persons wearing a cardiac pacemaker or defibrillator when near these high voltage facilities.

**Fire fighting in electrical installations**

- According to regulations, carbon dioxide (CO₂) **is required to be used** as extinguishing agent for fighting fire in electrical installations.
- Carbon dioxide is electrically non conductive and does not leave residues. It is safe to be used in energized facilities as long as the minimum distances are maintained. A CO₂ fire extinguisher must be always available within electrical installations.
- If, contrary to the regulations, any other extinguishing agent is used for fire fighting, this may lead to damage at the electrical installation. Megger disclaims any liability for consequential damage. Furthermore, when using a powder extinguisher near high-voltage installations, there is a danger that the operator of the fire extinguisher will get an electrical shock from a voltage arc-over (due to the powder dust created).
- It is essential to observe the safety instruction on the extinguishing agent.
- Applicable is DIN VDE 0132.

**WARNING****Dangers when working with high voltage**

Working on high voltage systems and equipment – especially in non-stationary operation – requires particular care and safety-conscious action on the part of test personnel. VDE regulations 0104 on setting up and operating electrical test systems, as well as EN 50191 and national standards and regulations must be strictly adhered to.

- The STX 40 generates a dangerous voltage of up to 40 kV during measurement operation. This is supplied to the test object via a high-voltage cable.
- The test system may not be operated without supervision.
- Never fail to use safety equipment or put it out of operation.
- Operation requires minimum two people whereas the second person must be able to activate the emergency switch in case of danger.
- To prevent dangerous charge accumulation, earth all metal parts in the vicinity of the high voltage equipment.

2 Technical description

2.1 System description

Functional description The fault location system STX 40 is a portable, multi-functional device suitable for outdoor use for testing and locating faults on low and medium voltage cables.



It comes with the following features:

- Dedicated DC test and breakdown detection up to 40 kV
- Dedicated Insulation test up to 20 kV
- Prelocation of faults with well-established HV methods such as arc reflection measurement (ARM), current decoupling (ICE), and voltage decoupling (DECAY)
- Conversion of faults by burning with up to 850 mA
- Pinpointing of faults by surging/thumping with up to 2.000 J in multiple voltage ranges
- Sheath test with up to 20 kV with automatic breakdown detection
- Pinpointing the location of sheath faults with up to 20 kV using the voltage gradient method (step voltage method)

The STX 40 has an integrated time domain reflectometer, which eliminates the time-consuming cabling work before locating faults and ensures a perfectly coordinated temporal sequence of surge decoupling and pulse reflection measurement.

With its easy-to-read 10 inch display, the reflectometer simultaneously forms the central control unit of the system and enables intuitive and fast selection and configuration of the operating modes.

A well-established integrated safety system ensures the safety of the operator by continuously monitoring the earthing and temperature conditions during operation.

Scope of delivery The scope of delivery includes the following components:

Component	Item number
Fault location system STX 40	1011497 (without 4 kV voltage range) 1013011 (with 4 kV voltage range)
Mains supply cable	Varies by region
Earthing cable drum with earthing cable, 25 m	2013151
Separate earthing cable (5 m) for connection between earthing drum and system	2013149
Reference earth wire (red, 5 m) for fault voltage (FU) monitoring + metal earth rod and hammer	820003013 (earth wire) 892479915 (earth rod) 892517507 (hammer)
High-voltage connecting cable, 25 m on drum	2012308
Various connectors and terminals	---
Device key	2012515
Manual	86883

Check contents Check the contents of the package for completeness and visible damage right after receipt. In the case of visible damage, the device must under no circumstances be taken into operation. If something is missing or damaged, please contact your local sales representative.

Optional accessories If the following optional accessories are not included in the scope of delivery, they can be ordered through Sales:

Accessory	Description	Item number
External safety device	For indicating the operating state and for emergency shutdown or locking the high voltage (in accordance with EN 50191)	2012574

2.2 Technical data

The STX 40 is defined by the following parameters:

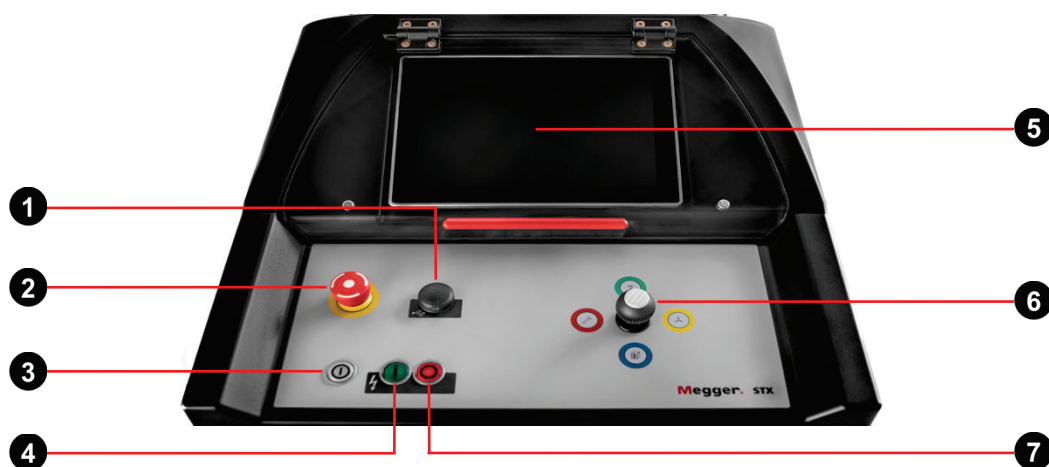
Parameter	Value
Insulation test • Measuring voltage • Measuring range	1 ... 20.000 V 100 ... 650 MΩ
DC test • Output voltage • Leakage current measurement	0 ... 40 kV ±1.5% (adjustable in steps of 0.1 kV) 0 ... 1A ±2%
TDR module • Measuring range (at v/2 = 80 m/μs) • Pulse width • Pulse amplitude (bipolar) • Resolution • Accuracy • Timebase accuracy • Data rate • Propagation velocity • Dynamic range • Output impedance • Distance-dependant de-attenuation (ProRange) • Number of traces	20 m ... 320 km 20 ns ... 10 μs 100 V 0.1 m at v/2 = 80 m/μs 0.1% <50 ppm 533 MHz As V/2 or NVP value 10 ... 149.9 m/μs or 33 ... 492 ft/μs 115 dB 50 Ω +40 dB, adjustable Up to 6 traces simultaneously (e.g. for phase comparison)
Surging • Surge levels¹ • Surge rate	0 ... 8 / 16 / 32 kV with 2,000 J 0 ... 4 kV with 1100 J (optional) Every 3 seconds at 2000 J at 32 kV Adjustable between 3 ... 10 seconds or single pulse

¹ If the system is connected to 120 VAC input voltage, surge power is limited to 1,600 W (as per ANSI/NEMA 5)

Parameter	Value
Fault pre-location methods - Inductive ARM Multishot - ICE - DECAY	Reflection measurement while the arc caused by a fault flash-over at the fault position is still burning. A total of 32 fault traces are recorded per measurement. Current decoupling from a traveling wave caused by a fault breakdown Voltage decoupling from a traveling wave caused by a fault breakdown
Burning	Max. 850 mA in 5 kV range Max. 400 mA in 10 kV range Max. 200 mA in 20 kV range Max. 100 mA in 40 kV range
Sheath test - Output voltage - Leakage current measurement	0 ... 20 kV $\pm 1.5\%$ 0 ... 1 A $\pm 2\%$
Sheath fault pinpointing - Output voltage - Pulse ratio	20 kV 0.5:1, 1:3, 1:4, 1:6
Safety	- FΩ protection device - FU protection device - Temperature monitoring - Device key for high voltage locking
Input voltage range	110 ... 230 VAC $\pm 10\%$, 50 / 60 Hz
Power consumption	2.5 kVA
Display	10.1" colour TFT WXGA 1280x800, capacitive touch screen, 1000 cd/m ² , LED-backlight
Memory	4 GB mSATA for program and data
Interfaces	1 x USB 2.0
Operating temperature	-20 °C ... +55 °C
Storage temperature	-40 °C ... +70 °C
Relative humidity	93% at 30 °C (non-condensing)
Dimensions (W x H x D)	74cm x 103cm x 65cm (with folded in handle)
Weight	124 kg (with 4 kV voltage range) 119 kg (without 4 kV voltage range)
Protection class (in accordance with IEC 61140 (DIN VDE 0140-1))	I
Ingress protection rating (in accordance with IEC 60529 (DIN VDE 0470-1))	IP43

2.3 Display and operating elements

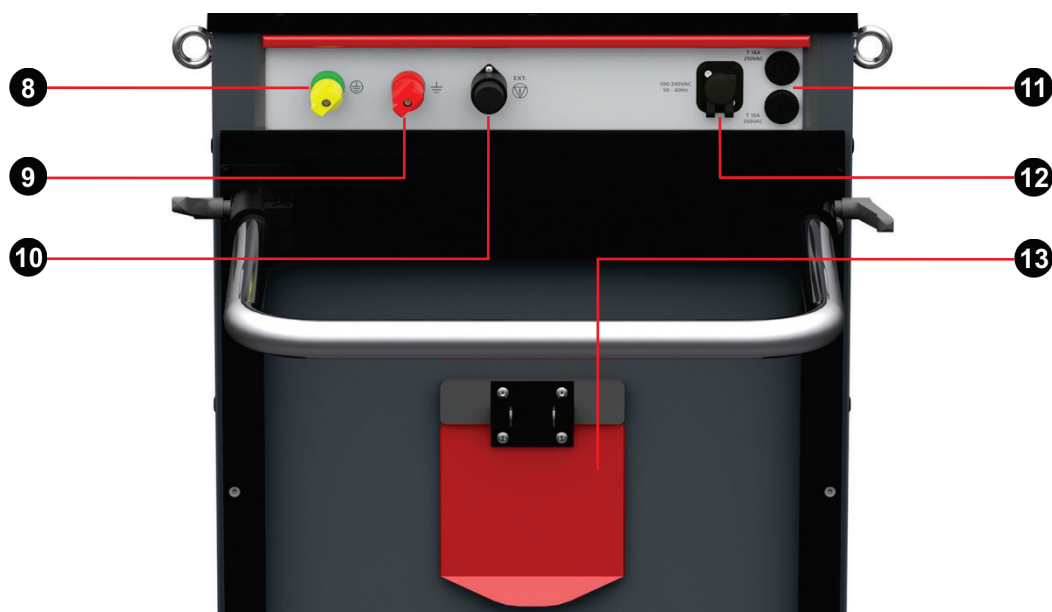
The following operating and display elements are located on the front panel of the STX 40:



Element	Description
1	USB port
2	Emergency stop switch
3	On/off button
4	"HV ON" button
5	Display
6	Rotary encoder with tilt function
7	"HV OFF" button

2.4 Connection elements

The following connection and fuse elements are located on the back of the STX 40:

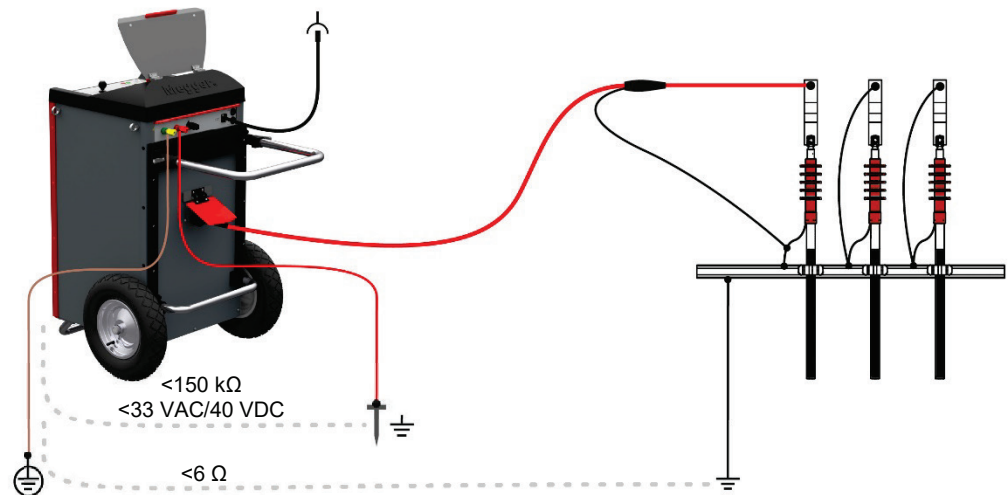


Element	Description
8	Protective earth connection
9	Reference earth connection for FU monitoring
10	Socket for connecting the device key or the external safety device
11	Fuses (2 x T16 A)
12	Mains socket
13	HV output

2.5 Safety devices

FΩ and FU monitoring In order to ensure sufficient earthing, the resistance between the operating and protective earth is continuously monitored during operation (FΩ monitoring). This must not exceed 6 Ω.

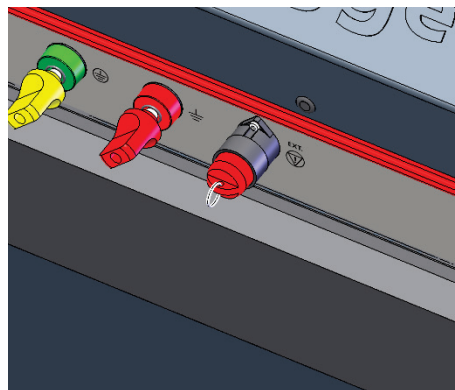
In parallel, the FU safety device checks that the voltage difference between the device and earth (reference earth) does not exceed 33 VDC or 40 VDC in order to protect the operator from step voltage potentials.



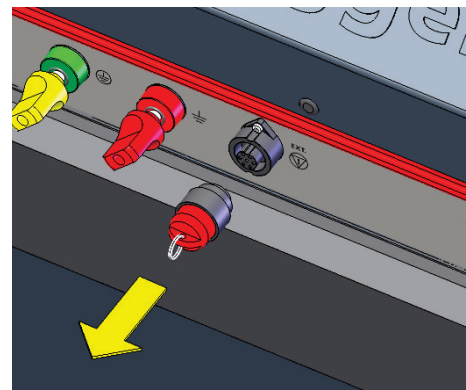
If one of the two protective devices detects that the specified limit values have been exceeded, any high-voltage operation is immediately interrupted automatically and the test object is discharged via a discharge resistor. It is only possible to switch on the high voltage again after the earthing conditions have been improved and the measured values are within the tolerance levels.

Device key For reasons of liability, it must be ensured that measuring devices that emit a hazardous voltage are secured against unauthorised access. For the STX 40, this is done by means of the device key, which must be screwed onto the socket 10 at the rear of the device in order to activate high voltage.

In the event that the device must be left unsupervised for a period of time, this key must be removed and carried by the person responsible for the device.



High voltage preparation possible



High voltage preparation locked

2.6 Operation in vehicle

The device can also be operated in or on a vehicle if the following requirements are met:

- The vehicle chassis must be connected to the protective earth connection **8** of the device with the lowest possible contact resistance.
- Both earth connections **8** and **9** must be connected to suitable connection points outside the vehicle (see page 19).
- The high-voltage output **13** must be connected directly to the object under test using a HV connection cable provided by Megger with a length of at least 25 m. Connection via a patch panel is not permitted.
- If several individual devices are transported in or on the vehicle, only operation outside the vehicle is permitted for safety and liability reasons!

3 Commissioning



WARNING

General safety instructions for set-up and commissioning

- The safety guidelines for the operation of mobile testing systems often differ from one network operator to another and are frequently subject to national regulations (such as the German BGI 5191). Before the measurement session, find out what the applicable guidelines are and follow the rules set out therein precisely, in respect of the organisation of work and the commissioning of the mobile test system.
- Select a location that is sufficient for the weight and size of the system and which ensures that it stands securely.
- The device may only be operated in upright position!
- When setting up or connecting the device, make sure that it does not impair the functional capability of any other systems or components. If other systems and components have to be modified, be sure to reverse these measures once the work has been completed. Always take the special requirements of these systems and components into account and only carry out work on them after consulting and obtaining approval from whoever is in charge of them.
- In the event of large differences in temperature between the storage and installation locations (cold to warm) condensation may form on components carrying high voltage (condensation effect). To avoid any risk of damage to people and devices caused by voltage flash-overs, the system must not be operated when in this condition. It should rather be left in the new environment to acclimatise for approximately one hour before putting it into operation.

3.1 Electrical connection

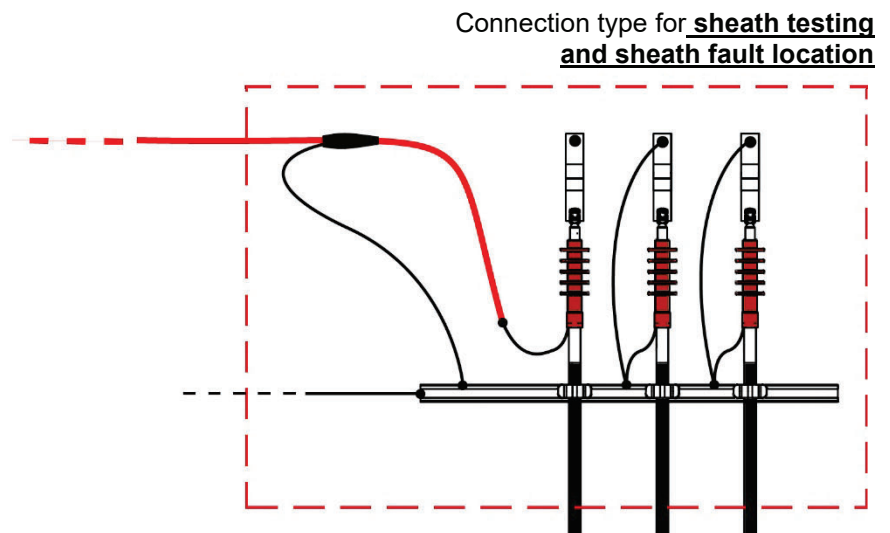
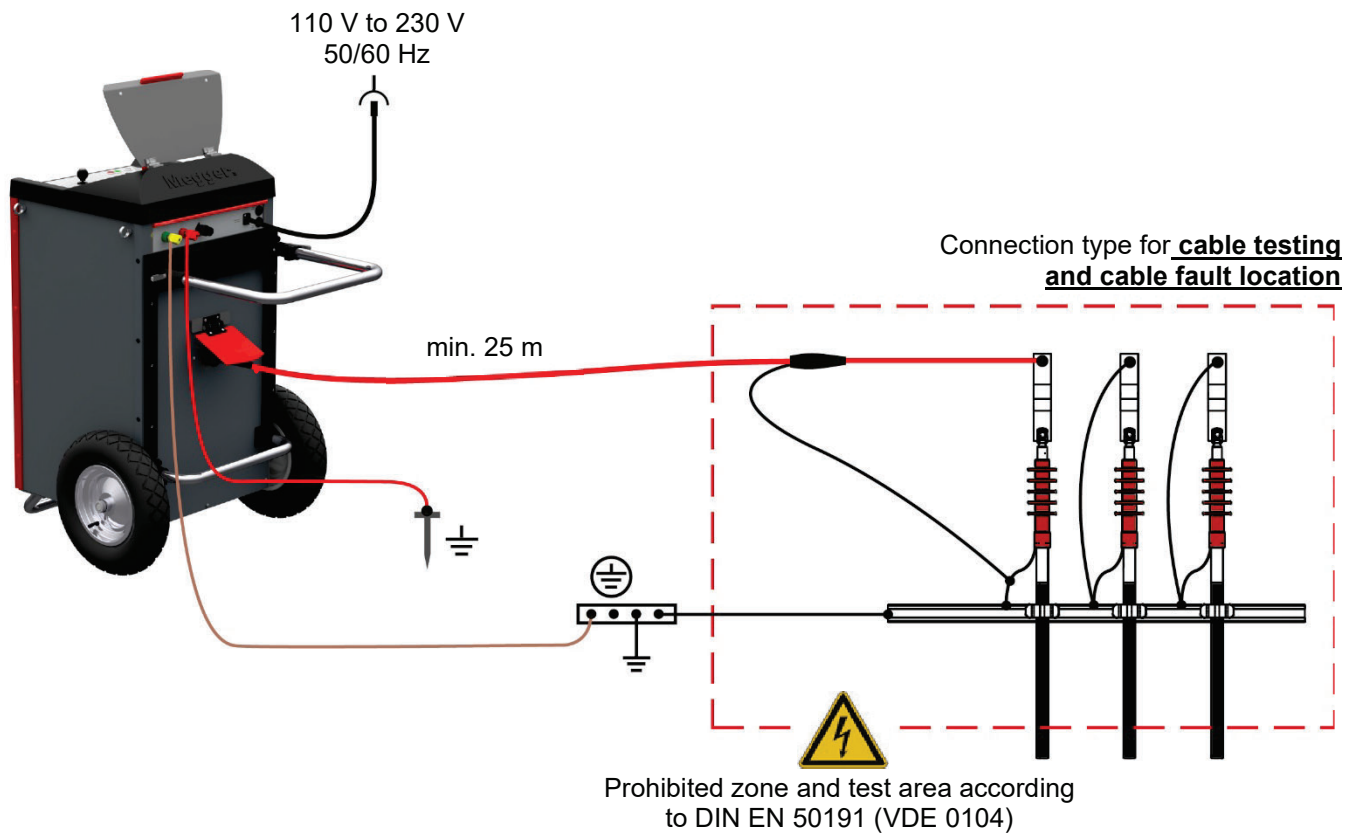


WARNING

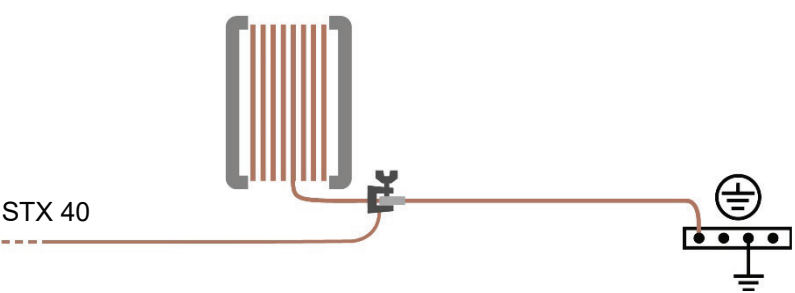
Safety instructions for the electrical connection

- The system may only be connected to **de-energized** equipment. The general safety instructions and, in particular, the five safety rules (see page 7) must always be followed prior to connection to the test object.
- Follow the specified connection sequence.
- All the cables at the measuring point that are out of operation and are not to be tested must be shorted and earthed.
- Because the amount of voltage applied to the test object poses a danger in the event of contact, the prohibition zone around live parts as defined in DIN EN 50191 (VDE 0104) must be protected in a way that it cannot be breached.
- The ends of the cables must be shielded to ensure that contact is not possible. When doing so, be sure to take all branches of the cables into account.
- The device should never be operated without the earth lead being connected. The earth lead establishes the connection between the device and protective earth and ensures that the device is touch-proof. Earthing provided through the earth contact of the mains connection or an earth spike is not sufficient. An earthing tester can be used to check the protective earthing. Unless reliable earthing can be guaranteed, the entire measurement setup must be considered live. In this case, follow the instructions of the sections related to live working in EN 50110-1. When working under these operating conditions, insulating protective gloves of class 1 (or higher) according to EN 60903 must be worn!

Connection diagram The following figure shows the simplified connection diagram of the fault location system:



Procedure To connect the STX 40 to the test object, proceed as follows:

Step	Action
1	Connect the device's protective earth connection 8 to a suitable point on the protective earth system (station earth or other suitable foundation earth electrodes). If necessary, the 5-meter earthing cable can be extended using the earthing cable drum.  Ensure that the connection points of the earth cable are not dirty or rusted and provide good metallic contact.
2	Insert the supplied earth probe into the ground as close as possible to the device and connect the earth probe to the auxiliary earth connection via the red reference earth wire 9. The direct connection between the measuring system and the surrounding ground (reference earth) is essential for functioning earth monitoring (FU) and safe measuring operation (see page 16). Even in heavily built-up areas where it is difficult to insert the earth spike, the protective devices of the system must not be bridged or neutralized! The following measures can help to establish a low-impedance earth connection: • Use the gaps between concrete slabs to establish good earth contact with the earth spike. • Use water to moisten the location where the earth spike has been inserted. • Connect the reference earth wire to a foundation earth (e.g. a lightning protection system). Do not use the same foundation earth to which you have already connected the main earthing cable.
3	Insert the HV connection cable plug into the HV output 13 and tighten the union nut until hand-tight. NOTICE Risk of damage to the device only HV connection cables provided by Megger with a length of at least 25 m may be used for the connection!

Step	Action	
4	If you want to perform a <u>cable test</u> or a <u>cable fault location</u> , ...	If you want to perform a <u>sheath test</u> or <u>sheath fault location</u> , ...
	... connect the shield of the HV connection cable to the earthed shield of the test object (system earth). Connect the internal conductor of the HV connection cable to the phase conductor of the test object.	... connect the shield of the HV connection cable to the earth rail of the cable system to be tested (system earth). Connect the internal conductor of the HV connection cable to the shield of the test object. The earthing of the shield must be removed at both ends of the cable.
5	Connect the supplied power cord to the system's power receptacle 12 and to a power socket.	

3.1.1 Use of an external safety device (optional)

Purpose With the aid of an external safety device, the current status of the system can be made clearly visible with coloured signal lamps (in accordance with EN 50191) and the generation of HV can be interrupted or locked with an EMERGENCY OFF switch and key switch.

Connection To be able to connect the external safety device, first unscrew the device key from the socket 10 and then connect the connection cable of the external safety device to exactly this socket. The locking function of the device key (see page 16) is now taken over by the “HV interlock” key switch on the external safety device.

Description The following figure shows the optional external safety device:

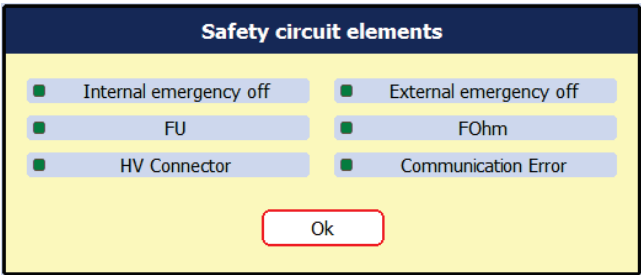


Part	Description
①	Green signal light Lights up when the system is switched on but is not in high voltage operation.
②	Red signal light Lights up as soon as high voltage can be generated. All discharge and earthing devices are open and the test object must be treated as live.
③	“HV interlock” key switch  High voltage unlocked  High voltage locked In the locked state, the key can be removed and the system can thus be protected against unauthorised high-voltage operation.
④	EMERGENCY OFF switch

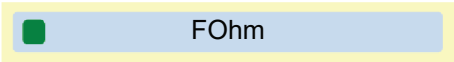
3.2 Switch on

Switch on Switch on the device by briefly pressing the on/off button **4**. The software starts within a few seconds and pauses at the main menu after starting.

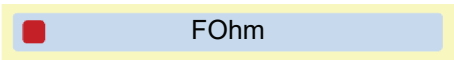
Indication of possible problems Various safety and monitoring devices are activated from the moment of switching on. Problems detected in the safety circuit or the system components are indicated immediately on the user interface and prevent the operating mode from being started or the high voltage from being enabled, depending on the severity of the problem.



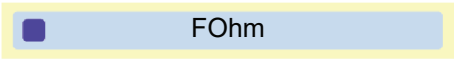
In order to close the dialog and proceed with the actual measuring operation, all signaled problems must first be solved. The status of the respective elements can be read from the color of the status icon:



The conditions of this safety circuit element are met and no action is required.



For this safety circuit element, deviations from the conditions required for operation were detected. Use the information in the table below to solve the problem.



A problem was signaled for this safety circuit element, but it no longer exists. Thanks to this special status, the operator can still identify the element triggering the safety message even if the problem only occurred briefly.

Depending on the problem description displayed, the following actions must be taken:

System reports...	Cause/remedy
actuated emergency off switch	One of the emergency stop switches (on the device itself or on the external safety device) has been activated and must first be reset.
actuated external emergency off switch	One of the following events has occurred: - Neither the device key nor an external safety device is connected to the socket 10. - The emergency stop switch on the external safety device has been activated - The "HV interlock" switch on the external safety device has been locked
FΩ monitoring: - earth resistance too high - cable shield not connected FU monitoring: - potential increase - fault voltage - dangerous voltage-time area	Impermissible earth resistances or voltage peaks were measured, which indicate poor earthing conditions. It must be checked that the following connections have been made correctly and provide good earth contact: - Earth cable - Reference earth connection - Cable shield of the HV connection cable  Never fail to use safety equipment or put it out of operation.
high voltage connectors not connected correctly	The connector of the HV connection cable is not fixed firmly enough into the high voltage output. The connector must engage noticeably when it is inserted.
an internal communication error	An error occurred during communication between the modules within the STX 40. The system should be restarted. If the fault cannot be cleared or occurs repeatedly, an authorised service center must be informed.

3.3 High-voltage control

Release high voltage Immediately after a measurement has been prepared and started by the operator, the green illuminated "HV ON" button 8 indicates the readiness for high voltage release. By pressing the button, the earthing at the HV output is cancelled. This switching state means: **High Voltage!**

Switch off high voltage If certain events occur (e.g. voltage breakdown in the test object, expiry of the defined test duration), the high voltage is automatically deactivated by the system. This also occurs if a problem has been detected in the safety circuit (see above).

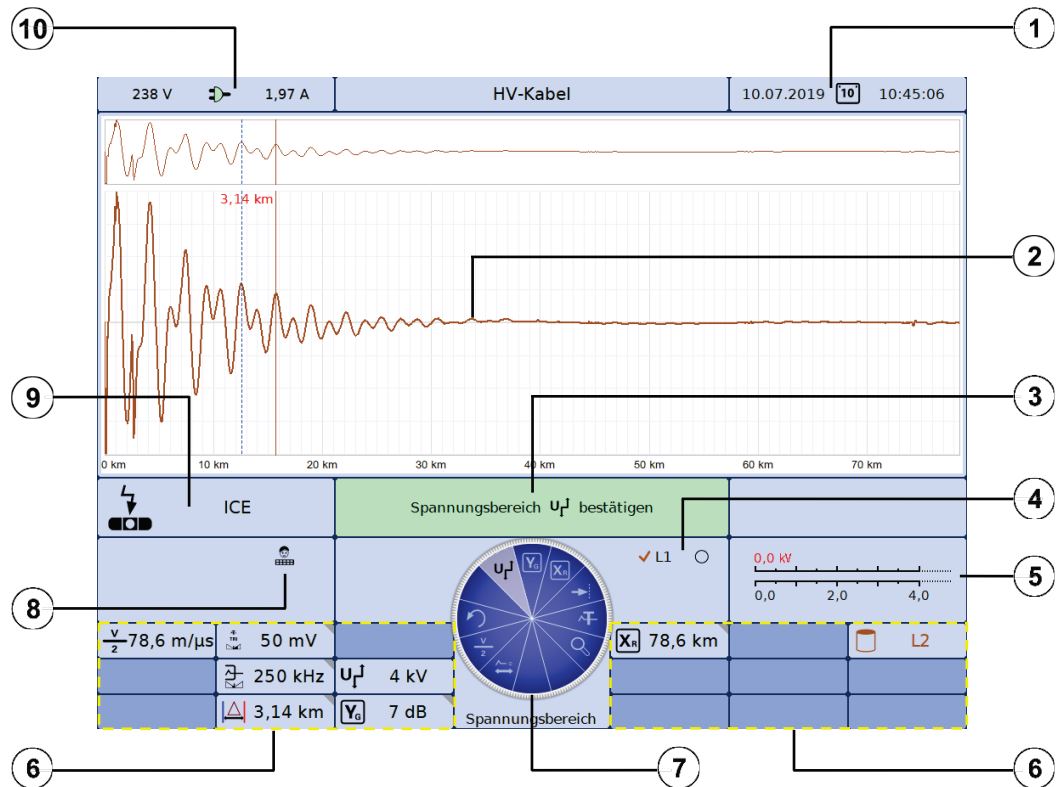
By pressing the red illuminated "HV OFF" button 7, HV operation can also be interrupted manually at any time.

The test object is discharged via the internal discharge resistor both during automatic and manual shutdown.

4 Operation

4.1 Screen layout

The following figure shows the typical screen layout:

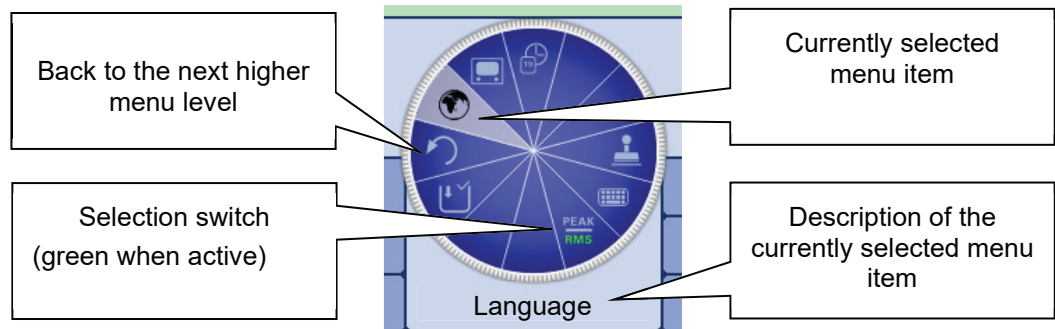


Segment	Description
①	Date and time
②	Curves of current measurement or loaded measurements. The display is split up into a general overview (top) and in an enlarged section (bottom).
③	Current status messages and information on the next step required in the test sequence.
④	Information on the states of the high voltage outputs. The symbols indicate the following states:  High voltage generation is switched off and the HV output on the STX 40 is discharged and connected to earth through a resistor.  The resistor discharge is not effective. High voltage is active!

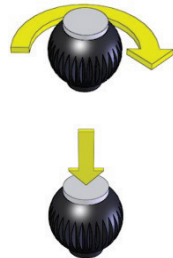
Segment	Description
⑤	Voltage display bar graph Blue bar: Set value Red bar: Actual value
⑥	The display elements arranged in the lower area of the screen may contain the following information: • Set measurement parameters • Current measurement values, which are continuously updated as the measurement progresses • Legend of traces currently shown in display (see page 32). Information (such as, e.g. measurement values) which apply for a particular trace only, is shown in the respective colour.
⑦	Selection menu (see page 28)
⑧	Current system state — The system is currently in standby.  Pulse reflection measurement currently under way.  The measurement was stopped and the traces frozen.  The device is in measurement operational readiness and waiting to be triggered.  The user operating the system has successfully logged into the administration menu (see page 39) and identified himself / herself as administrator.
⑨	Current operating mode
⑩	Current input voltage

4.2 Basics of control system

Selection menu Navigation within the menus is effected almost entirely from the circular selection menu:

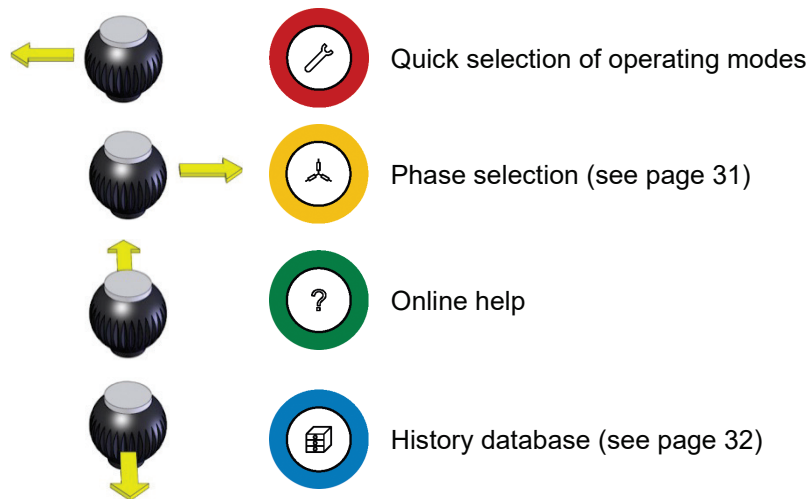


Operation with rotary encoder The system can be operated using the rotary encoder **6** as follows:



- Select the required menu item
- Increase or decrease the value of a variable parameter
- Select an option from a selection list
- Call up the selected menu item
- Confirm the setting or the selection made

The four side menus are accessed by tilting the rotary encoder

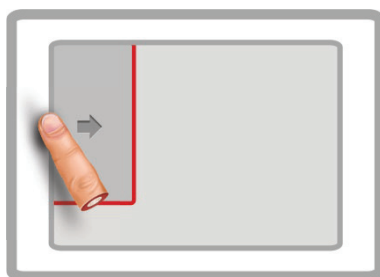


Operation using the touchscreen As the device is equipped with a touch-sensitive display, the software can also be operated just by using your fingers.

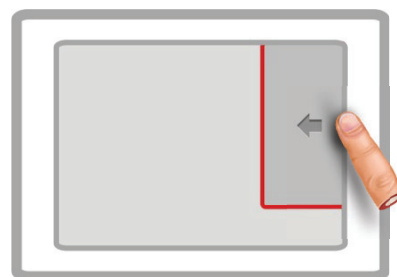
Briefly tapping on the buttons in the various menus, and tapping and holding the buttons in isolated cases, allows the respective functions to be activated in the same way as the rotary encoder control.



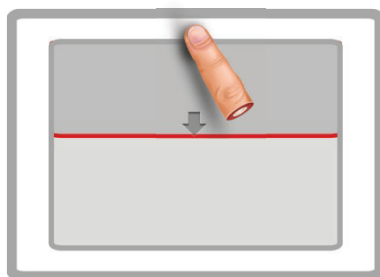
The four menus at the side can be opened by a swiping motion.



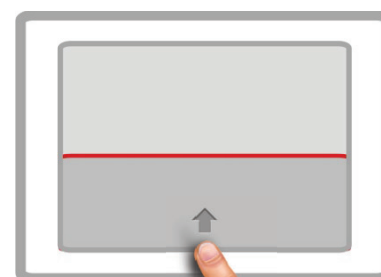
Quick selection of operating modes



Phase selection (see page 31)

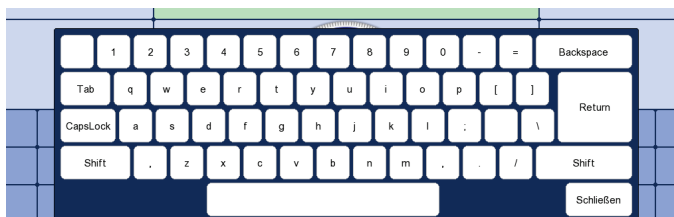


Online help

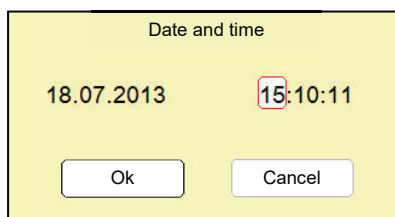


History database (see page 32)

Whenever character strings need to be entered or changed, an on-screen keyboard appears at the lower edge of the display:



Dialog boxes A few settings, which require values to be entered, are not made directly using the Selection menu, but rather in a separate dialog box.

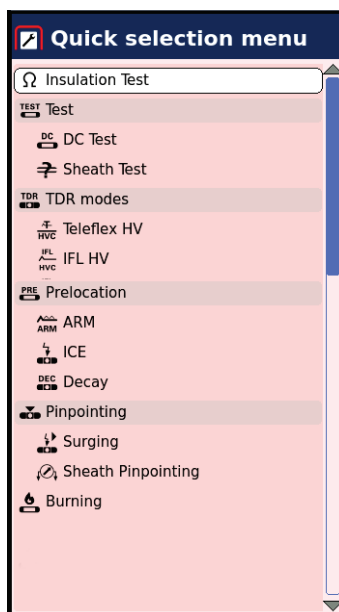


By tilting the rotary encoder **6** to the side the user can switch back and forth between the individual buttons in a dialog box. Each active button is then highlighted in white or it is surrounded by a red frame. Whenever the selected button requires letters or digits to be entered the screen keyboard automatically appears, and it can then be used to make the entries.

To close a dialog box, the corresponding button must be selected and then the rotary encoder pressed.

4.3 Quick selection of operating modes –

Tilting the rotary encoder **6** towards the symbol  enables the quick selection menu to be called up at any given time (and to close it again). The menu provides direct access to all available operating modes.

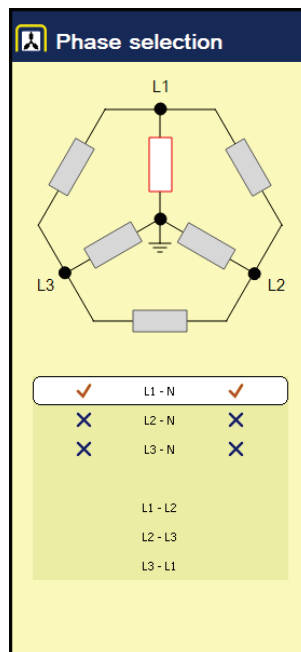


4.4 On-line help –

Tilting the rotary encoder **6** towards the symbol  enables the compact on-line help menu with its basic operating information to be called up at any given time.

4.5 Phase selection –

Tilting the rotary encoder **6** towards the symbol  enables the phase selection which can be opened and adjusted till the actual measurement is started.



Selecting the phases The desired phase can be marked for selection by turning the rotary encoder and then selected or deselected by pressing it.



Option is active



Option is not active

Only one option can be selected at a time.

Confirming the phase selection Only once a valid selection has been made can the phase selection menu be closed and the phase selection be confirmed by tilting the rotary encoder towards the symbol . Up to the time at which the operating mode starts, the phase selection menu can be called up again and a change can then be made to the selection.



Make sure that the phase selection matches the actual connection situation! Otherwise, the measuring data will be stored with incorrect phase details whereupon the data will not be able to be correctly assigned afterwards.

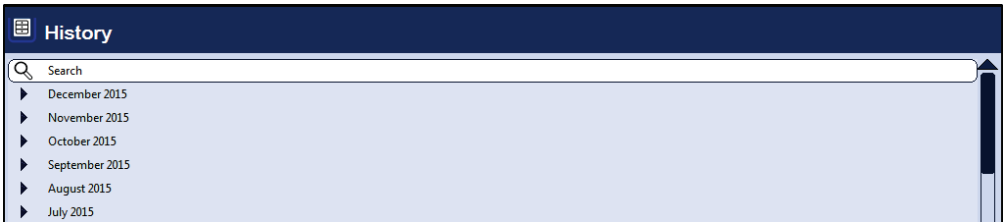
4.6 History database -

Purpose Each conducted measurement is temporarily stored in the History database and it can be retrieved from there again. This enables the user to access old traces and to compare them with the current traces. The parameters under which the measurement was conducted are also shown.

In addition to the individual measurements, the measurement logs created using the log function are also archived in the History database.

Searching in the History database Tilting the rotary encoder  towards the symbol  enables the database to be opened at any given time.

The measurement data records are organised by date in sub-directories.

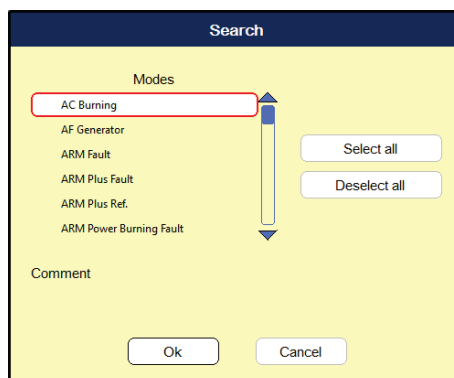


After the desired month and then the desired day have been selected, the measurement data records registered on this days can be searched through and retrieved.

Date and time of measurement		Operating mode		Measurement parameters and results	
   	2017/06/06 02:22:41	Teleflex-IFL LV	L1	2.335 km	
	2017/06/06 02:15:43	 Teleflex LV	L1,L2	2.335 km	
	2017/06/06 02:15:27	Teleflex LV	L1	2 km	comment
	2017/06/06 02:14:36	 Teleflex LV	L1,L2	20 m	
Storage period (see next page)		Tested phases		Comment	

Via the  list entry you can always return to the next directory level up.

Via the  list entry you can reach the search mask using which you can search for particular operating modes and comment entries through the data records of the current directory and all sub-directories.



If you are searching for both an operating mode and comment entry at the same time, only those results which fulfil both criteria will be displayed. Holding down the  button will cause the search criteria to be discarded and all the data records to be displayed again.

Storage period The default setting stores the measurement data for 90 days in the history database. The following symbol indicates how long a measurement has already been stored:

Symbol	Description
No symbol	The data record has been conducted within the last 85 days. An automatic deletion is not imminent.
	The data record is at least 86 days old and will be automatically deleted during the next few days.
	The data record is either imported or permanently stored (see page 46). There will be no automatic deletion.

Managing data records In order to delete / export a data record or a complete folder it needs to be selected with the rotary encoder **6** first. Afterwards, the rotary encoder needs to be tilted to the right or the left until the appropriate marking is shown.

Symbol	Description
	The data record or the folder (incl. all data records in it) is marked for deletion.
	The data record or the folder (incl. all data records in it) is marked for export.
	Several data records within the folder have been marked for deletion.
	Several data records within the folder have been marked for export.
	The folder contains both data records marked for deletion and data records marked for export.



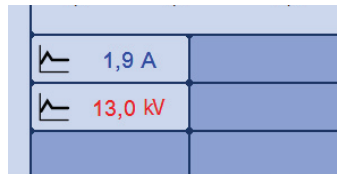
After selection of the measurements the data deletion or export process must be initiated in the data menu (see page 37). Otherwise the markings will expire the next time the device is started up.

Accessing measurement data from the history database

To access curves and data from old measurements, first access the history database and then use the rotary encoder **6** to select the respective measurement from the directory structure. **Briefly pressing** the rotary encoder enables all the curves and measured data for this measurement to be loaded. To this end, the software proceeds as follows:

- If the operating mode currently selected is the same operating mode in which the loaded measurement was recorded in, the accessed curves are shown together with the currently recorded curves. This enables the results of different measuring operations to be easily compared.
- If the current and the loaded measurement are not of the same operating mode, the current measurement is automatically ended and only the loaded measurement is displayed.
- If there are not enough free slots to display the loaded curves, the currently recorded curves are overwritten. To avoid this, it is advisable to select curves from the History database one by one (see below) so that you can assign them individually to slots that are free or no longer needed.

The colour-coded legend on the bottom right edge of the screen provides information relating to the measured values of the curves currently displayed.



Current and loaded curves can be differentiated between using the symbols in front of them.

Symbol	Description
	Curves which were recorded during the measurement in progress.
	Curves which have been accessed from the history database.

By **Holding down** the rotary encoder a context menu can be opened from which the following special functions can be accessed:

- Add / edit a comment for the measurement
- Access special measurement data or only individual traces of this measurement (possible in certain modes only)

4.7 System settings -

The System menu can be access directly through the  menu item when in the main menu, and it contains the following menu items:

Menu item	Description
	Submenu for managing the measurement data (see page 37).
	Basic settings (see page 38)
	Default values can be adapted for nearly all the system settings. If user management (see page 41) is active then each user can define and store his / her own default values. These defaults are then loaded each time the system starts or a user logs in. The submenu contains the following items:  This menu item enables the current settings to be stored as default values. Naturally, only the changes made during this session are taken into consideration.  When saving the default values, note that all values that have been changed since the last system start are saved, which means that you might inadvertently save some changes that you do not want. To be on the safe side, you can first reload the current defaults (see below), make the required settings and then save them.  This menu item can be used by the current user to reload his / her stored default values.  This menu item restores the factory settings.  This menu item enables the default values for the current user to be exported as XML files to the <i>DefaultValues</i> directory of the inserted USB flash drive.  This menu item can be used to import defaults values that are stored on an inserted USB flash drive into the system. The imported values then become immediately applicable. When user management (see page 41) is active, the imported default values are only applicable for the user currently logged on.
	Service menu which can only be accessed by a service technician.
	The administration menu (see page 39) enables a user with the appropriate permissions to access extended system functions.

Menu item	Description
	This submenu enables various settings to be made for scale graduation on the X-axis and for entering the propagation velocity. It provides the following menu items:  Depending on the setting of this switch, the X-axis is either scaled in seconds (runtime) or in length units (distance).  <u>Only available when the X-axis is scaled in length units (see above)</u> This menu item can be used to switch the unit of the X-axis between meters and feet.  <u>Only available when the X-axis is scaled in length units (see above)</u> To achieve reliable distance details, knowledge about the exact signal propagation velocity for the test object is absolutely essential. This can be specified in two different ways: • NVP (Nominal Velocity of Propagation) - The signal propagation velocity is stated relative to the speed of light, e.g. NVP 0.53 = 0.53 x c. • SPEED - The signal propagation velocity is stated with half the actual propagation speed (the cable's so-called V/2). Depending on the above settings, a default propagation velocity value can be defined using the menu items $\frac{V}{2}$ and NVP respectively. This value is then preset whenever a measurement is started.
	Submenu for displaying and exporting important system information.  Information on software version  Information on system hardware and the current IP address  LOG This menu item enables messages stored in the System log to be displayed, and exported to an inserted USB flash drive (<i>SystemLog</i> directory).

4.7.1 Data menu -

The Data menu enables stored measurement data to be imported, exported or deleted. It contains the following menu items:

Menu item	Description
DEL	Menu item to enable measurement data records to be deleted from the History database. The measurements to be deleted must be marked beforehand (see page 32).
 EXP DATA	Menu item that enables measurement data records from the History database to be exported to the inserted USB flash drive (<i>Winkis</i> directory). The data records to be exported must be marked beforehand (see page 32).
 IMP DATA	Menu item to enable measurement data records / logs to be imported. To do so, a window is opened in which the user can navigate through the directories on the plugged-in USB flash drive.
	List of common cable types that can be extended by own cable and insulation types. This eliminates the need to manually enter the propagation speed during cable fault pre-location. Instead, the appropriate cable type can simply be selected from the list and its stored propagation speed automatically applied. Two filters (cable type and cable insulation) can be used to limit the number of cables displayed. Saved cable types can only be edited or deleted with administration rights (see page 39).
 EXP	Menu item to enable the cable list (see above) to be exported to a USB flash drive (<i>Cables</i> directory).

4.7.2 Basic settings -

The following menu items can be used to adapt the software's basic settings:

Menu item	Description
	Sets the language. Select the desired language by turning the rotary encoder and activate by pressing it. The language selection is immediately active.
	Date and time.
	This menu item enables the following functions that influence the measurement sequence to be activated or deactivated:  Activates / deactivates automatic scaling adjustment of the X axis as soon as a trace is recorded.  Activates / deactivates automatic gain adjustment of the Y axis as soon as a trace is recorded.  Activates / deactivates the automatic positioning of the marker on the suspected fault location as soon as a trace is recorded.
	Layout of the on-screen keyboard. This can be switched depending on the language area in which the system is used.
	This menu item enables the currently logged-on system user to be changed. Once a new user has been selected, the new user's default settings are then loaded. The menu item is only available if at least one user exists in the database. The administrator can manage user accounts in the administration menu (see page 39).

4.7.3 Administration menu - (administration password required)

Purpose The administration menu is password-protected and provides access to advanced system settings such as the user administration, as well as update and backup functions.

The software's menu structure has concealed menu items added to it when administration rights are issued. These enabled functions, which are only rarely used during day-to-day operation of the device, are described in greater detail throughout the course of the manual.

Access To open the administration menu, you must first enter the password. Proceed as follows:

Step	Action
1	Select menu item  , to access the Control Panel and then select menu item  .
2	Select menu item  . Result: The password entry dialogue appears in the display.
3	Enter the password and confirm your entry with OK . Result: If you entered the password correctly, the menu items of the administration menu appear (see below). If your entry is incorrect, you must repeat the procedure from Step 2 .

Menu items The Administration menu offers the following menu items:

Menu item	Description
	Software update (see next page).
	Various system data (such as the log file and the configuration file) can be exported to the inserted USB flash drive via this menu item. The directory name consists of the system serial number and a sequential number. These data can provide important information about the cause of the problem when servicing and should be made available to service personnel on request.
	The database can be completely emptied via this menu item, i.e. all measurement results, users, cable types and system logs are deleted. However, calibration and configuration data are retained. Once the function has been called up, the system must be switched off and then on again. After the restart, the database reset must be confirmed once again.
	Menu item used to manage the users accounts (see page 41) of the system.
	Menu item to activate/deactivate the connection lead calibration mode (see page 42).
	Menu item used to disable administrator rights and to protect the administration menu with a password again.

4.7.3.1 Updating the software - $\frac{UP}{DATE}$

Proceed as follows to update the software:

Step	Action
1	Download the latest software from the Megger website.
2	Unpack the update package into the root directory of a USB flash drive.
3	Insert the USB flash drive into the USB port.
4	Call up the $\frac{UP}{DATE}$ menu item in the Administration menu. Result: A selection dialogue appears.
5	Select the option System Software (RPM/DEBIAN package) . The option Single file (file selection) enables the import of individual files, but should only be used in the event of an error and after consultation with a service employee.
6	Start the update via OK and confirm the following message. Result: The system / unit switches off.
7	Switch the system / unit on again. Result: During the boot process, the update package on the inserted USB stick is recognised and automatically installed. Do not switch off the system / device during the update!

4.7.3.2 User administration -

User administration allows you to set up various user accounts on the system, so that each user can adjust the default values and the way the system behaves according to his own preferences.

Menu item	Description
	A new user can only be created if a user name is entered. You can also limit the maximum voltage that the user can adjust and protect the account with a password. If you do not specify a password, the user does not need to enter a password when logging in, which makes the procedure quicker. The default values for the new user are the same as the factory settings. If necessary, you can import (see page 35) the default values from another user account (or even another system).
	This menu item can be used to edit the name, voltage range and password of a user.
	This menu item can be used to delete individual users from the user database. If the last user has been deleted, the user management is deactivated and there is no longer a login procedure when the system is started.  You can only delete the last user by interrupting the login. When deleting a user, his default values are lost. Therefore – particularly for the last user – you should export the default values beforehand (see page 35) beforehand.
	This menu item allows you to export a selection of user profiles from the system together with the respective standard values as an XML file to the inserted USB flash drive's <i>User</i> directory.
	This menu item can be used to import user profiles that are stored on an inserted USB flash drive into the system. This does not affect existing users. If two user names are the same, the system asks whether you want to overwrite or keep the existing user in the system.

4.7.3.3 Connection Cable Calibration -

Purpose A properly calibrated connection cable ensures the accuracy of all operating modes which function according to the TDR principle (Teleflex, IFL, ARM). The length of the connection cable is not only automatically hidden from the visible diagram area, but also automatically subtracted from the calculated distance specifications.

As a principle, a calibration was already performed using the connection cable supplied during the final test. A repeat calibration should only be performed when the connection cable was replaced with a cable with a different length. In this case, an individual calibration must be performed Teleflex mode.

Procedure To calibrate a pre-measuring cable, proceed as follows:

Step	Action
1	Activate calibration mode using the menu item  in the administration menu.
2	Select the menu item  from the TDR submenu in order to start the operating mode.
3	Choose any phase.
4	Perform a measurement with the end of the connection cable open.
5	Exit the operating mode and then open it again immediately. Select the same phase as in Step 3 .
6	Open the trace recorded in the history database beforehand (see page 32).
7	Short circuit the connection cable at its end, and perform another measurement.
8	Select the menu item  and move the red cursor exactly to the point at which both traces diverge. Then press the rotary encoder and keep pressing it until the new zero position is applied.
9	Deactivate calibration mode using the menu item  in the administration menu.

5 Performing measurements

5.1 Good to know ...

5.1.1 Propagation velocity

Introduction To enable the exact distance between the start of the cable and the fault position to be calculated, the TDR must be aware of the propagation velocity in the cable. This velocity depends on several physical variables in the cable: insulation material and thickness, cable diameter, etc.

If the setting for the propagation velocity value is out by 2%, then the measurement result will also be out by 2%.

Determining unknown propagation velocity If the correct physical length of the cable under test is known, the propagation velocity can be measured. To do so, perform a pulse reflection measurement, and make sure that the end cursor is positioned exactly on the identified end of the cable. The propagation velocity is then continuously altered until the actual cable length is displayed. The propagation velocity should then be noted down for future measurements.

If the length of the cable under test is unknown because of elbows, reserves, etc., then a piece of the same cable can be measured in the workshop and the determined propagation velocity used for the cable out in the field. A reference cable such as this however, should be at least 50 metres in length.

5.1.2 Pulse width

Due the attenuation and dispersion characteristics of a cable, signals get changed in amplitude and shape as runtime progresses. Naturally, this also applies to the measuring pulse and its reflections.

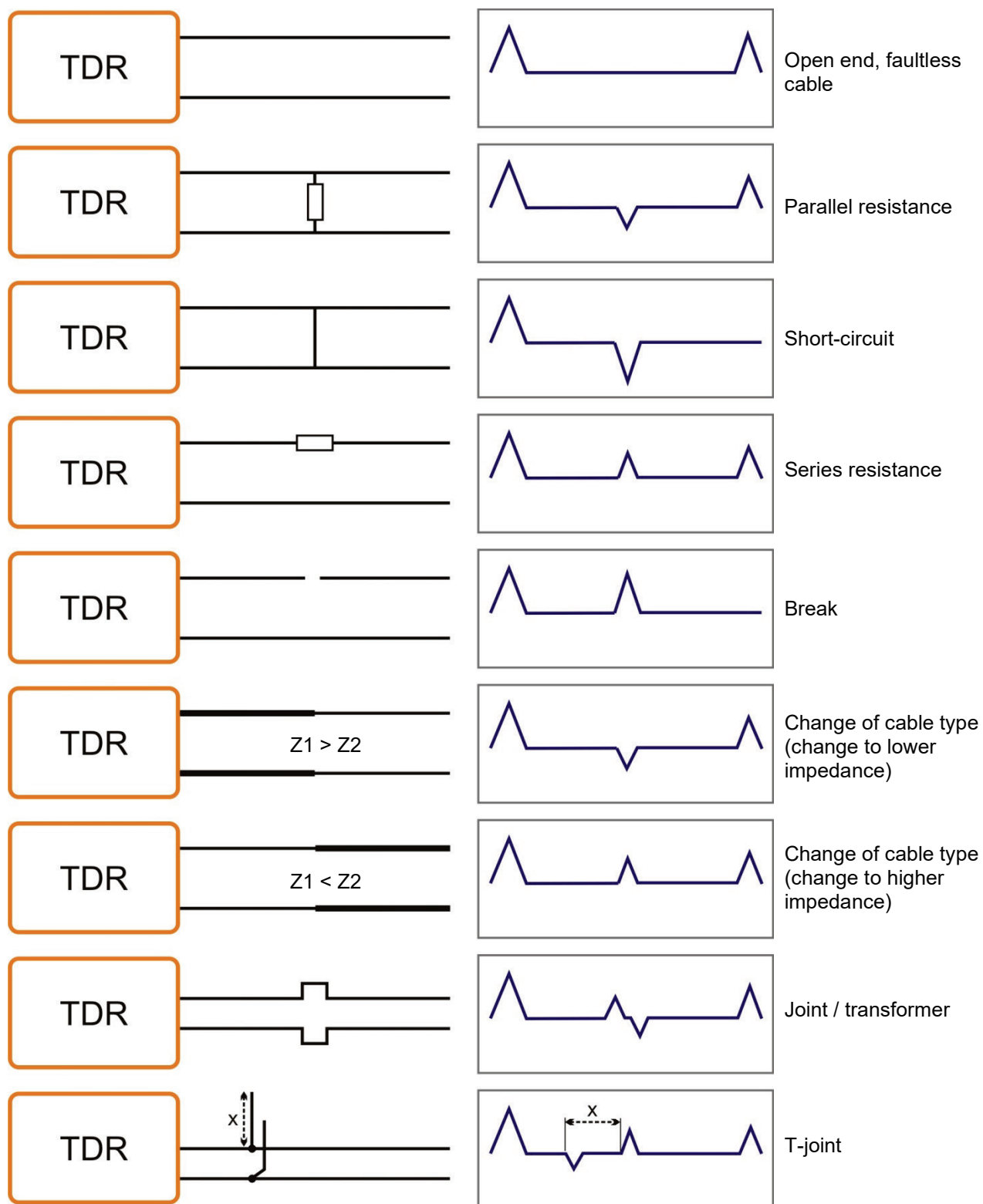
Narrow pulses, which contain a large portion of high frequencies, are subject to greater deformation than wide pulses. Consequently, narrow pulses are more suited for shorter ranges in which they can provide an image with higher resolution than wide pulses, whereas over larger distances they suffer from greater attenuation and dispersion. Here, wide pulses (up to 10 μ s) must be used, as they are subject to significantly lower attenuation and therefore they supply a much clearer echo over longer distances.

The following table provides an overview of the pulse widths recommended for each required distance range:

Required distance range	Recommended pulse width
<100 m	20 ns
100 m ... 200 m	100 ns
200 m ... 1 km	200 ns
1 km ... 2.5 km	500 ns
2.5 km ... 10 km	1 μ s
10 km ... 30 km	2 μ s
30 km ... 80 km	5 μ s
>80 km	10 μ s

5.1.3 Typical TDR reflectograms

The following illustration shows several idealised examples for TDR reflectograms:



5.2 Standard functions

Generally available functions For all operating modes in which measured data are recorded and displayed, the following standard functions are available in the respective measurement menu:

Menu item	Description
	This menu item can be used to move the cursor along the X axis. The current, voltage, time or distance values of the currently marked position are displayed in the bottom part of the screen.
	This menu item can be used to increase or reduce the visual range on the X-axis. The section aligns itself with the current cursor position here.
M	This menu item can be used to access a list of all data records stored in the History database which match the currently active operating mode. Only the permanently stored data records are taken into account here. Using the rotary encoder enables a data record in the list to be selected and then accessed. This way, e.g. a reference trace previously recorded on the same cable can be quickly located and compared with the current trace. Furthermore, the menu item  can be used to store the current measurement permanently in the History database.

Standard functions for pulse reflection measurements Due to the numerous functions, the measurement menus of all operating modes working according to the TDR principle (e.g. Teleflex operating modes, ARM operating modes, ICE and DECAY) feature two additional submenus.

In the actual measurement menu and in the Teleflex menu , all measurement parameters relevant for recording and displaying the curves as well as several additional functions are consolidated. Depending on the operating mode, these menus include a selection of the following menu items:

Menu item	Description
	In all the operating modes in which the measurement has to be triggered (e.g. ARM), the respective trigger threshold can be manually adapted. Normally the trigger threshold is automatically pre-configured to a suitable value. If the measurement should however be interrupted by low voltage reflections which are clearly not induced by the transmitted pulses, then the trigger threshold should be manually increased. If, instead of this, no reflections are displayed at all, then it may be helpful to reduce the threshold.
	This menu item can be used to set the gain. For pulse reflection and ARM measurements, the gain can be set for the received signal. If the setting is good, the reflection for the open cable end can be clearly identified as a positive reflection. In the ICE and DECAY operating modes, any change of the gain setting requires a new fault flash-over to be triggered for the effect to become visible.

Menu item	Description
	This menu item can be used to set the measurement range (X-axis). For pulse reflection and ARM measurements, the end of the cable should be visible as a positive reflection at the right-hand edge of the screen. In the ICE and Decay operating modes, the measurement range should be set to five times - ten times the cable length. Whenever the measurement range is changed, the settings for filter, pulse width, pulse amplitude and de-attenuation are automatically adapted.
	This menu item can be used to move the red cursor along the X-axis. By pressing and holding the rotary encoder a blue mark can be set on the current position of the cursor whereupon the red cursor can then be moved further. In this way, e.g. the real distance between two noticeable positions along the trace can be measured. Depending on the operating mode, the distance (calculated from the runtime) between the two marks is shown in one of the following fields at the lower edge of the screen:  The full distance between the blue mark and the red cursor  Half the distance between the blue mark and the red cursor (in Decay operating mode only).
	This menu item can be used to set the bandpass filter, which limits the frequency range to be measured. Interference signals outside this frequency range are suppressed. The filter value is reset to its default value as soon as one of the following operations has been performed: • change to the operating mode • change to the pulse width • change to the measurement range
$\frac{V}{2}$ NVP	Setting signal propagation velocity (see page 43). The type of entry depends on the system settings (see page 35). The signal propagation velocity can also be adopted directly from one of the cables filed in the Cable database (see page 37). To do so, the menu item must first be called up and then the rotary encoder 6 pressed for at least two seconds.

Menu item	Description
DEL 	This menu item can be used to delete individually no longer required traces from the current display, to make it easier to read the important traces.
	The de-attenuation function enables the attenuation of the electrical pulses in the cable to be counteracted. This is done through amplification of the input signal which increases as the runtime increases, i.e. as distance increases the reflections are further amplified. The amplification increases exponentially up to a fixed maximum amplification. The ideal de-attenuation setting depends on the length of the cable, so the de-attenuation setting is effectively adapted whenever the measuring range is changed.
	This menu item can be used for all types of pulse reflection measurement to set the pulse width (see page 44) for the measurement pulse.
	This menu item can be used to manually set the pulse amplitude if required. For fault positions in close range, it may be helpful to experiment with lower pulse amplitudes. Conversely, higher amplitudes are suited for particularly long cables. With each adaptation of the distance range (X-axis) the pulse amplitude is automatically adjusted by the system to a suitable value.

The trace functions menu which can be activated during a pulse reflection measurement using the menu item  provides diverse options to adapt the arrangement of traces on the screen to meet individual requirements:

Menu item	Description
	This menu item can be used to move trace 1 along the Y-axis.
	This menu item can be used to move trace 2 along the Y-axis.
	This menu item can be used to move trace 3 along the Y-axis.
	This menu item can be used to move all visible traces along the Y-axis.
	This menu item can be used to move the traces mapped on the display further apart from each other along the Y-axis and back in position.  All traces are separated from each other by 50 pixels along the Y-axis.  The traces are moved back into their original position and they are at the same level again.
	This menu item can be used to move all visible traces along the X-axis.
	The difference between trace 1 and 2 is used to calculate and display a new trace. All other traces are hidden here.
	The difference between trace 2 and 3 is used to calculate and display a new trace. All other traces are hidden here.
	The difference between trace 3 and 1 is used to calculate and display a new trace. All other traces are hidden here.
	This menu item can be used to move one of two traces along the X-axis.



Functions which can only be applied to traces 1 to 3 are only available when the respective slots are actually occupied.

Loading a trace from the History database into one of these slots has to be done by calling up the individual trace (see page 32) instead of the complete measurement data record.

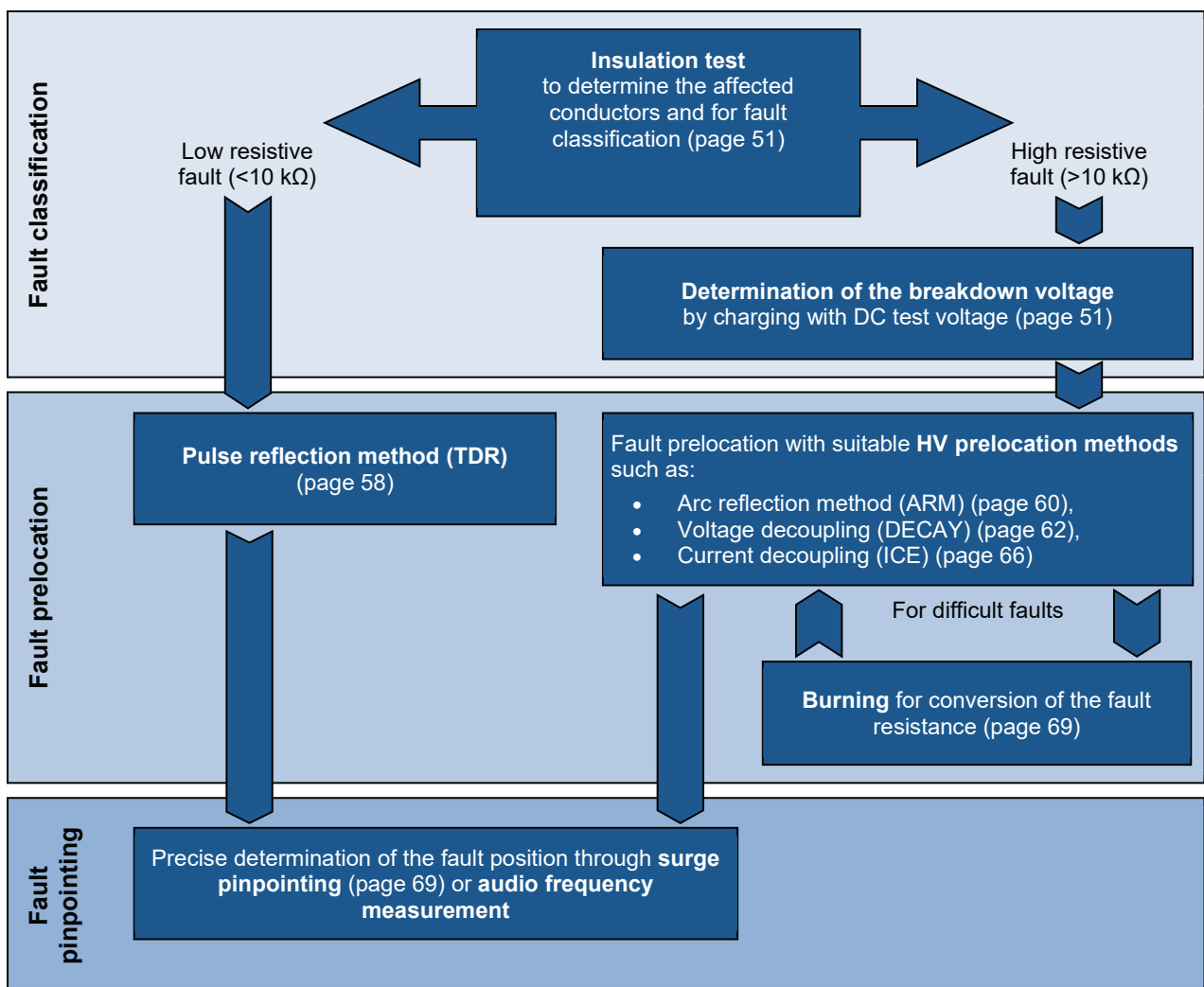
5.3 Systematics of cable fault location

Introduction Daily work with a cable test van is divided into the following two main areas:

- **Condition-oriented maintenance**
Testing, diagnosis and partial discharge measurement
- **Event-oriented maintenance**
Localisation of all types of cable faults

While there are many different concepts of and approaches to condition-based maintenance, the approach described below has established itself in event-oriented cable fault location.

Schema The following schema illustrates the typical approach for detection, classification and location of cable faults using the methods of measurement available in STX 40:



5.4 Insulation test - Ω

Introduction A basic fault classification can often be carried out in advance by measuring the ohmic insulation resistance.

Thus, low- and medium-resistance cable faults can, for example, be directly detected and appropriate follow-up measurements (e.g. Teleflex measurements) can be undertaken.

Even in the event of high-impedance cable faults, conclusions can be drawn about the affected phases based on resistance deviations within a cable system.

It can also be helpful to repeat resistance measurements after application of certain pre-location methods (e.g. ARM, ICE) or fault conversion methods (burning) and to compare the measurement results with those stored in the database.

Call up operating mode and make settings The operating mode can be called up directly from the main menu via the menu item Ω .

The voltage range is queried immediately after entering the operating mode, which limits the maximum voltage that can be set during the insulation test.

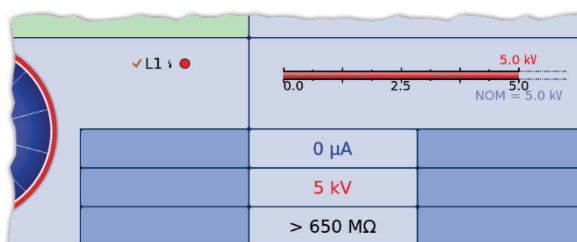
If necessary, the phase selection menu can be called up via  in order to set the testing phase actually connected. The phase selection menu must then be closed via .

Performing the measurement The measurement can be started via the menu item  without any previous settings. The high voltage must then be released via the “HV ON” button and the measuring voltage must be set. For safety reasons, the voltage setting dialogue closes automatically after a few seconds, but can be called up again via the menu item U_{NOM} .

As soon as high voltage is enabled, the “HV OFF” button lights up red signalling “high voltage at the HV output”

The system starts with the voltage conditioning. The voltage can also be adjusted during the measurement via the menu item U_{NOM} .

After the resistance value has been read at the bottom right of the screen, the manual switch-off can be carried out using the “HV OFF” button or the menu item **HV Off**.



5.5 DC voltage test / breakdown detection

Introduction A DC voltage test not only allows the dielectric strength of the connected test object to be checked, but also the breakdown voltage of the fault location to be reliably determined in the event of insulation problems.

Procedure To conduct a DC voltage test perform the following steps:

Step	Action
1	Call up the menu item  from the sub-menu  .
2	Set the voltage range that limits the maximum selectable voltage during the test
3	Open the phase selection menu via  and select the connected testing phase. Then close the menu by clicking  .
4	Use the menu item  to set the test time required.
5	Use the menu item  to specify whether the test voltage should be automatically ramped up to the set test voltage at an increase rate of 5% of the set voltage range per second (Ramp setting) or you want to manually control the test voltage using the rotary encoder  (Manual setting).
6	Start the DC test via the menu item  .
7	Release the high voltage via the "HV ON" button.
8	Use the rotary encoder  to increase the voltage to the required test voltage and confirm the value by pressing the encoder. For safety reasons, the voltage setting dialogue closes automatically after a few seconds, but can be called up again via the  menu item. Result: If the Ramp setting is enabled, the high-voltage source automatically starts charging the cable to the set voltage. Otherwise, the voltage must be manually raised to the desired setpoint. Voltage and current run are shown in the display. If the cable cannot be charged to the set nominal voltage, overcurrent is detected during the test or a voltage breakdown occurs, the test is automatically aborted, the cause of the shutdown or breakdown voltage is displayed and the high voltage is switched off. This also happens after the test time has expired and the test has thus been successfully completed.

5.6 Sheath test and sheath fault detection

Introduction Testing for sheath faults can be performed with a DC voltage of up to 20 kV, which also allows testing on cables with a thicker outer sheath (such as cables with a nominal voltage of 230 kV).

If a voltage leak occurs during a sheath test or if the measured leakage currents indicate a sheath fault, it is possible to start locating the sheath fault immediately after the test.

During peripheral fault detection, DC current pulses are coupled into the earth-faulted shield with an adjustable cycle rate.

With each coupled pulse, the current flowing into the earth around the exit point (fault location in the sheath) forms a voltage drop, the centre of which can be located precisely with the aid of an earth fault detection device and the associated earth probes (step voltage method).

Selecting the operating mode To start a sheath test, the sub-menu of the test modes must be opened via the menu item  and the menu item  must be called up from this menu item.

A peripheral fault location can be started from the sub-menu  via the menu item .

5.6.1 Perform sheath test -

Setting test parameters The voltage range is automatically queried when entering the operating mode, but –, like all other settings, – can still be adjusted until the actual start of the test.

The following test parameters can be set:

Function / menu item	Description
	The phase selection must be made according to the actual connection situation. The phase selection menu must then be closed via .
	The set voltage range limits the maximum voltage that can be set during the test. For this purpose, the following reference values are specified in relevant standards (such as VDE 0276), which may deviate from local specifications or factory standards: - PVC cable ≤ 3 kV - Medium voltage PE cable ≤ 5 kV - High voltage PE cable ≤ 10 kV
	The test duration can be specified within a range of 1 to 60 minutes. In relevant standards (such as VDE 0276), the test duration of a sheath test is indicated at 5 to 10 minutes depending on the cable type.
	This menu item can be used to specify whether the test voltage should be automatically ramped up to the set test voltage at an increase rate of 5% of the set voltage range per second (Ramp setting) or controlled manually using the rotary encoder 6 (Manual setting).

Starting the test Once all settings have been made, the test can be started via the menu item . The high voltage must then be released via the 'HV ON' button and the test voltage must be set.

From the moment of release, the red illuminated 'HV OFF' button indicates 'high voltage at HV output'. The high voltage source starts with the voltage conditioning. The voltage can also be adjusted during the test via the menu item U_{NOM} .

Course of the test During the test, the display area shows the voltage curve and the measured leakage current. The test duration can also be adjusted later when the test is running via the menu item  or reset via the menu item .

In addition to the current and voltage values, some other relevant parameters are displayed at the bottom of the screen:

Symbol	Description
	Remaining test duration
	Set test duration

Completing the test If a test time has been defined, the high voltage is automatically switched off after this time has elapsed. A manual switch-off can be performed at any time using the 'HV OFF' button or the menu item .

During both automatic and manual shut-off, the high voltage output is earthed and the test object discharged via the internal discharge resistor. The measurement data recorded until shutdown are written to the History database (see page 32).

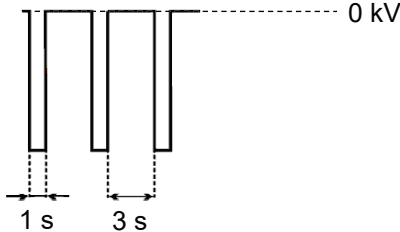
Evaluating the test results If the leakage current values during the test are above the limit values set by the cable owner, the tested cable should be investigated in more detail soon or at least included in a shorter inspection cycle.

5.6.1.1 Pinpointing a sheath fault -

Setting the measurement parameters

The voltage range is automatically queried when entering the operating mode, but –, like all other settings, – can still be adjusted until the actual start of the tracking.

The following measurement parameters can be set:

Function / menu item	Description
	The phase selection must be made according to the actual connection situation. The phase selection menu must then be closed via .
	The set voltage range limits the maximum voltage that can be set during the tracking. For this purpose, the following reference values are specified in relevant standards (such as VDE 0276), which may deviate from local specifications or factory standards: - PVC cable ≤ 3 kV - Medium voltage PE cable ≤ 5 kV - High voltage PE cable ≤ 10 kV
	This menu item can be used to set the cycle rate of the dc pulse in seconds. For example: At a clock rate of 1:3, each 1 second DC pulse is followed by a 3 second pause. 
	This menu item can be used to activate/deactivate the current cycle. If the clock is deactivated, the cable is simply supplied with untimed DC voltage.
	Limiting the maximum current (50 ... 850 mA). If the set value is exceeded, the tracking is automatically cancelled.

Starting the pinpointing After all settings have been made, the pinpointing can be started via the menu item . The high voltage must then be released via the 'HV ON' button and the test voltage must be set.

From the moment of release, the red illuminated 'HV OFF' button indicates 'high voltage at HV output'. The high voltage source starts with the voltage conditioning. The voltage can also be adjusted during the further course of the pinpointing via the menu item U_{NOM} .

Locating the sheath faults After the high voltage has been released and the desired voltage has been set, the fault position can be located precisely with the aid of an earth fault detector (e.g. ESG NT).



For detailed information on the use of the earth fault detector, please refer to the relevant operating instructions.

**WARNING**

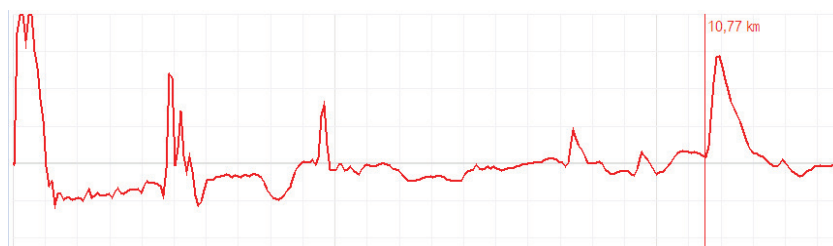
The safety of the system in operation must be ensured permanently by the person responsible for the work in accordance with the applicable safety regulations and guidelines, including during line and fault location.

Stopping the measurement After the fault location has been completed, the high voltage must be switched off manually using the 'HV OFF' button or the menu item **HV Off**. The high voltage output is then earthed and the test object discharged via the internal discharge resistor.

5.7 Pulse reflection measurement (TDR) -

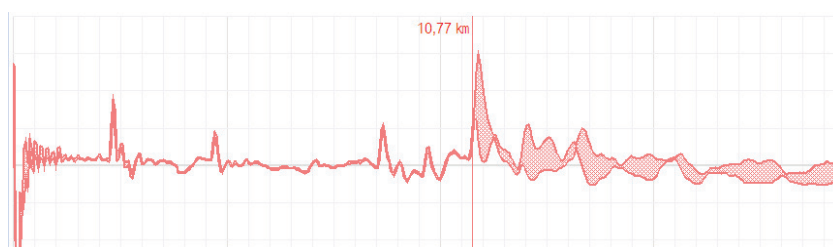
Introduction Low-resistance cable faults can be localised using the tried-and-tested and widely-used pulse reflection measurements. This method is based on the radar principle and makes use of the fact that any sudden deviations in the characteristic impedance of a cable reflect part of the energy transmitted into the cable. The degree of reflection is dependent on the magnitude of the deviation in the characteristic impedance, the number of reflections, the cable length and the distance to the fault position.

The recorded curve shows any deviation in the cable's characteristic impedance. Naturally, this means that not only fault positions, but also other changes in resistance such as, e.g. in joints are also recorded. These recordings can indeed also represent an additional orientation aid for accurate pinpointing of the fault position.



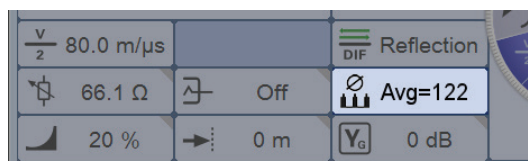
The special IFL operating mode (Intermittent Fault Locating) can be used to localise sporadically (time-variant) occurring low-resistance cable faults (caused, e.g. through traffic vibrations).

To this end, the individual curves in this operating mode are not continuously updated, but rather they form an enveloping curve from all the recorded measurements. In this way, any changes that occur (e.g. temporary fault triggering) during continuous measurements are rendered visible for the user.



Averaging In the operating mode $\frac{F}{HVC}$ the averaging function can be activated or deactivated using the menu item . When averaging is active, the curve shown on the display presents the average of all previously recorded measurements. A maximum of 256 measurements are taken into consideration here. After reaching this figure, the recording stops automatically.

The number of measurements taken into consideration for the averaging function is shown at the bottom area of the display and it is continuously updated.



Performing measurements

Proceed as follows to perform a pulse reflection measurement:

Step	Action
1	In the sub-menu TDR  , call up the menu item $\frac{\Delta}{HVC}$ (normal measurement) or $\frac{IFL}{HVC}$ (IFL measurement with envelope curve).
2	Open the phase selection menu via  and select the two conductors of the test object to which you have connected. Then close the menu by clicking  .
3	Use the Teleflex menu (see page 46) to make appropriate settings for the propagation speed, pulse width, pulse amplitude and filter, and enable the averaging function (see above) if necessary.
4	Start the measurement using the menu item  .
5	Release the voltage conditioning using the 'HV ON' button. Result: Measurement pulses are continuously coupled into the phases involved in the measurement. Depending on the operating mode, the recorded curves are either continuously updated or combined into an envelope curve.
6	Examine the recorded reflectogram for deviations (see page 45) and use the available functions (see page 46) to improve the accuracy and display of the curve, if necessary. In IFL mode, you may try to trigger an intermittent fault by appropriate means.
7	Stop the measurement using the menu item  Result: The measurement is interrupted and the current curve is frozen. If necessary, the measurement can be continued via the menu item  .

5.8 Pre-location of high-resistance cable faults -

In order to perform accurate pinpointing of the cable fault in as small a segment of the cable route as possible, a thorough prelocation procedure should be conducted beforehand. This achieves a significantly shorter total location time while also protecting the cables.

High-resistance cable faults reflect the low voltage pulses of a normal pulse reflection measurement either inadequately or not at all, so that the fault location cannot be identified using the recorded reflectogram. In this event, several other pre-location methods have established themselves, each of which combines a high-voltage process with the pulse reflection method. All these methods force arcing at the fault location through a “breakdown” caused by a sudden discharge of a charged capacitor or by charging the cable. Because the fault assumes the state of a low-resistance cable fault for a short time, its position can be measured beyond this period with a pulse reflection measurement.

The fault position can also be pre-located with sufficient accuracy using the oscillating travelling wave between the fault location and the measurement system that is triggered after the voltage breakdown.

5.8.1 Arc reflection measurement (ARM) -

Introduction The ARM method is suited for the pre-location of high-resistance cable faults on power cables with a total length of up to 10 km. For faults with low ignition voltage (<32 kV), pre-location should be started with this method.

When locating the fault position a reflectogram is taken first under normal conditions (reference trace). The charged surge capacitor is then discharged suddenly into the cable and 32 reflection measurements are carried out in the static arc caused by faulty ignition. The user can then select the most suitable fault pattern from the 32 recorded patterns.

The direct comparison of reference and fault pattern usually makes possible immediate, clear identification of the fault location, because, due to the reflection at the burning arc, the fault pattern displays a significantly negative reflection at the fault location compared to the functional image.

Delay between TDR measuring pulses

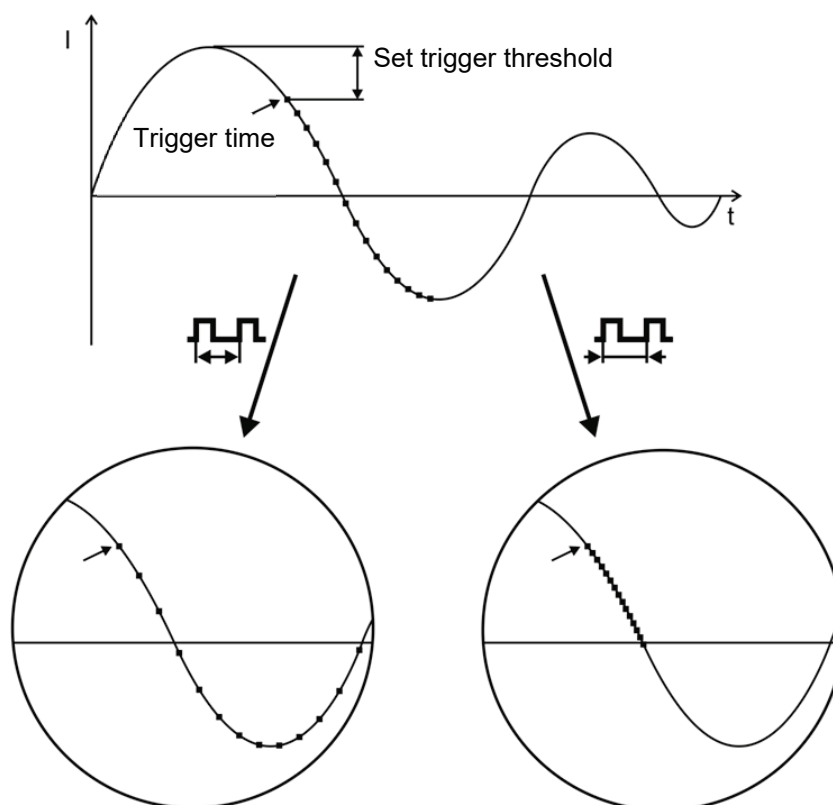
Before recording a fault trace, the user can manually configure the delay between two successive pulses using the menu item . This type of delay however, should not be confused with the trigger delay time (see next page), which only delays the first pulse.

In principle it is advisable to record the first series of fault traces with a default delay of 256 μ s.

If required the delay can be varied to suit between 0 μ s and 3.84 ms and a renewed faulty ignition undertaken.

For a setting of 0 μ s the pulses are triggered as quickly as possible one after the other.

The effect of a delay adjustment is best illustrated in the current curve following a voltage flash-over:



■ Triggering a measuring pulse

As can be clearly seen in the figure, an increase in the delay enables a “wider” period to be mapped, in which the arc - under certain circumstances - is extinguished before igniting again.

Adjusting trigger delay time A user issued with Administration rights (see page 39) can use the menu item  to adjust the delay time between the received trigger signal (configured trigger threshold exceeded) and the actual start of the TDR measurement.

This is intended to give the ignition process at the fault position sufficient time to form a stable arc.

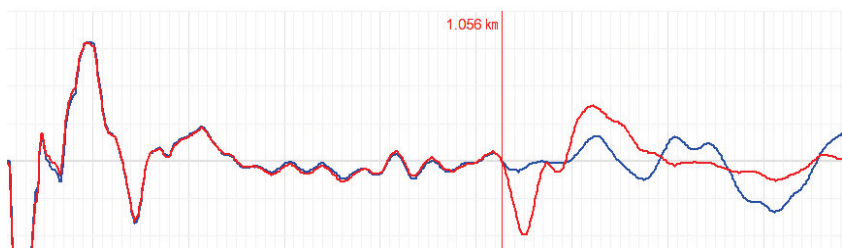
Basically, the delay time is set to an ideal setting at the factory for the system configuration and it should only be adjusted in exceptional cases (in very special measurement layouts) and this should be conducted by experienced users only.

Any improper adjustment to the delay time poses the following risks:

- **Delay time too short:** The arc is unstable and the reflectogram is not representative or it is faulty.
- **Delay time too long:** As the delay time increases the risk of conducting a measurement in the decay curve's zero crossing increases. The ignition procedures repeated at this point in time can falsify the reflectogram. If the delay time is excessively high there is also a risk that the arc may already be completely extinguished.

Procedure To locate a cable fault using the ARM method, perform the following steps:

Step	Action
1	Connect the STX 40 to the faulty phase of the test object.
2	Call up the menu item  from the sub-menu  .
3	Set the voltage range to a few kV above the detected ignition voltage in order to select the lowest possible voltage level and thus ensure the highest possible shock energy. For non-chargeable cable faults, you should increase up to the fault ignition voltage in multiple iterations.
4	Open the phase selection menu via  and select the connected phase of the test object. Then close the menu by clicking  .
5	Use the Teleflex menu (see page 46) to make appropriate settings for propagation speed, pulse width, pulse amplitude and filter.
6	Start recording the reference trace using the menu item  .
7	Enable the high voltage using the "HV ON" button. Result: Following a brief calibration procedure the reference trace is shown on the display.

Step	Action
8	Check that the recorded curve, and in particular the marked cable end, match the expected result. If necessary, use the available functions (see page 46) to improve the accuracy and display of the low voltage trace and repeat the recording via the menu item .
9	Prepare the system for fault trace recording using the menu item $\frac{\text{REF}}{\text{FAU}}$.
10	Set the surge voltage while taking into account the required ignition voltage and then trigger the surge discharge via the menu item $\frac{\text{REF}}{\text{FAU}}$. Result: If a voltage flash-over occurs at the fault position, a red (fault) curve is shown on the display. If triggering failed to occur, and therefore a fault trace could not be made, it may then be necessary to adjust the trigger threshold or the surge voltage before triggering a further surge.
11	Turn the rotary encoder to select one of the 32 recorded curves and confirm your selection by pressing it briefly. The selected curve can be changed using the menu item  up until the next measurement is started or the operating mode is changed. Result: The red marking is automatically positioned at the location identified as the fault position (at which the two curves diverge). 
12	If necessary, use the available functions (see page 46) to optimise the curve display (filter, amplification) and re-adjust the marked fault position. Then read off the fault distance.
13	Switch off the high voltage using the menu item $\frac{\text{HV}}{\text{OFF}}$.

5.8.2 Voltage decoupling (DECAY) -

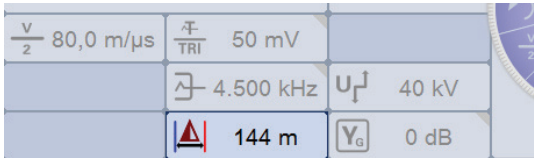
Introduction The decay method is used to pre-locate high-resistance cable faults using a high fault ignition voltage in rechargeable cables.

To this end, the cable is charged with a DC voltage until the voltage exceeds the fault's breakdown voltage. The energy stored in the cable capacitance discharges through the fault and generates a travelling wave, which is recorded and displayed by the system as an attenuated oscillation. The period of this oscillation can be used along with the following formula to determine the actual fault distance:

$$\text{Fault distance} = \frac{\text{Full period distance}}{2} - \text{Length of HV connection cable}$$

Procedure To locate a cable fault using the Decay method, perform the following steps:

Step	Action
1	Connect the STX 40 to the faulty phase of the test object.
2	Call up the menu item  from the sub-menu  .
3	Set the voltage range while taking into account the required fault ignition voltage.
4	Open the phase selection menu via  and select the connected phase of the test object. Then close the menu by clicking  .
5	Use menu item $\frac{V}{2}$ or NVP to set the propagation velocity and then use menu item  to set the measuring range to roughly five to ten times the complete length of the cable.
6	Start the measurement using the menu item  .
7	Enable the high voltage using the "HV ON" button.

Step	Action
8	Increase the voltage to the desired test voltage using the rotary encoder and confirm the value by pushing in the rotary encoder. The dialogue for setting the voltage closes automatically after a few seconds for safety reasons but it can be accessed again using the menu item U_{NOM}. Result: The test object is charged to the set voltage. Once the fault breaks down, an attenuated and oscillating voltage curve is shown in the display and the voltage conditioning is interrupted.  The software automatically attempts to calibrate a period of the oscillation and to set corresponding markings.
9	Switch off the high voltage using the menu item HV OFF .
10	If the recorded decay curve is superimposed to an excessive degree by interference signals, it uses the available filter settings (see page 46) to smooth the characteristic of the curve. Amplitudes that are too high can be counteracted by reducing the amplification (see page 46). Each time an adjustment is made, you must repeat the procedure from Step 6.
11	If the automatically set markings do not enclose a period exactly, you can use the function $\rightarrow$ to correct their positions. Half the distance of one period is shown directly next to the cursor and in the bottom left corner of the display. 
12	Subtract the length of the connecting cable from this value. The calculated value corresponds to the approximate distance between the connection point and the fault. For technical reasons, this method has a slightly higher tolerance than, for example, pre-location using the ARM method.

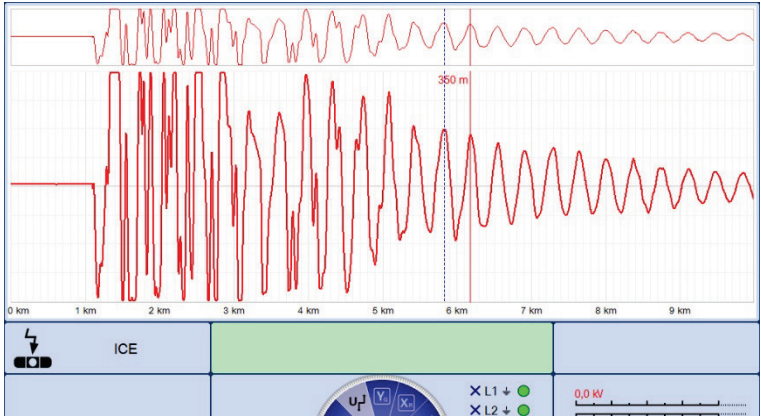
5.8.3 Current decoupling (ICE) -

Introduction Prelocation using current decoupling has established itself, particularly with regard to faults in the lower kOhm range and for extremely large fault distances, in which the ARM- method often fails to achieve any results.

As with the ARM method, an abrupt discharge of the surge capacitor triggers a breakdown in the fault. Consequently, an attenuated transient wave moves back and forth between the fault location and the measurement system. Inductively decoupling the current causes the display of an oscillation, which has a period equivalent to a single fault distance. However, the length of the pre-measuring cable still needs to be deducted from this distance.

Procedure Proceed as follows to pre-locate a cable fault using the ICE method:

Step	Action
1	Connect the STX 40 to the faulty phase.
2	Call up the menu item  from the sub-menu PRE  .
3	Set the voltage range to a few kV above the identified fault ignition voltage, to preset a low voltage level and to thus ensure a high surge energy. For non-chargeable cable faults, you should increase up to the fault ignition voltage in multiple iterations.
4	Open the phase selection menu via  and select the connected phase of the test object. Then close the menu by clicking  .
5	Use menu item $\frac{V}{2}$ or NVP to set the propagation velocity.
6	Use menu item  to set the measuring range to roughly five to ten times the complete length of the cable.

Step	Action
7	Start the measurement using the menu item  .
8	Enable the high voltage using the “HV ON” button.
9	Set the voltage, taking the required fault ignition voltage into consideration. If the fault will be caused by surge discharge to breakdown, this needs to be initiated using the menu item  once the surge capacitor has been charged to the set voltage. If instead the cable should be charged to the fault breakdown, the system starts immediately with voltage conditioning. Result: If a voltage flash-over occurs at the fault position, the display shows an attenuated and oscillating current curve.  The software automatically attempts to calibrate a period of the oscillation and to set corresponding markings. If triggering failed to occur, and therefore a fault trace was not made, it may then be necessary to adjust the trigger threshold or the surge voltage before triggering a further surge.
10	Switch off the high voltage using the menu item HV OFF .
11	If the recorded decay curve is superimposed to an excessive degree by interference signals, it uses the available filter settings (see page 46) to smooth the characteristic of the curve. Amplitudes that are too high can be counteracted by reducing the amplification (see page 46). Each time an adjustment is made, you must repeat the procedure from Step 8.

Step	Action
12	If the automatically set markings do not enclose a period exactly, you can use the function $\rightarrow$ to correct their positions. The distance of one period is shown directly next to the cursor and in the bottom left corner of the display. 
13	Subtract the length of the connecting cable from this value. The calculated value roughly corresponds to the distance between the connection point and the fault. For technical reasons, this method has a slightly higher tolerance than, for example, pre-location using the ARM method. With the ICE methods, often 5 ... 10% larger distances are measured, which is why measurement technicians should first walk toward the test van when pinpointing the pre-located fault position.

5.9 Burning -

Introduction What is known as “burning” enables ongoing conversion of high-impedance faults into low-impedance shunts right up to saturated short-circuits. To this end, the fault is first caused to breakdown by charging the test object and then continuously fed a high current, which keeps the arc burning. Ideally, this causes the burned insulating material to form a conductive carbon bridge, thus reducing the resistance of the fault (the fault then becomes locatable) or the moisture that penetrated into the cable evaporates.

Thanks to steady improvement in pre-location methods, this material-stressing method must be used only very rarely with difficult faults, such as moist sleeves.

Selecting the operating mode The burning operating mode can be accessed directly from the main using the  menu item.

Setting the measurement parameters The voltage range is automatically queried when entering the operating mode, but – like all other settings – it can still be adjusted until the actual start of the measurement. The following measurement parameters can be set:

Function / Menu item	Description
	The defective phase must be selected in accordance with the actual type of connection. The phase selection menu must then be closed using  .
	A burn time can be specified in minutes. On expiry of the burn time, the high voltage is switched off automatically.
	Voltage range for the upcoming measurement. The actual voltage can only be set within this range.
	Setting the current range. In the Auto setting, the range is always automatically adjusted to the currently measured currents.
	Limitation of maximum current (50 ... 850 mA) If the set value is exceeded, the burning process is automatically stopped.

Starting and stopping the burning process After all relevant parameters and the faulty phase have been set, the measurement can be started via the menu item . The high voltage must then be released via the “HV ON” button and the nominal voltage must be set. From the moment of release, the red illuminated “HV OFF” button indicates 'high voltage at HV output'. The voltage is raised directly to the set setpoint even without prior confirmation.

For safety reasons, the voltage setting dialogue closes automatically after a few seconds, but can be called up again via the menu item U_{NOM} .

The voltage and current curves are shown on the display. When the fault location is ignited, the voltage drops abruptly while the burning current rises sharply. A few minutes are usually enough to convert the fault resistance so that it may be localised using an HV pre-location method.

5.10 Surge pinpointing - /

Introduction Surge pinpointing is the preferred method for precise location. It can be used for about 90% of all cable faults.

Using an abrupt discharge of the surge capacitor, surge voltage pulses are continuously fed into the defective cable, causing voltage arc-overs at the fault location. The resulting flashover noise propagates in the ground and can be recorded with a ground noise sensor on the surface (acoustic location). The distance to the fault can be calculated using either the volume of the flashover noise or the time difference between the arrival of the magnetic pulse and the flashover noise.

Selecting the operating mode The surge operating mode can be called up using the menu item  from the sub menu .

Setting the measurement parameters The phase and the voltage range are automatically queried when entering the operating mode, however – like all other settings – they can be adjusted until the actual start of the test.

The following test parameters can be set:

Function / Menu item	Beschreibung
	The defective phase must be selected in accordance with the actual type of connection. The phase selection menu must then be closed using .
	Voltage range for the upcoming surge pinpointing. The actual surge voltage can only be set within this range. Set the voltage range to a few kV above the identified fault ignition voltage, to preset a low voltage level and to thus ensure a high surge energy.
	Switch between automatic and manual surge decoupling. With automatic surge decoupling, the desired distance between two surges (surge rate) can be set down to the second using the menu item .

Carrying out fault pinpointing

The safety of the system in operation must be ensured permanently by the person responsible for the work in accordance with the applicable safety regulations and guidelines, including during line and fault location!

In order to avoid subjecting the cable to unnecessary stress, surge mode should not be activated until the measuring technician has reached the prelocated fault position.

Once the operating mode has then been started via menu item , the high voltage must be enabled via the “HV ON” push-button and the target voltage set. The dialogue for setting the voltage closes automatically after a few seconds for safety reasons but it can be accessed again using the menu item U_{NOM} .

As soon as high voltage is enabled, the “HV OFF” button lights up red signalling “high voltage at the HV output”. The surge capacitor is directly charged to the set surge voltage.

Using the menu item , the automatic surge mode is started and a voltage breakdown is caused at the fault location in the set surge interval. In manual surge mode, each surge discharge must be initiated manually using the menu item .

During surge operation, the fault position can now be pinpointed in the pre-located area using a suitable surge wave receiver.



For more details about operating the surge wave receiver, please read the accompanying instructions.

The measurement technician who remains in the test van should maintain telephone contact with their colleagues at the fault location and if necessary modify the settings (surge voltage, surge mode, surge interval), initiate individual surges or pause/continue surge operation.

6 Completing the work

Exporting and processing measurement data

After the actual measurement job, the recorded measurement data can be conveniently analysed, archived and summarised in a report on a Windows PC.

To do this, the desired data must first be marked for export in the History database (see page 32) and then exported to an inserted USB flash drive via the data menu (see page 37). On the Windows PC, the data can then be imported into the protocol software and processed further. Depending on the version of the protocol software, the following functions are available:

	Megger Book Lite (free download on the Megger website)	Megger Book (full version) (article number: 2015875)
Analysis of the measurement data with practical tools	●	●
Creation of a report based on extensively customisable report templates	●	●
Creation and maintenance of a cable database		●
Archiving of measurement activities in the data stock of the respective cable		●

Switching off the system and disconnecting from the test object

After the measurements have been completed, the STX 40 can be switched off by pressing the on/off button **3**.

When disconnecting the test system, proceed in reverse sequence to the manner in which the connection (see page 19) was made. The following safety instructions must be strictly adhered to.

 WARNING	• Follow the five safety rules (see page 7). • Even if switched off properly and discharged using the discharge device, the system components that were under voltage should only be touched once they have been discharged using a suitable discharge rod as well as having been earthed and short-circuited. • Only undo the earthing and short-circuiting measures when the test object is to be operated again.
---	---

7 Transportation, storage and care

Transportation The vertical position of the rear handle can be adjusted to allow an ergonomic stance when pushing or pulling the device. To do this, simply loosen the locking screws slightly on both sides and tighten again after adjusting the height.



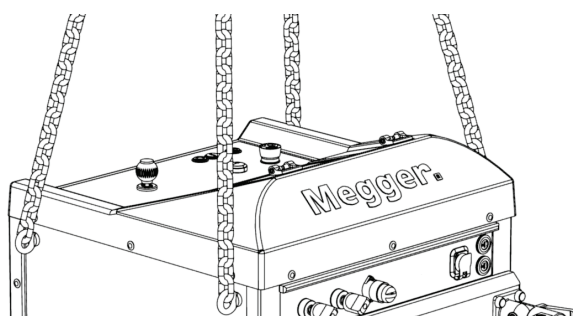
The device can be transported over long distances (e.g. in vehicles) in either a vertical (standing) or horizontal position.

The four eyelets on the top of the device can be used to load the device onto a vehicle via lifting equipment.

Note

Risk of damage

The bearing capacity of the eyelets can only be guaranteed as sufficient if the lifting equipment is secured to all four eyelets, as this allows the weight to be distributed evenly.



The eyelets can also be used to secure the device when transporting it in a vehicle.

Storage If the system is not used for a long period of time, it should be stored in a dust-free and dry environment. Persistent humidity, especially in combination with dust, can reduce critical insulation gaps that are essential for safe high-voltage operation.

Care of the display Do not clean the display with harsh cleaning agents such as solvents or gasoline.

Instead, lukewarm water with some washing-up liquid should be used and applied to the display using a microfibre cloth.

8 Troubleshooting and maintenance

Replace fuses If the system cannot be switched on even though the mains supply is connected, check the two fuses next to the mains socket **11**. To do this, the fuse holder must be pulled out.

If the fuses are defective, they must be replaced with suitable fuses (T16A 250V, type SPT 6,3x32mm).

If the fuses continue to trip, please contact an authorised service centre to have the fault rectified.

Behaviour in the event of continuous faults In the event of damage, irregularity or faults that cannot be rectified using the instructions in this manual (see page 24), the system must be immediately taken out of service and marked accordingly. Please contact the Megger service immediately to correct the problem. The system must not be put back into operation until the fault has been rectified.

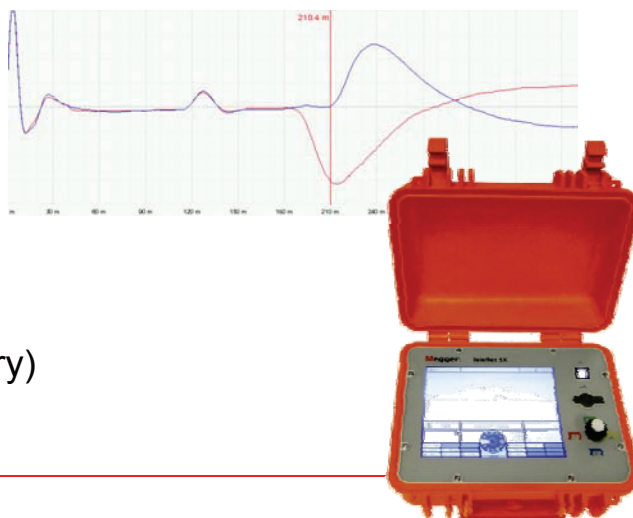
Repair and maintenance Repair and maintenance work has to be carried out by Megger or authorised service partners using original spare parts only. Megger recommends having the system tested and maintained at a Megger service centre once a year.

Megger also offers its customers on-site service. Please contact your service centre if needed.

The connections and connection leads of the system must be regularly checked for integrity and the absence of damage in accordance with the applicable national and company agreements.

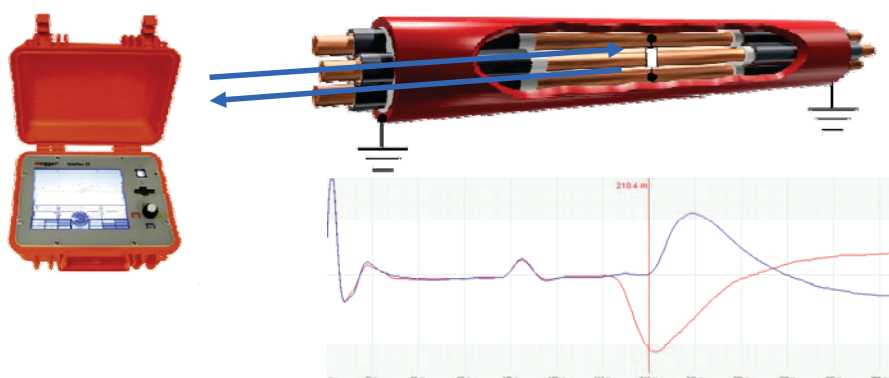
Cable Fault Prelocation

Basics of TDR
(Time Domain Reflectometry)



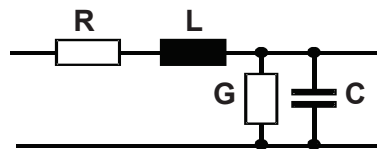
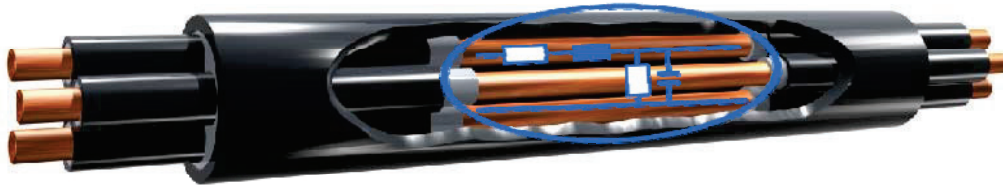
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Principles of the Time Domain Reflectometry (TDR Technology)



- The TDR works on the same principle as a radar unit
- The pulse travels down the cable. The pulse is reflected on each changing of the impedance and travels back to the TDR
- The TDR then converts this time to the distance

Electric Line Model / Equivalent Circuit Diagram



R ... series resistance
L ... series inductance
G ... parallel conductance
C ... parallel capacitance

Electric Line Model / Impedance

- The ohmic fault resistance is determined by **R** and **G**
- The characteristic impedance of the cable is determined by **L** and **C**

- General formula for calculating the characteristic impedance of the cable

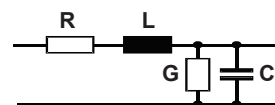
$$Z = \sqrt{\frac{R + j \omega L}{G + j \omega C}}$$

- Simplified formula for high frequencies

$$Z = \sqrt{\frac{L}{C}}$$

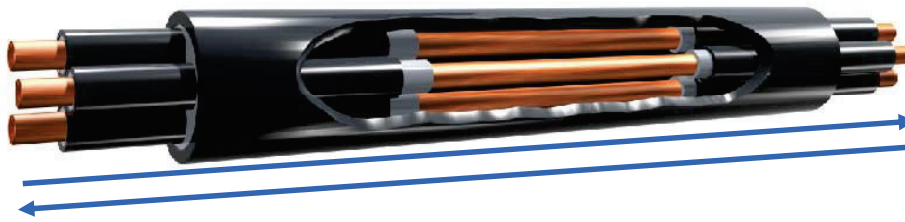
- Impedance

Overhead line	300 Ω
Telecom cable	135 Ω
Coax cable	50 Ω, 75 Ω
Energy cable	20 Ω
Tramway cable	5-10 Ω



R ... series resistance
L ... series inductance
G ... parallel conductance
C ... parallel capacitance

Propagation Velocity and Distance



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

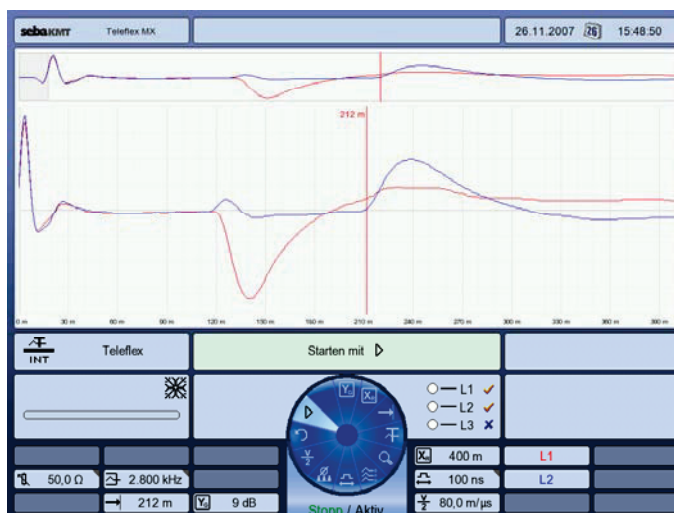
$\left(\frac{v}{2} \right)$ Half of propagation velocity

v Propagation velocity of the electric impulse

t_x Propagation time of the impulse to the end of the conductor and back

l_x Length of the conductor

Propagation Velocity and Distance



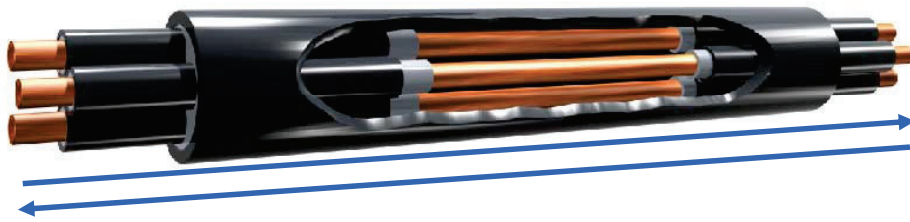
Cursor Position at different Propagation Velocities :

212 m at $v/2 = 80.0 \text{ m}/\mu\text{s}$

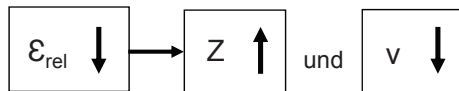
199 m at $v/2 = 75.0 \text{ m}/\mu\text{s}$

238 m at $v/2 = 90.0 \text{ m}/\mu\text{s}$

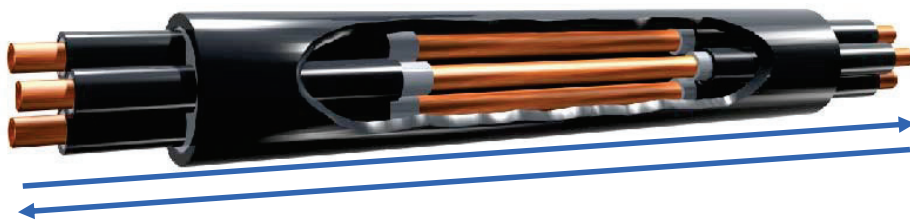
Propagation Velocity of an Electrical Pulse



Dielectric	Guide values ϵ_{rel}
Vacuum	1
Plastics	2 to 4
Water	81



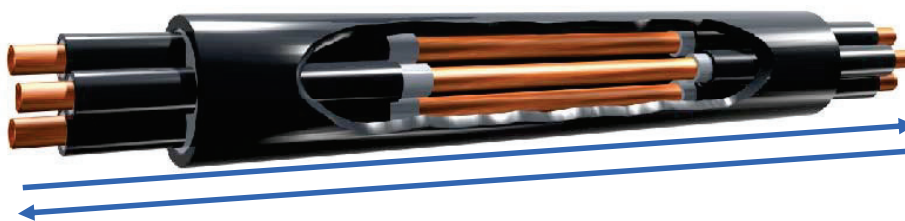
Propagation Velocity of an Electrical Pulse



Propagation velocity $v/2$ (m/ μ s):

- PILC 80 m/ μ s (77-82 m/ μ s)
- PVC 78 m/ μ s (70-80 m/ μ s)
- XLPE 85 m/ μ s (82-86 m/ μ s)
- mixed line 83 m/ μ s
- Telecom cable 95 – 120 m/ μ s
- Overhead line 147.5 m/ μ s

Propagation Velocity Influences



Factors that affect Propagation Velocity:

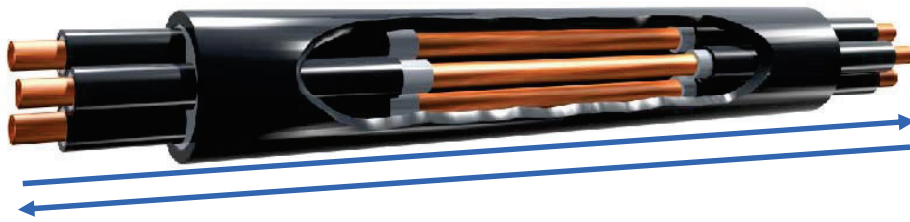
- Impedance
- Dielectric (colour, type of insulation)
- Age of the cable
- Temperature
- Water $v/2 = \text{approx. } 65 \text{ m}/\mu\text{s}$
- Position of the cores inside the cable

Propagation Velocity $v/2$ in $\text{m}/\mu\text{s}$ or $\text{ft}/\mu\text{s}$

Cable type (based on VDE)	Insulation		Diel. const. $\epsilon \cdot \text{rel}$	$V/2$	Deviation $\text{m}/\mu\text{s}$	
A-2YF(L)2Y	PE		2.3		94	small
A-2Y(St)2Y	PE		2.3		100	small
A-02Y(LCo)2Y Foam-Pe		1.7		116	small	
A-PMbc	Paper		1.6		112(118)	110-126
A-PWE2Y	Paper		1.6		118	110-126
NAEKBA	Paper/Pulp		3.5		80	77-83
NAKBA	Paper/Pulp		3.5		80	77-85
NAKLEY	Paper/Pulp		3.5		80	77-83
NAHEKB	Paper/Pulp		3.5		80	77-83
NAKEBA	Paper/Pulp		3.5		80	77-83
NKBA	Paper/Pulp		3.5		80	77-85
NKLEY	Paper/Pulp		3.5		80	77-83
NAYY	PVC		5.0		78	70-82
NAYCWY	PVC		5.0		75	69-78
NYCY	PVC		5.0		78	70-82
NYCWY	PVC		5.0		75	69-78
NA2XY	XLPE		2.3		85	small
NA2XSY	XLPE		2.3		85	82-86
NA2XSIV	XLPE		2.3		85	82-86
NA2XS(F)2Y	XLPE		2.3		85	82-86
N2XSY	XLPE		2.3		85	82-86

(sometimes you find "nvp": natural velocity of propagation as a relation to speed of light)

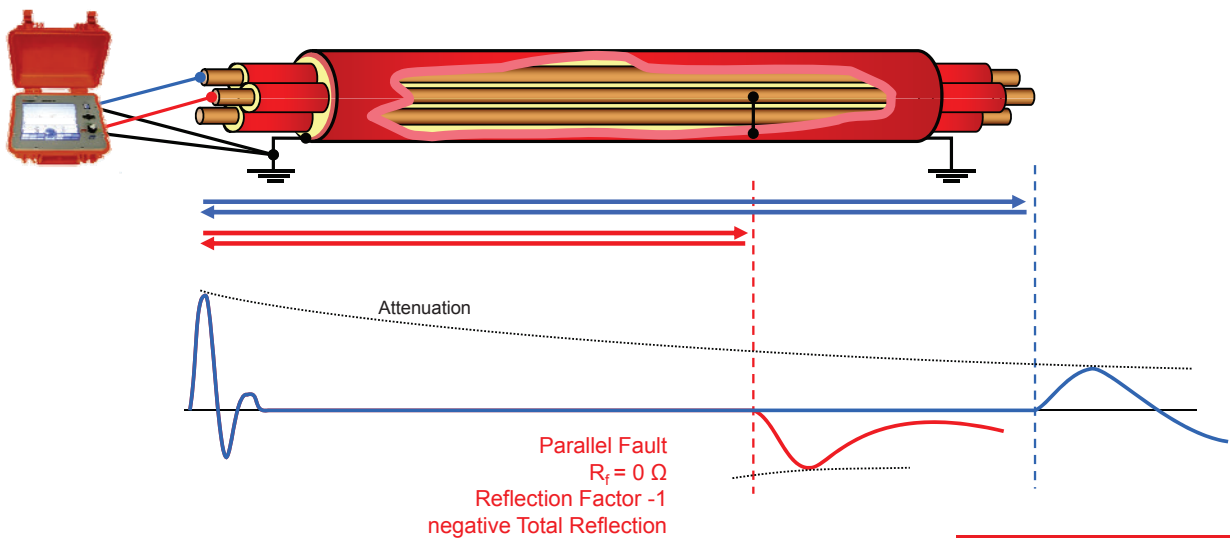
Reflection Factor



- No changing of the impedance - no reflection
- Change of the impedance - good reflection
- Short and break - total reflection

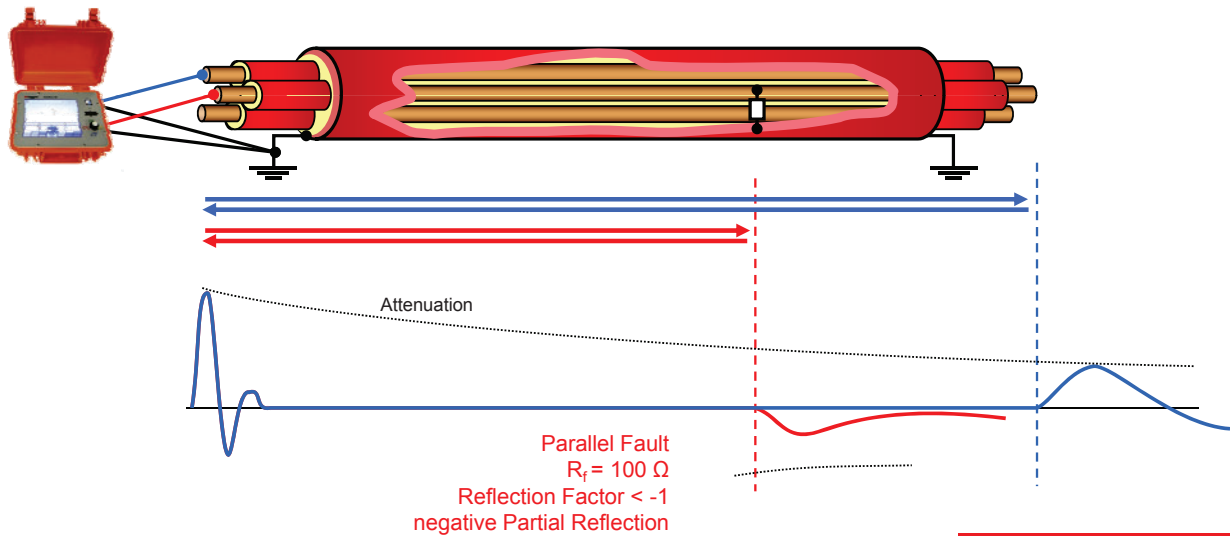
Reflection Factor

Short Circuit 0 Ω



Reflection Factor

Parallel Fault 100 Ω



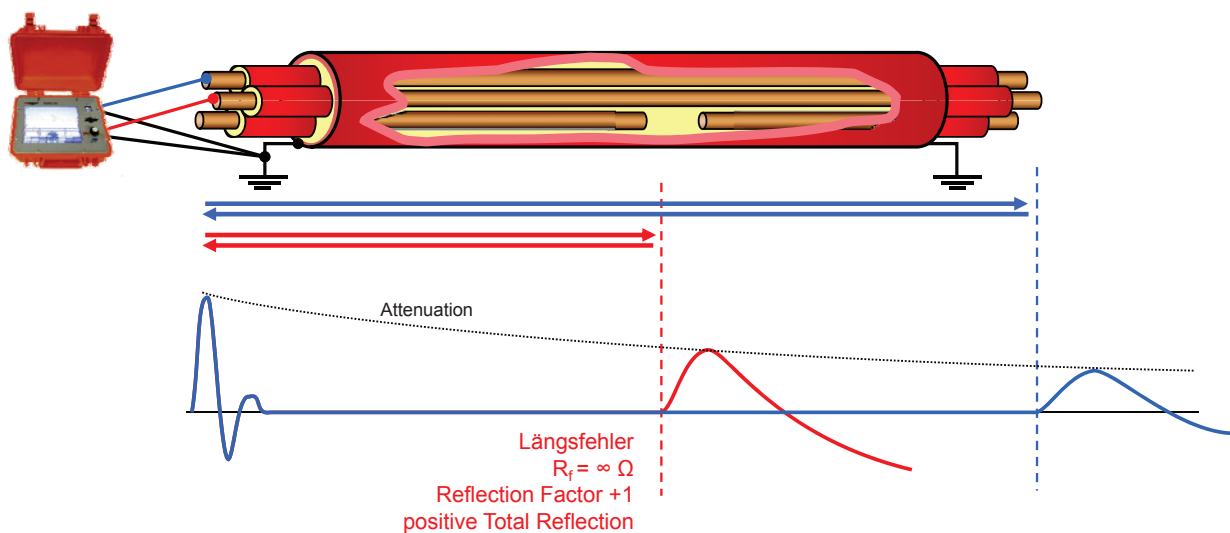
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Reflection Factor

Interruption, Break, Open Circuit



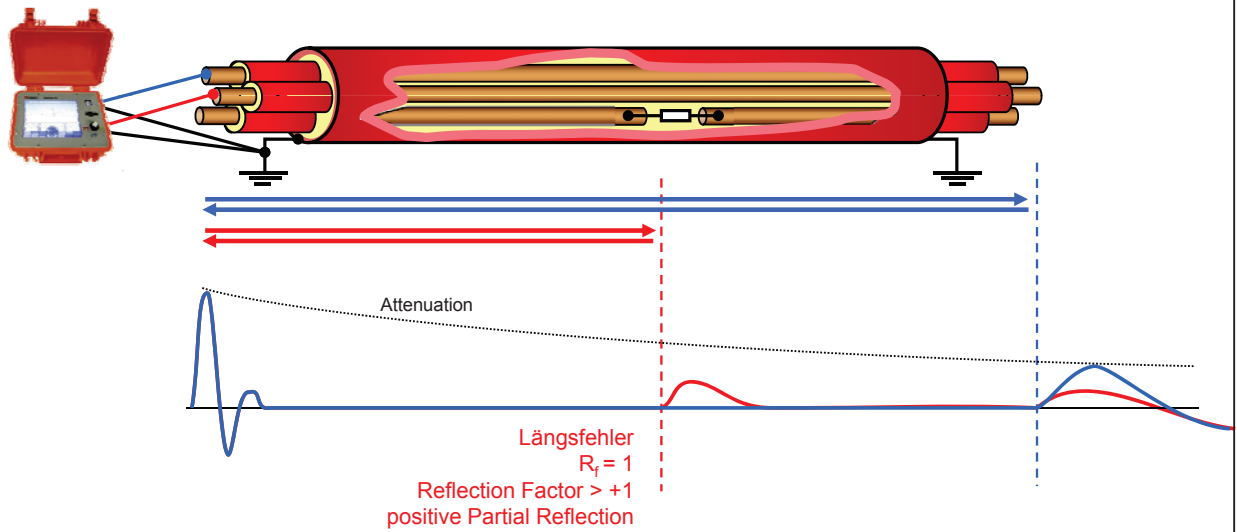
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Reflection Factor

Serial Fault > 0 Ω



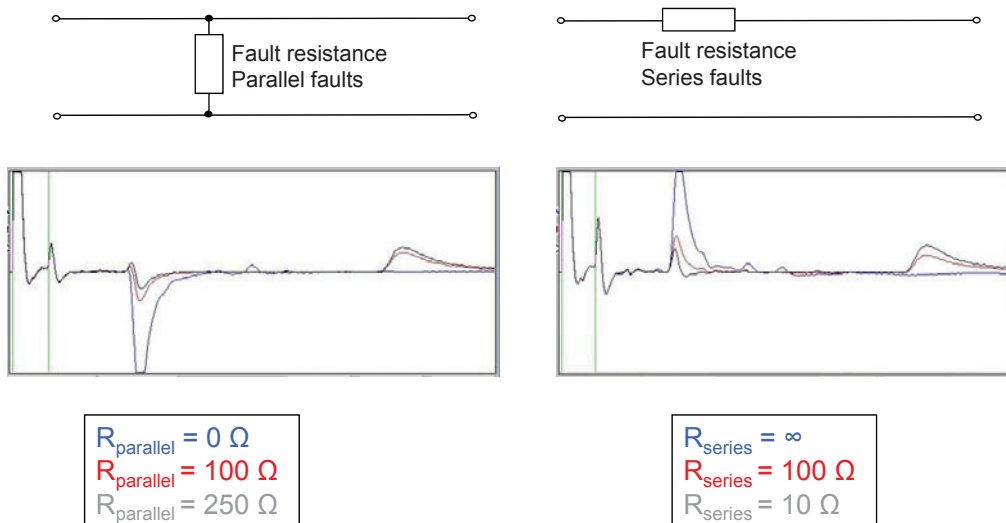
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Reflection Factor

Parallel and Series Fault Resistance

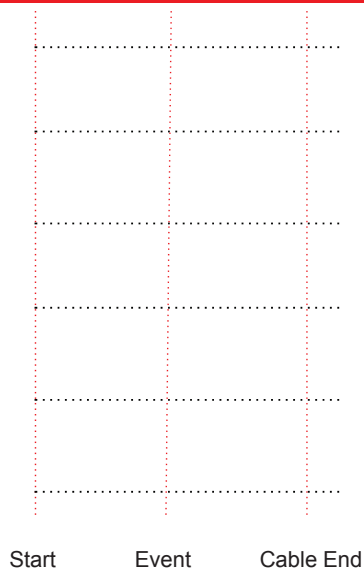
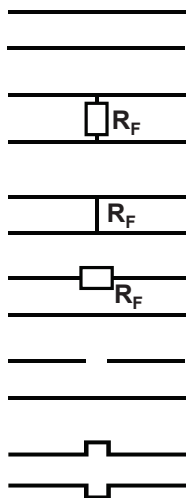


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Typical Reflections



Cable without fault

Parallel fault

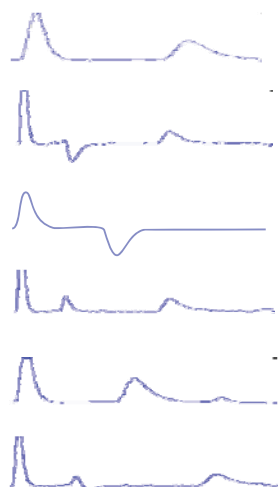
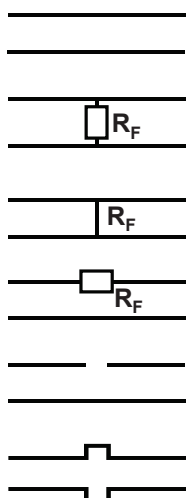
Short

Series fault

Break, open end

Joint

Typical Reflections



Cable without fault

Parallel fault

Short

Series fault

Break, open end

Joint

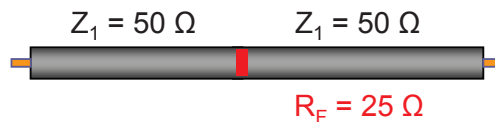
Reflection Factor Examples

Cables with different impedance
(e.g. cable type change)



Negative Reflection
(tramway cable)

Lines with ohmic fault
resistance
(e.g. insulation damage)

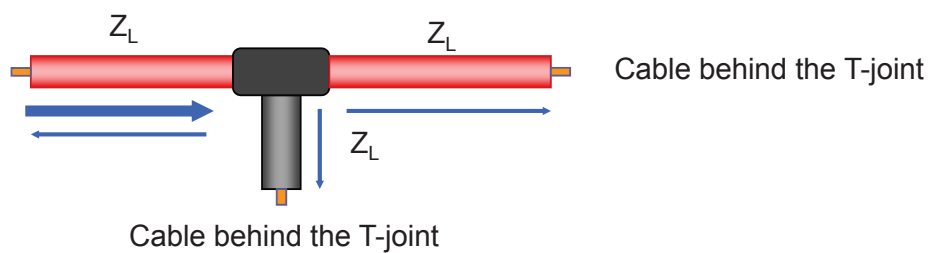


Negative Reflection
(parallel fault)



Positive Reflection
(overhead line)

Reflection Factor Branched Network

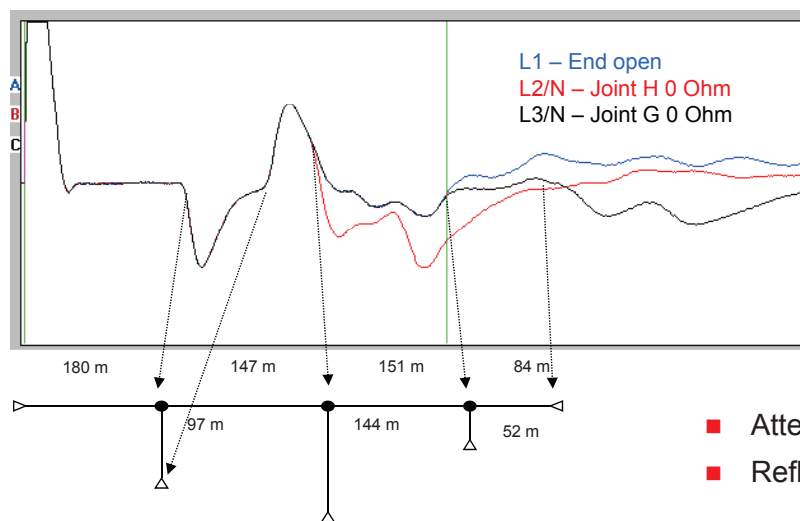


$$r = -\frac{1}{3}$$

Negative Reflection
(T-joint, cables with equal impedance)

Reflection Factor

L1, L2, L3 - Fault in the Joints G and H



- Attenuation in each T-joint
- Reflection from each end

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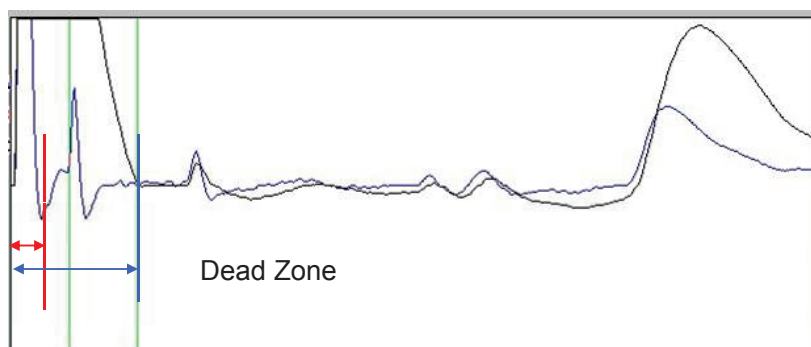
Pulse Width / Dead Zone

Narrow pulse

short distance
high resolution
short dead zone

Wide pulse

long distance
low resolution
long dead zone



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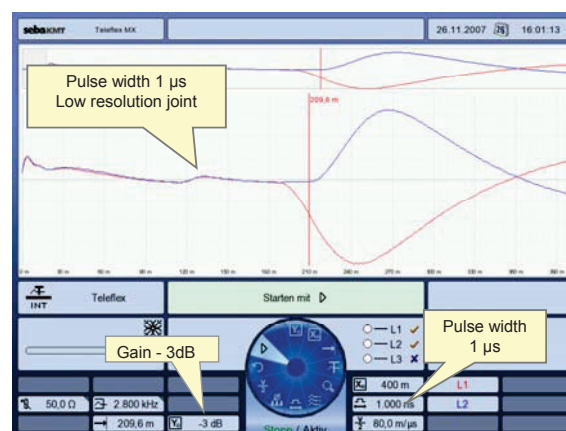
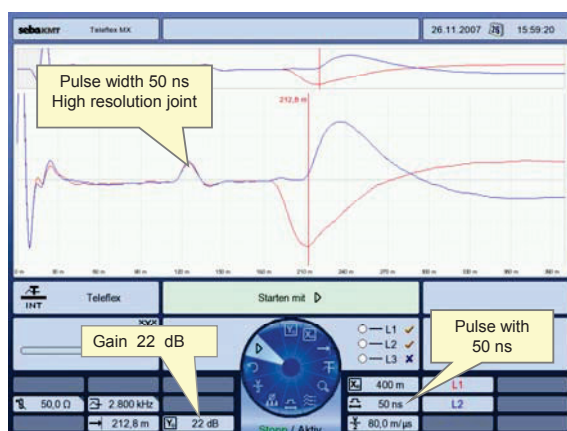
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Pulse Width

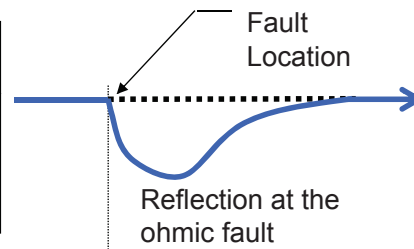
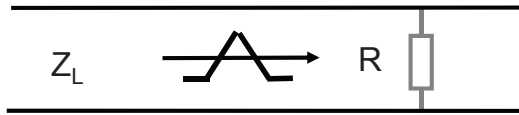
Pulse Width	Range [time]	Range [distance] ($v_{1/2} = 80 \text{ m}/\mu\text{s}$ oder NVP = 0.533)	Dead-Zone
100 ns	Bis zu 6.25 μs	Bis zu 500 m	8 m
200 ns	6.25 μs ... 31.25 μs	500 m ... 2,5 km	16 m
500 ns	31.25 μs ... 93,75 μs	2,5 km ... 7,5 km	40 m
1 μs	93,75 μs ... 375 μs	7,5 km ... 30 km	80 m
2 μs	375 μs ... 750 μs	30 km ... 60 km	160 m
5 μs	750 μs ... 2 ms	60 km ... 160 km	400 m

Pulse Width

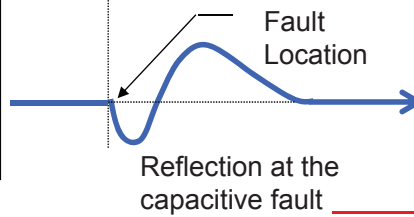
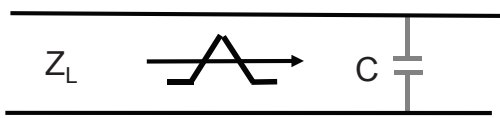


Ohmic Fault – Capacitive Fault

Ohmic Fault:



Capacitive Fault (wet cable):

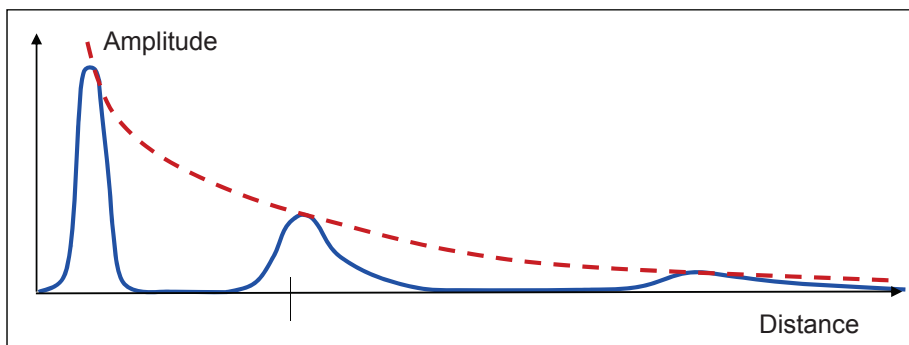


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Cable Attenuation – Cable Dispersion



Cable attenuation: $\alpha \text{ [ca.]} = \frac{R}{2Z} + \frac{GZ}{2} \text{ Np /km}$

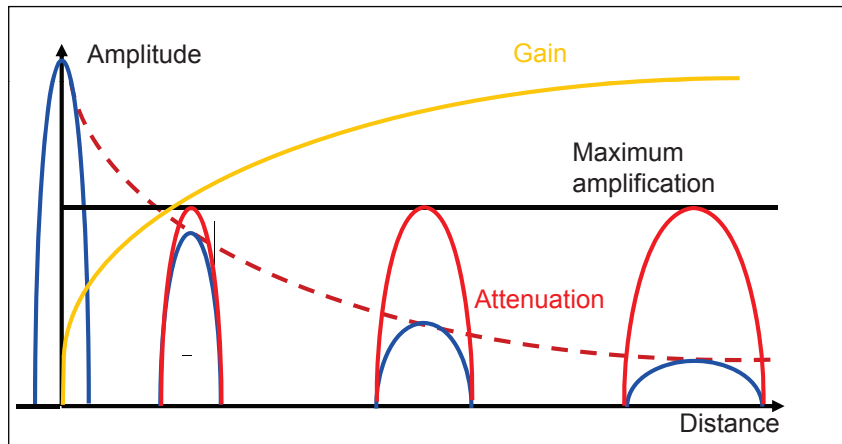
Cable dispersion: $\alpha \text{ [ca.]} = \sqrt{\frac{R \omega C}{2}} \text{ Np /km} \quad (\text{bei } \omega L \geq R)$

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Distance dependant Amplitude Correction

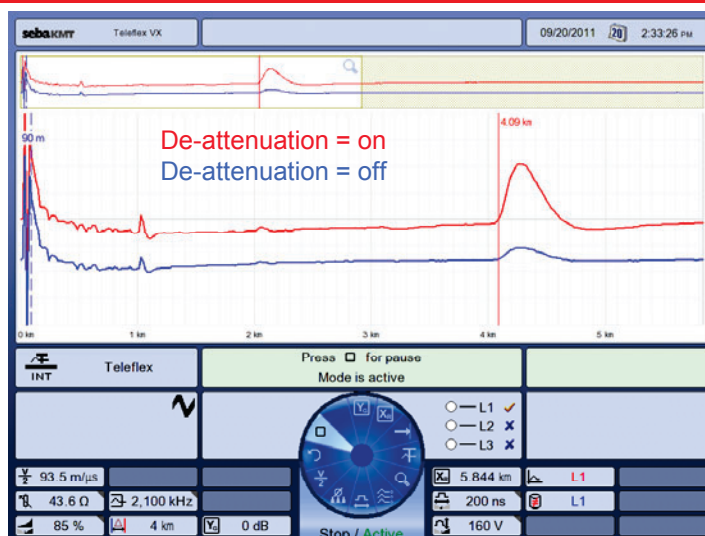


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ProRange



- Distance depending amplitude de-attenuation as known from our telecom units
- Important! This is not a ramp gain, but an exponential de-attenuation!

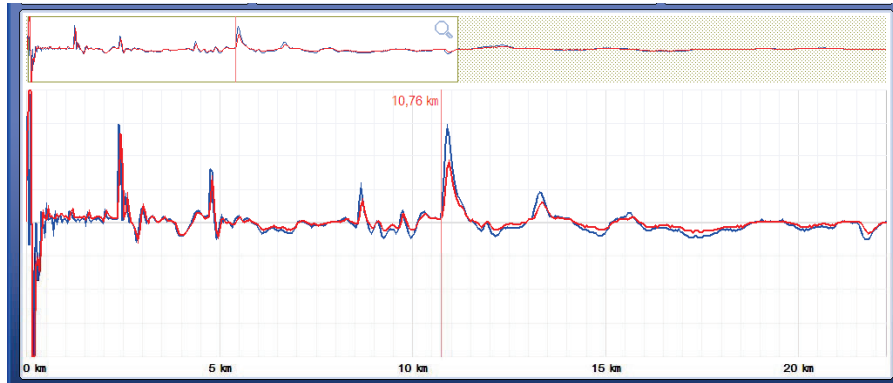
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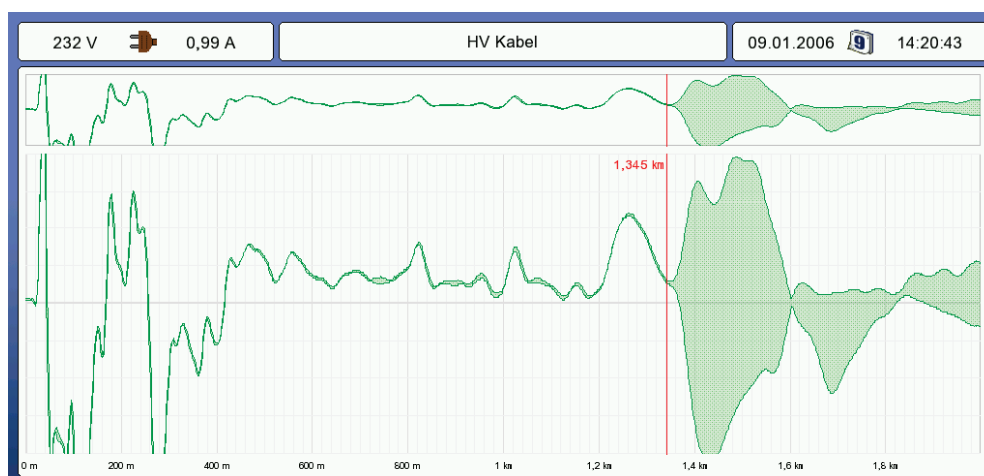
ProRange

Especially for cables with a high attenuation, long cables or wet PILC, but also as shown here with cross bonded cables this feature shows its strength!

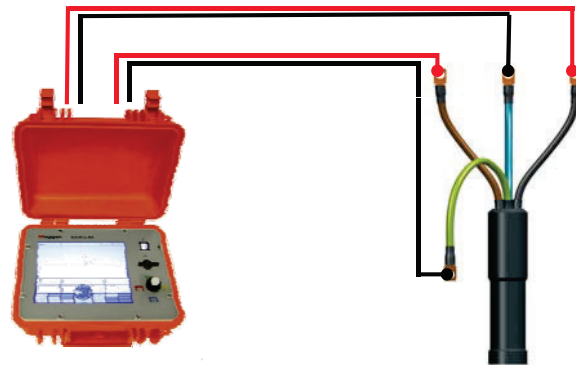


Example: Crossbonded cable of 10 km length with four crossings

Reflection Measurement – IFL Mode

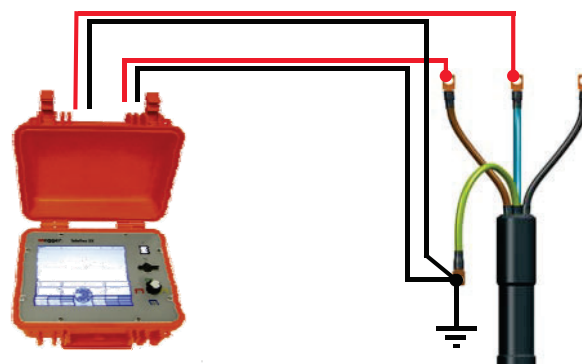


Symmetric coupling of TDR's



- Telecom cable Pair – Pair
- LV-cable without shield Core – Core
- Core – Neutral (Neutral disconnected from the ground)

Asymmetric coupling of TDR's

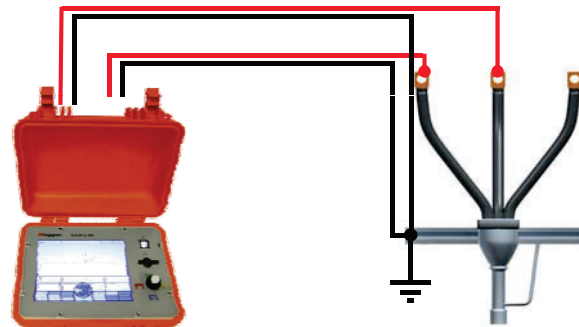


- Telecom cable Core – Shield
- LV-cable without shield Core – Neutral
- LVC-cable with shield Core - Shield

Black connecting
lead at the neutral

Red connecting
lead at
L1, L2 or L3

Asymmetric coupling of TDR's



Black connecting lead at the shield
Red connecting lead at L1, L2 or L3

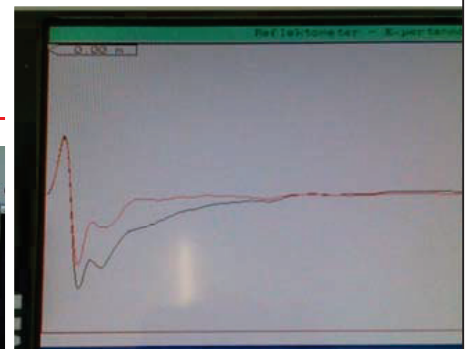
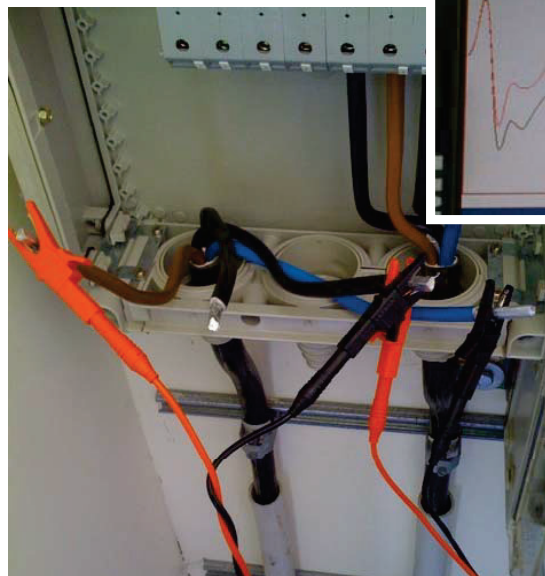
■ MV-Cable

Core – Shield

Asymmetric coupling of TDR



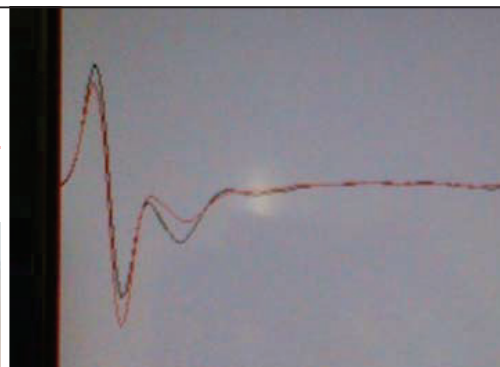
wrong connection:
additional reflections



Asymmetric coupling of TDR



better:
connecting leads
together at the neutral
red connecting leads at
L1 and L2 or L3

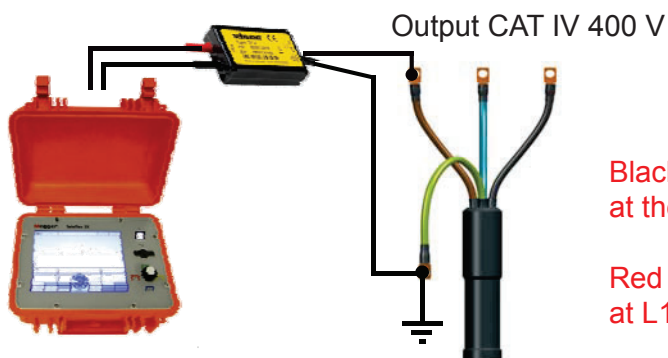


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Connection of TDR's via separation filter TF3 at live LV cables



Black connecting lead
at the neutral

Red connecting lead
at L1, L2 or L3

- Connecting at the house box or at the cable end
- TF3 can be used for all TDR

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Cable Fault Pinpointing

Acoustic Method with
Surge Wave Generator (SWG)



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Pinpointing – Acoustic Method

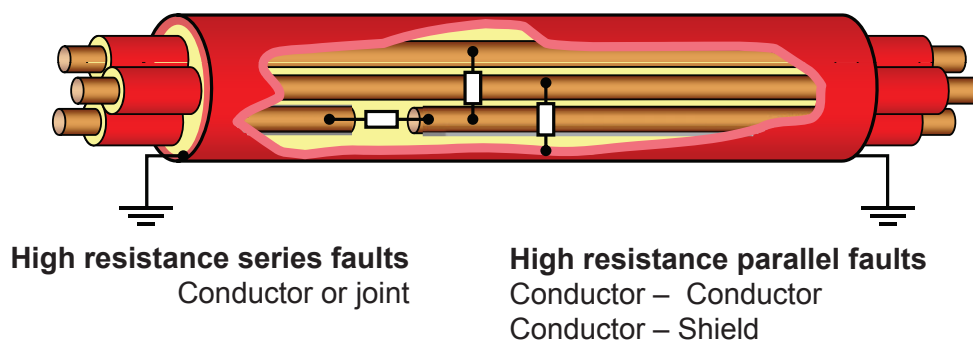
Cable Fault Pinpointing : Acoustic Method



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Pinpointing – Acoustic Method

Which faults can be pinpointed?



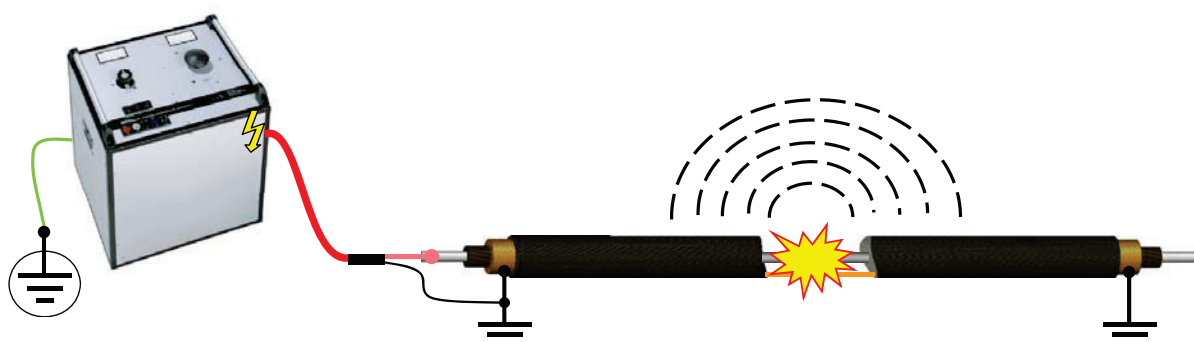
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3

Connection of portable HV Instruments

Connection Core - Sheath



Attention: low resistance protective ground < 2 Ω

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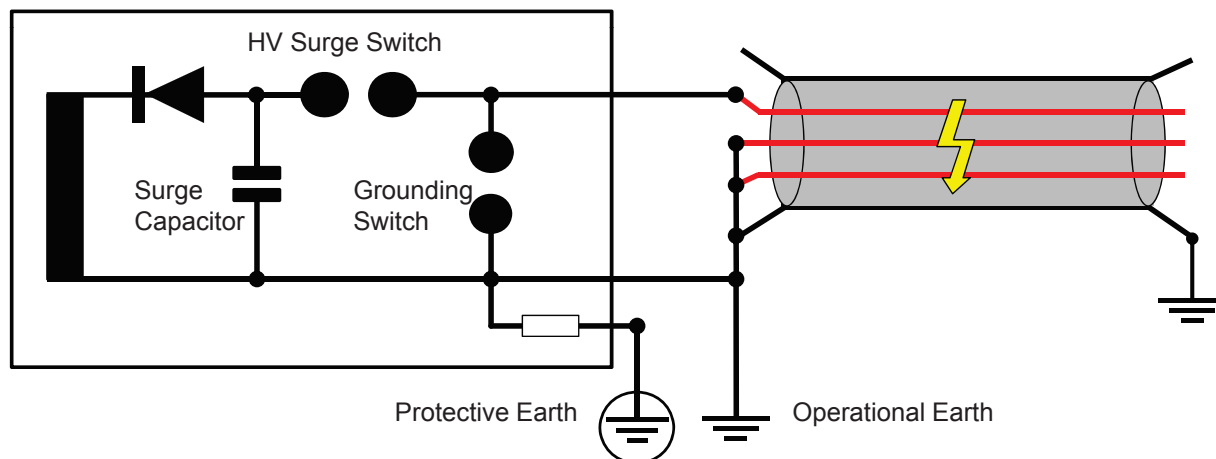
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4

Pinpointing – Acoustic Method

Surge Wave Generator Set-Up

Connect to Cable with Metal Jacket or Sheath



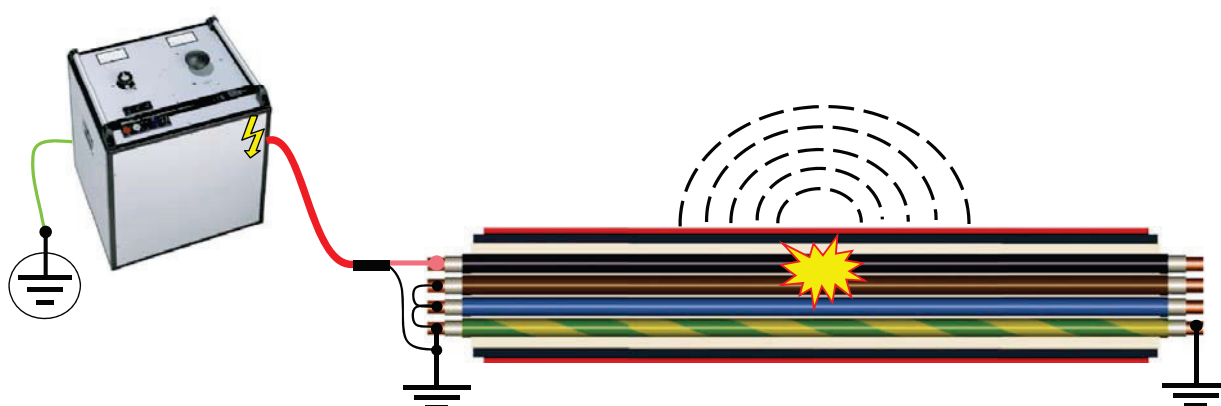
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Connection of portable HV Instruments

Connection Core - Core



Attention: low resistance protective ground < 2 Ω

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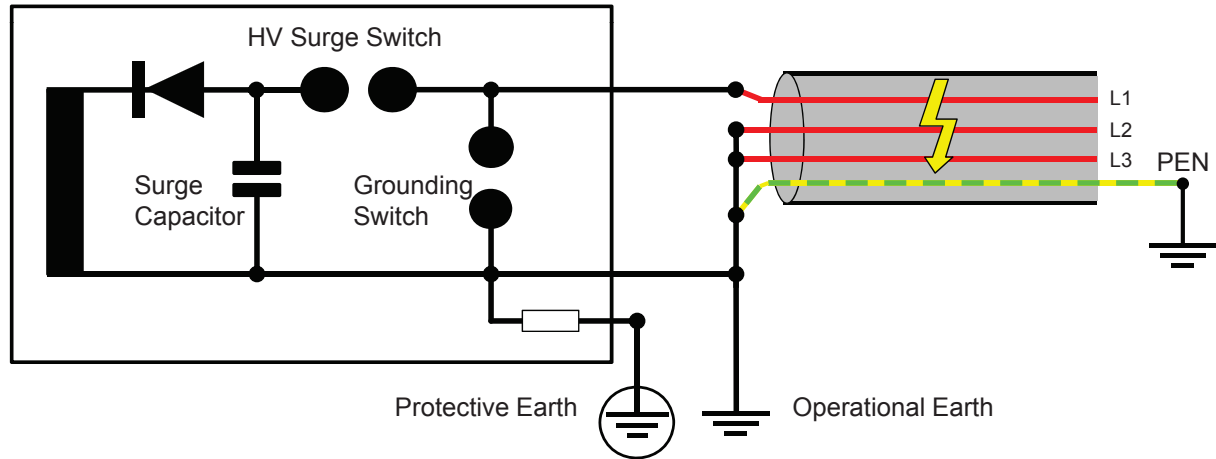
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6

Pinpointing – Acoustic Method

Connection to a 4-Conductor Low Voltage Cable

Phase-to-Phase-Fault



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Pinpointing – Acoustic Method

Dependence on volume intensitiy

Energy of surge generator

- 500 J is sufficient at portable surge generator
- min. 1.000 J in KMW (damping in 50 m connection cable)
- min. 1.000 J in branched cable system

Type of fault (low-resistance, high-resistance)

Ground conditions

- loose ground, e.g. sand, root area → damped sound waving
- short distance 1-3 m: high frequencies are good to hear
- long distance 3-5 m: low frequencies are better to hear

Contact sensor to earth

- sheet, tripod, peak

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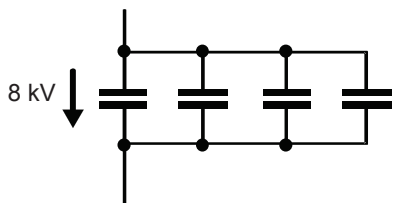
8

Pinpointing – Acoustic Method

Surge Generator – Switching Voltage Ranges/Capacitors

8 kV – position, 31.2 μF

$$C_{\text{total}} = 4 \cdot C_{\text{single}}$$

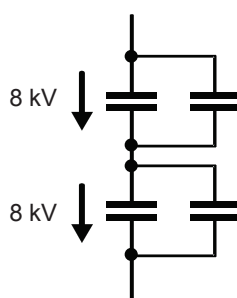


Surge Energy

$$E = \frac{1}{2} C \cdot U^2$$

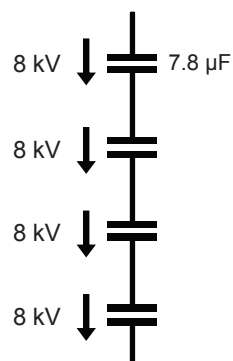
16 kV – position, 7.8 μF

$$C_{\text{total}} = C_{\text{single}}$$



32 kV – position, 1.95 μF

$$C_{\text{total}} = \frac{C_{\text{single}}}{4}$$



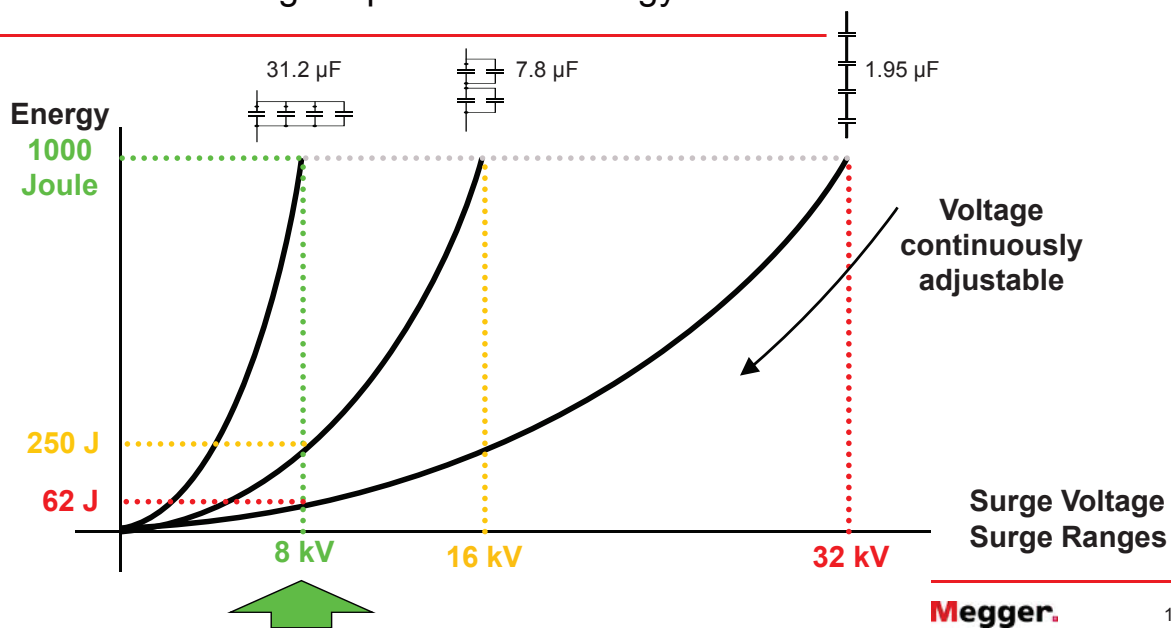
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Pinpointing – Acoustic Method

Influence of Voltage Square to the Energy Formula



10

Pinpointing – Acoustic Method

Influence of Voltage Square to the Energy Formula

Surge energy

$$E = \frac{1}{2} C \cdot U^2$$

Example: Fault flashover voltage 8 kV needed

We want as much energy as possible at lowest possible voltage.

- keep voltage range low (8 kV)
- use as much voltage of your range as needed (100%)

8 kV @ 8 kV position
total capacity: 31.2 µF

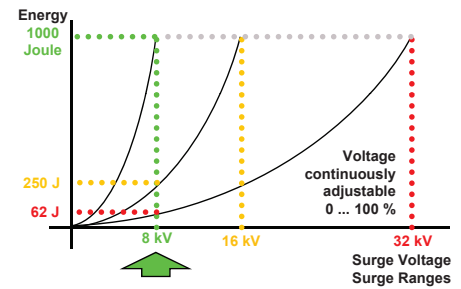
$$E = \frac{1}{2} 31.2 \mu\text{F} \cdot (8 \text{ kV})^2 = 1000 \text{ J}$$

8 kV @ 16 kV position
total capacity: 7.8 µF

$$E = \frac{1}{2} 7.8 \mu\text{F} \cdot (8 \text{ kV})^2 = 250 \text{ J}$$

8 kV @ 32 kV position
total capacity: 1.95 µF

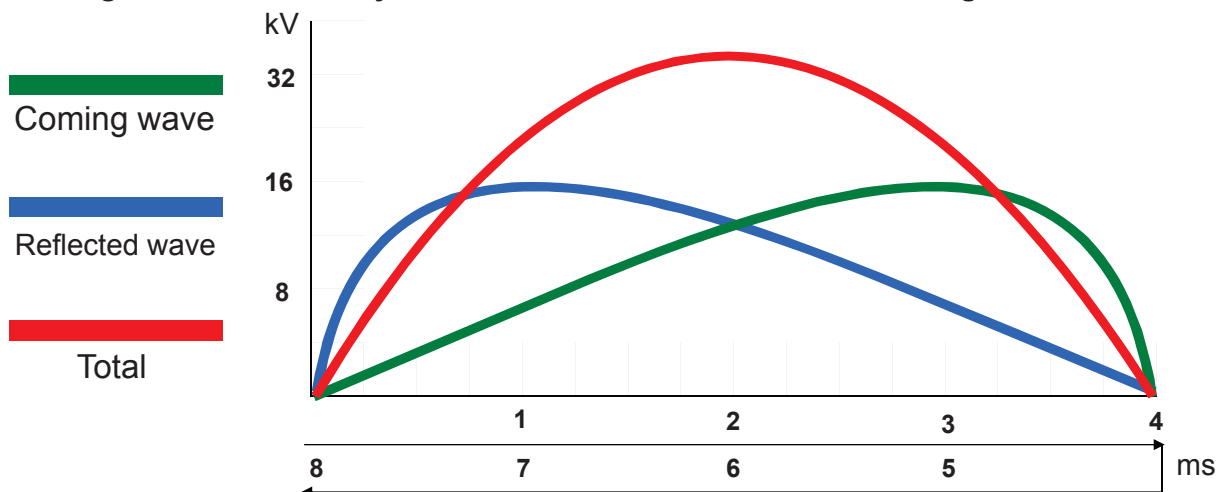
$$E = \frac{1}{2} 1.95 \mu\text{F} \cdot (8 \text{ kV})^2 = 62.5 \text{ J}$$



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Pinpointing – Acoustic Method

Voltage could increase by 2.5 times at the far end when not flashing over



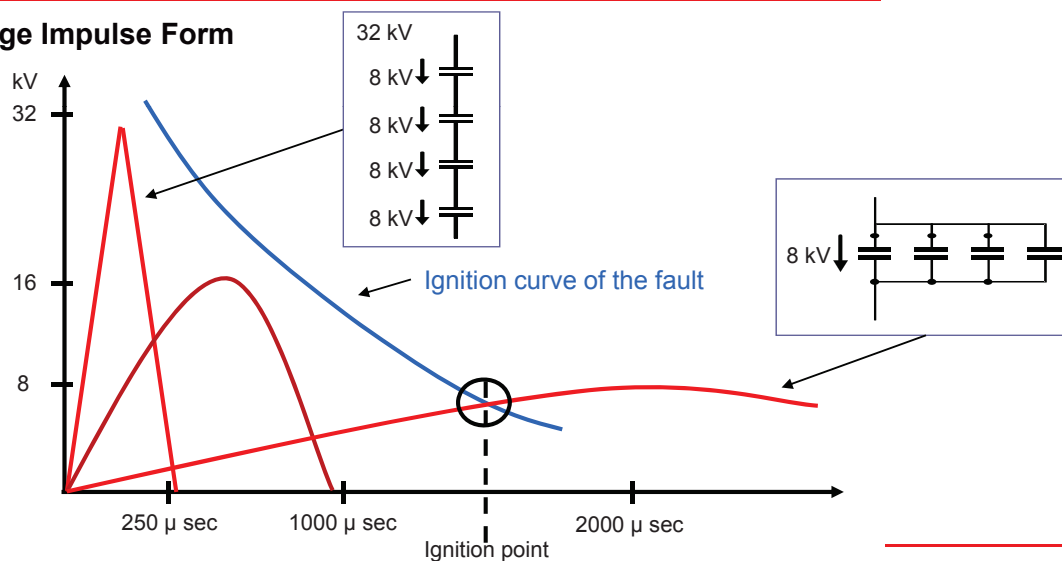
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Pinpointing – Acoustic Method

Progression of Fault Ignition Voltage

Surge Impulse Form



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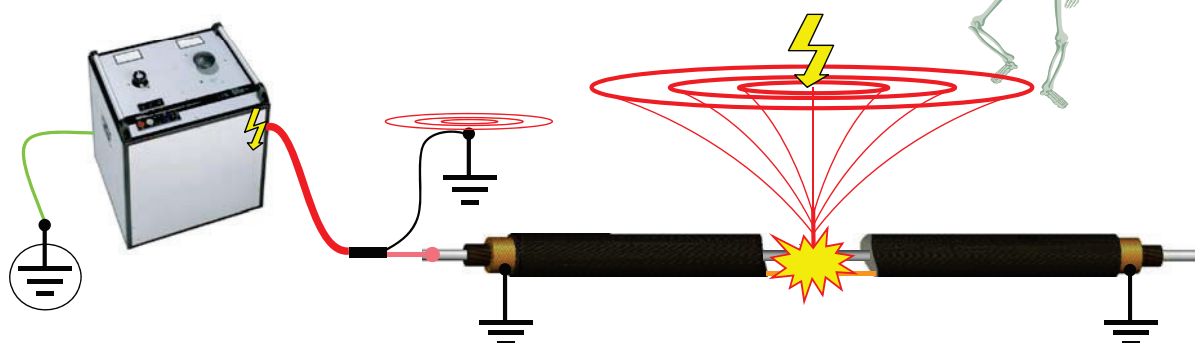
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Connection of portable HV Instruments

Never surge discharge against earth – DANGER TO LIFE!!

- This danger consists for all cables without sheath or metal jacket!
- Keep an eye on the discharge conditions of the surge generator!
- Alternative DC - or AF – step voltage method

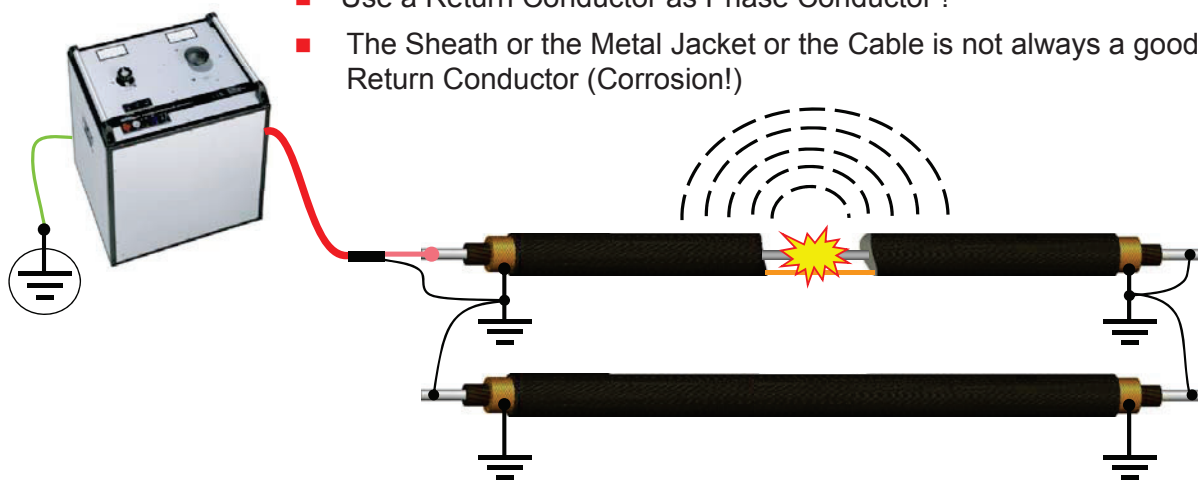


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Pinpointing – Acoustic Method



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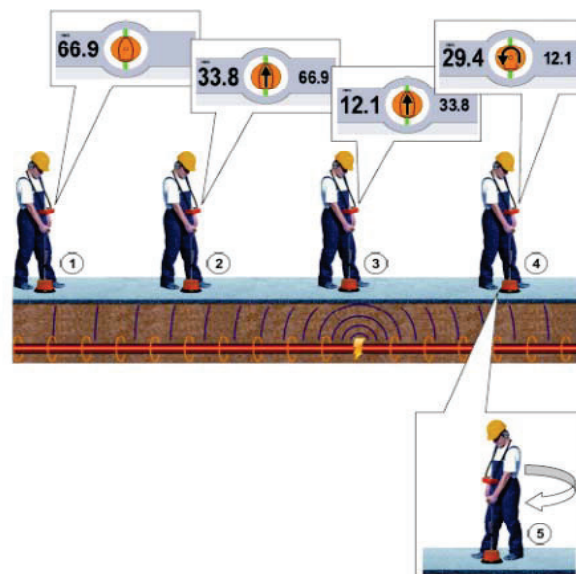
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Pinpointing – Acoustic Method Distance Method digiPHONE⁺



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digiPHONE⁺

The **digiPHONE⁺** System consists of:

- the Receiver
- the Sensor
- and the Headset

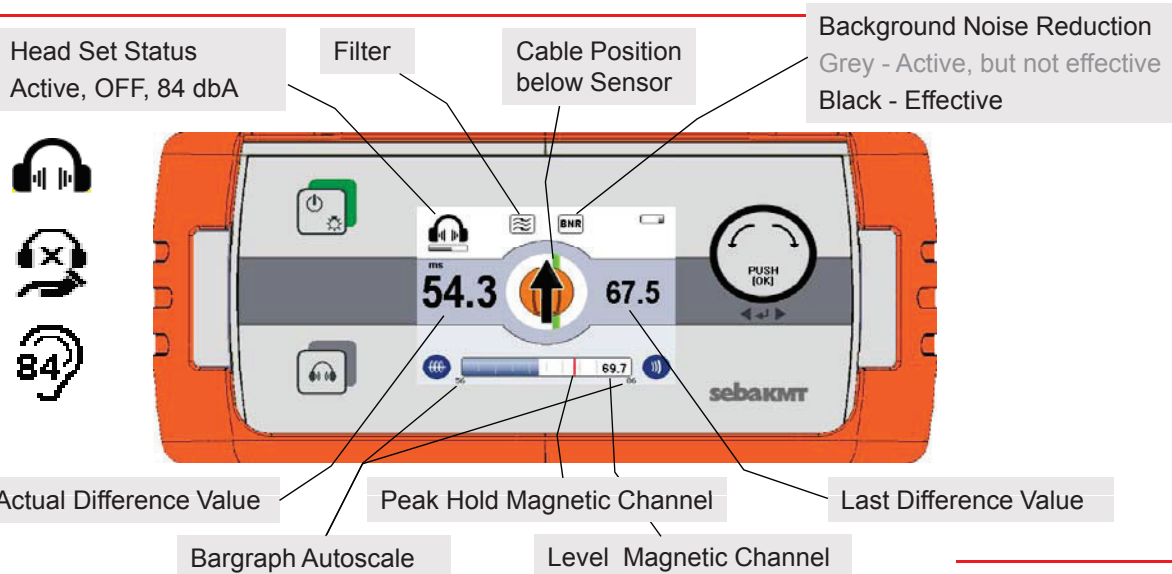


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Display elements

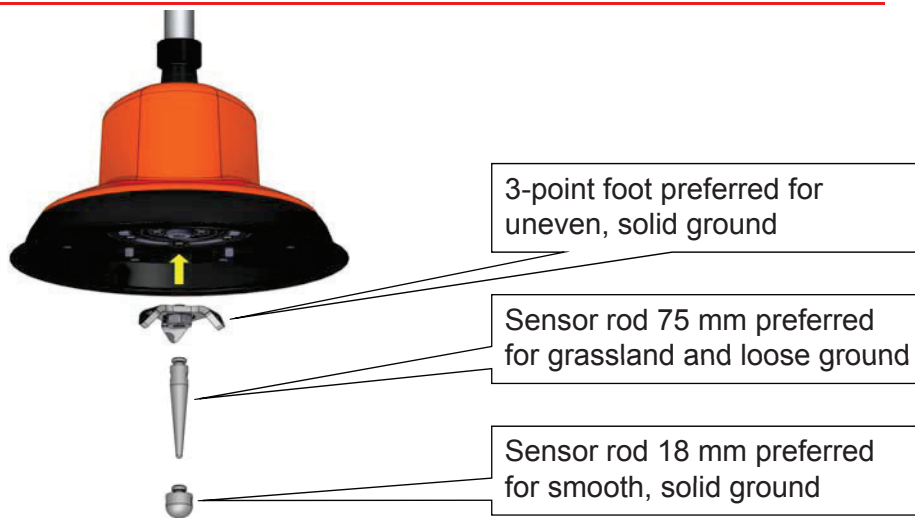


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Sensor connection to the ground

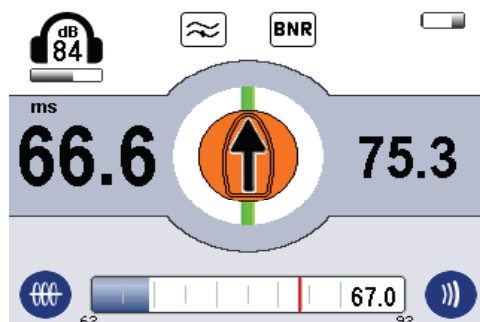


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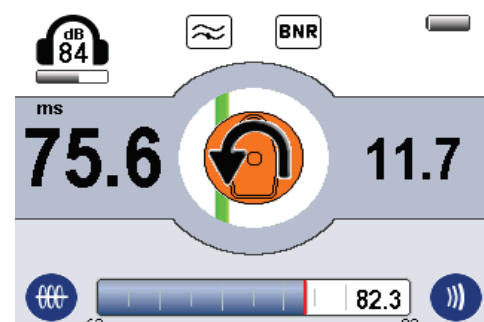
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digiPHONE+ Compass



Before the fault:
The new value is lower than
the old difference value



After the fault:
The new value is higher than
the old difference value

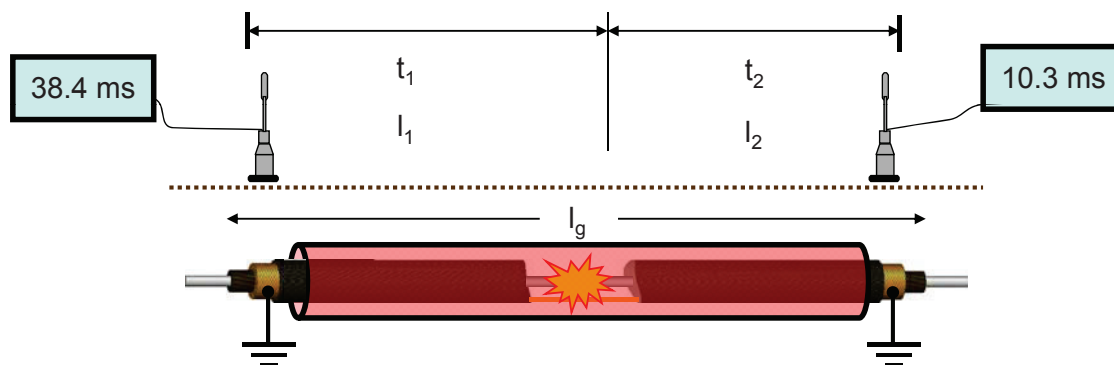
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Pinpointing – Acoustic Method

Fault locating in cables inside a conduit



Example: $t_1 = 38.4$, $t_2 = 10.3$, $l_g = 50$ m

$$l_x = l_g \frac{t_1}{t_1 + t_2}$$

$$l_x = 50 \cdot \frac{38.4}{38.4 + 10.3} = 39.4 \text{ m}$$

Cable Fault Prelocation

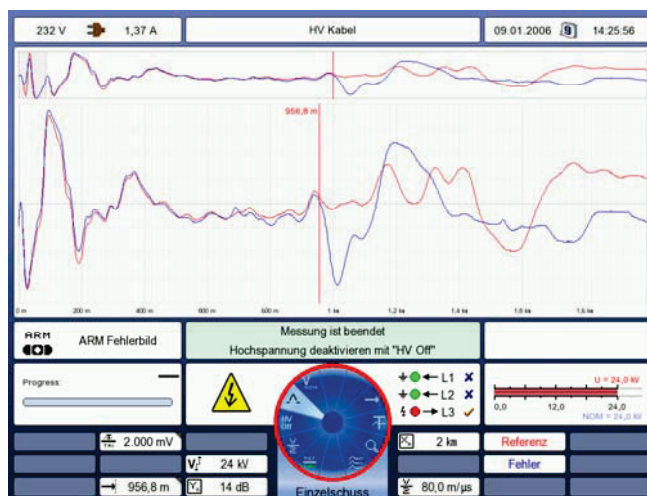
HV – Methods for
high resistance Faults



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Prelocation ARM – Arc Reflection Method

Cable Fault Location : Prelocation with HV



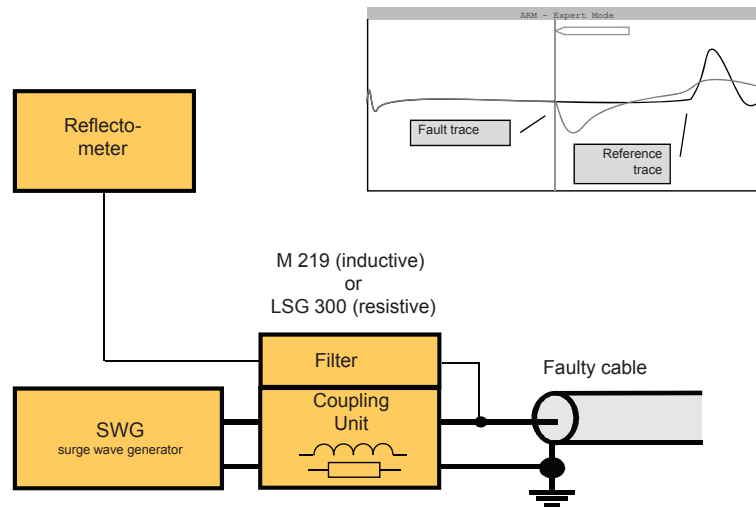
Arc Reflection Measurement (ARM)

Passive coupling

Voltage level with ARM:

Up to max. 32 kV with stand-alone units

Up to max. 50 kV in a test van (depending on equipment)



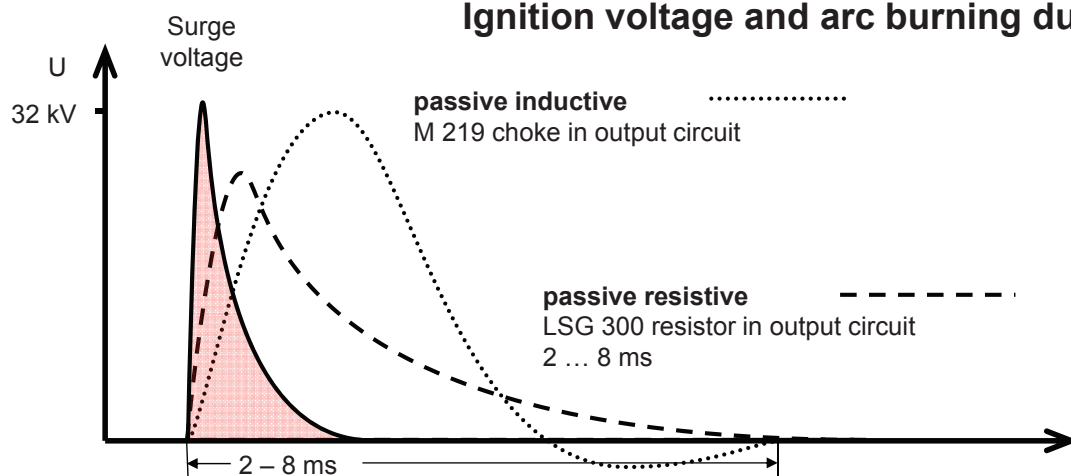
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Passive Arc Stabilisation

Ignition voltage and arc burning duration



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Pre location – ARM Slide

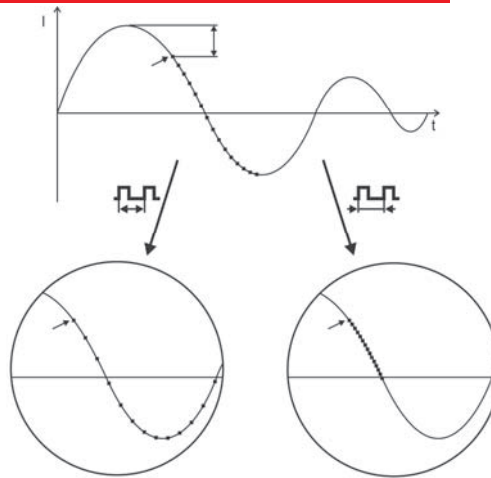
ARM-Slide is not a specific operational mode, but is always a standard contained in the normal ARM mode.

The measurements are done as follows:

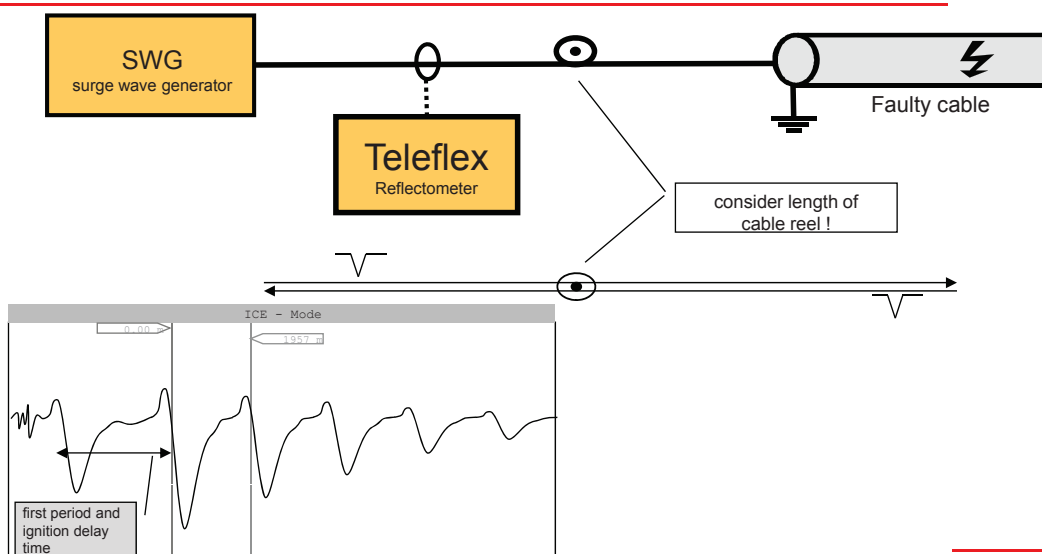
- 1st Measurement with trigger after current maximum
- 2nd-15th Measurement with adjustable timing

The delay may be varied between

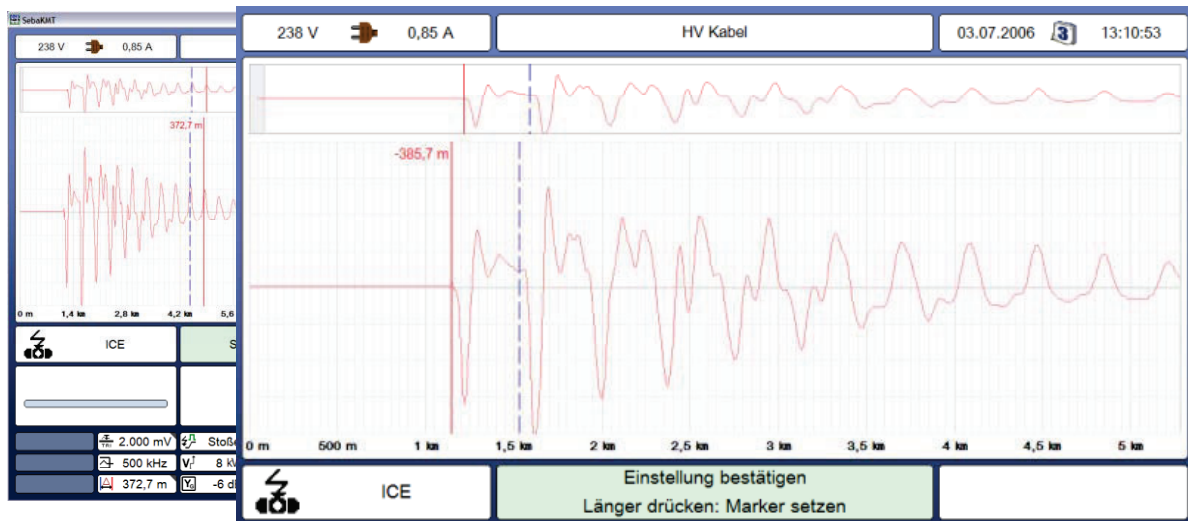
0 μ s and 3.84 ms



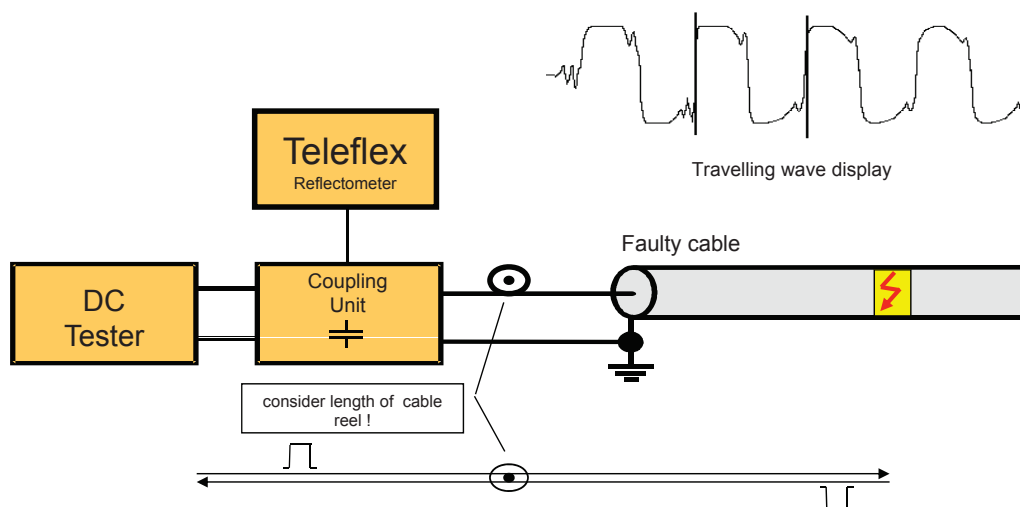
Test Setup ICE (Impulse Current Equipment)



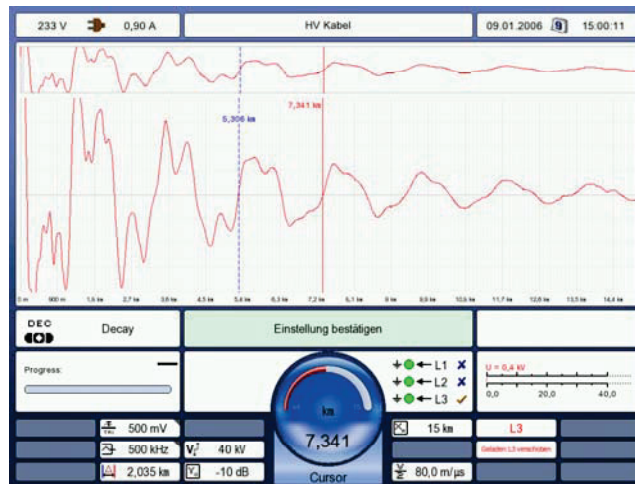
Field Test



Test Setup Decay Method



Reflectometer Figure Decay



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Comparison of basic HV-Prelocating Methods

ARM

- most common HV-fault locating method
- most details visible (joints, cable end, ...)
- up to SWG-voltage (typically 32 kV)
- connecting cable automatically subtracted
- set TDR range to cable length

ICE Impulse Current

- good for long lead cables and faults in wet joints
- up to SWG-voltage (typically 32 kV)
- set TDR range to 5 or 10 times cable length
- measure length of one period
- don't consider first period (includes ignition delay time)
- measured length may be 7 to 15 % too long due to varying $v/2$, depending on pulse ignition and shape
- subtract connecting cable

Decay

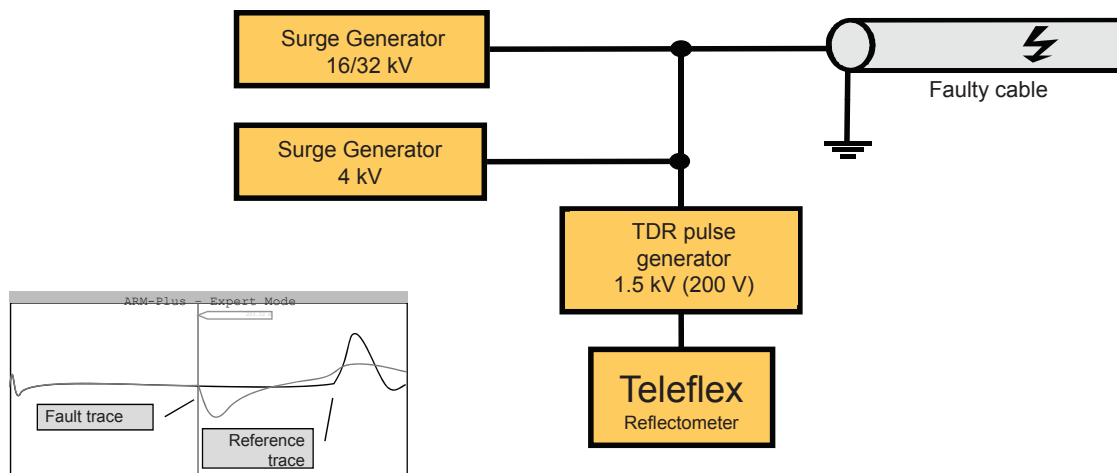
- good for HV-fault locating at higher voltages (Centrix up to 80 kV, Variant up to 130 kV)
- faulty cable has to be "chargeable", failing with a flash-over. Leakage current faults cannot be located
- set TDR range to 5 or 10 times cable length
- measure length of one period
- subtract connecting cable

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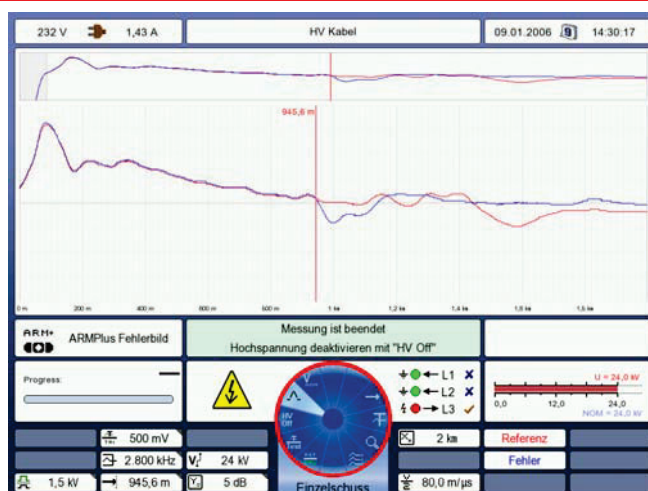
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Test Setup ARM Plus



Prelocation - ARM Plus



Measuring Sequence ARM Plus

■ Step 1

- Measurement of the good trace (reference) with a test impulse of 1500 V (or adjustable to 200 V for lower flashover voltage)

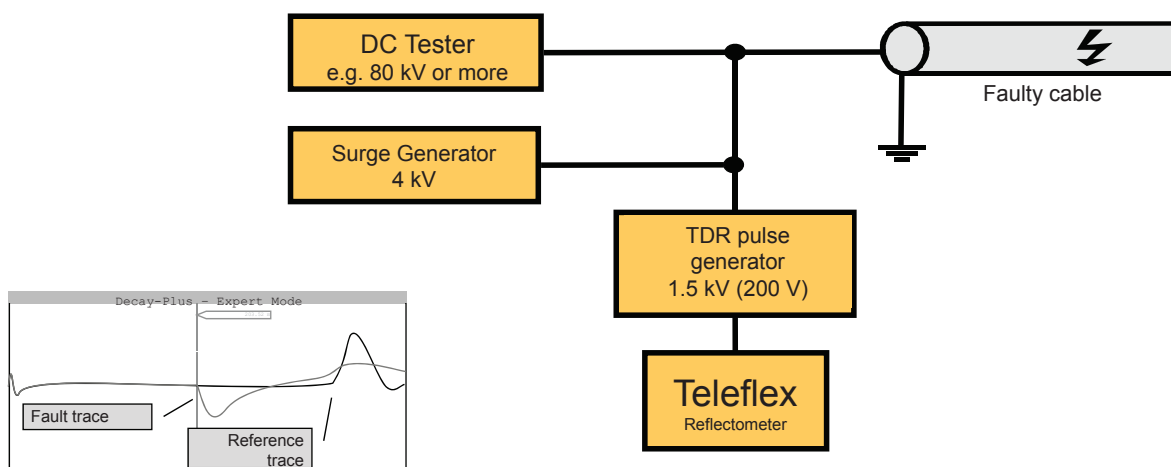
■ Step 2

- Measurement of the fault trace during a

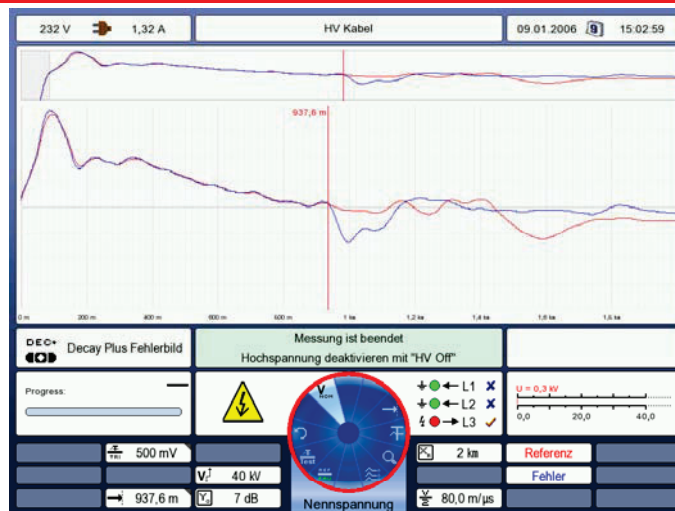
surge	0 ... 4 kV
surge	0 ... 8 kV
double surge	0 ... 16 kV / 4 kV
	0 ... 32 kV / 4 kV

into the flashover with a test pulse of 1500 V (or 200 V).

Test Setup Decay Plus



Prelocation - Decay Plus



Measuring Sequence Decay Plus

- Step 1
 - Measurement of the good trace with a test impulse of 1500 V (reference trace)
- Step 2
 - Flashover of the fault at test voltages from 32 kV up to 80 kV
- Step 3
 - Surge with 4 kV into the existing flashover
- Step 4
 - Measurement of the fault trace with a test impulse of 1500 V into the flashover



PRACTICAL TRAINING

Underground Cable Fault Location

Presented by

[Instructor's Name]

National Power Training Institute of Nigeria (NAPTIN)

[Date]

1

I. Introduction

Training Objectives

What you will learn in this course.



Understand Fundamentals

Compare underground and overhead lines, and learn the basic structure of power cables.



Identify Faults

Learn common cable faults, their causes, and the associated protection methods.



Cable Diagnostics

Master modern cable testing techniques like VLF, Tan Delta, and Partial Discharge.



Locate Faults

Learn the systematic, 3-step process for locating underground cable faults in the field.

2

I. Introduction

Introductions

Let's get to know each other.



Photo

Your Instructor

[Instructor's Name]

[Brief bio of the instructor, their experience in the power sector, and expertise in cable fault location.]



Let's Meet You

Please introduce yourself:

Your Name, Your Role, Years of Experience

3

I. Introduction

Agenda

The structure of our training session today.

1. Introduction to Power Lines
2. Underground Cable Fundamentals
3. Cable Faults and Failures
4. Cable Testing and Diagnostics
5. Cable Fault Location Techniques
6. Practical Session: Hands-on Training
7. Q&A and Wrap-up

4

I. Introduction

Safety First!



Working with high-voltage equipment is dangerous. Always adhere to safety protocols.

- ⚠ Always de-energize and lock-out/tag-out circuits before working.
- ⚠ Use appropriate Personal Protective Equipment (PPE), especially insulated gloves.
- ⚠ Ensure proper grounding of **all** test equipment.
- ⚠ Maintain a safe distance from energized components.

5

II. Underground vs. Overhead

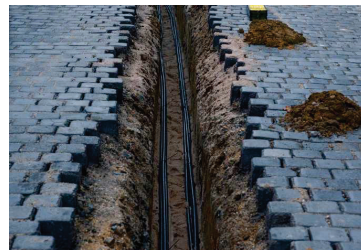
Power Line Installation Methods

Two primary ways to deliver electricity.



Overhead Lines

Wires are strung on utility poles, carrying electricity above the ground.



Underground Lines

Insulated cables are buried in trenches below the ground surface.

6

II. Underground vs. Overhead

Overhead Lines: Advantages & Disadvantages

✓ Advantages

- ✓ Lower cost to install and repair.
- ✓ Quicker construction time.
- ✓ Easier and faster to locate and repair faults.

✗ Disadvantages

- ✗ More susceptible to bad weather (wind, storms).
- ✗ Vulnerable to damage from trees and animals.
- ✗ Visually less attractive.

7

II. Underground vs. Overhead

Underground Lines: Advantages & Disadvantages

✓ Advantages

- ✓ Not impacted by wind and tree branches.
- ✓ Visually more attractive (unobstructed views).
- ✓ Less susceptible to vehicle collisions.

✗ Disadvantages

- ✗ More expensive to build and repair.
- ✗ Locating faults is significantly more difficult.
- ✗ Susceptible to flooding and damage from digging.

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II. Underground vs. Overhead

Which Method to Choose?

The best choice is a balance of competing factors.

Underground

Ideal for residential, parks, historical areas.

Cost

Appearance

Reliability

Maintenance

Overhead

Works well for long distances, high voltages.

The ultimate mix provides the highest quality of service at the lowest possible price.

9

II. Underground vs. Overhead

Summary & Q&A

Key Takeaway

There is no single "better" method. The choice between overhead and underground lines is a strategic decision based on a trade-off between cost, reliability, and aesthetics for a specific location.

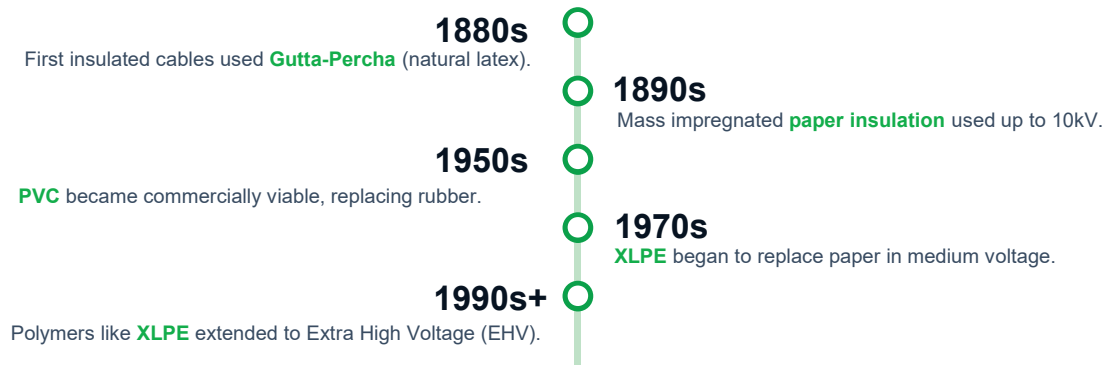
Questions?

10

III. Underground Cable Fundamentals

A Brief History of Power Cables

From natural latex to modern polymers.

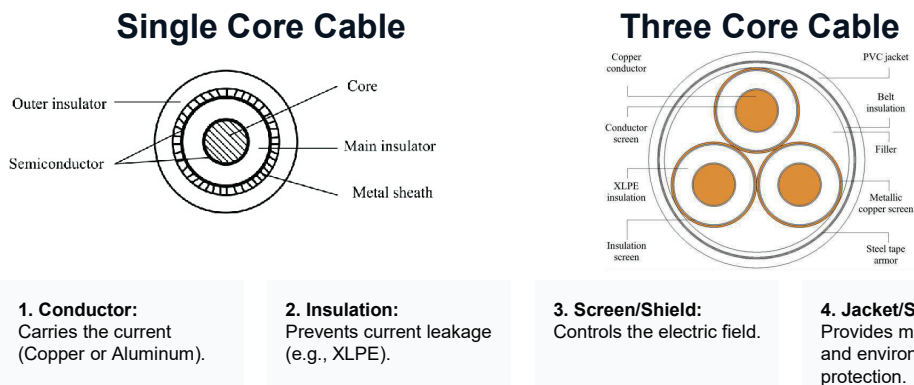


11

III. Underground Cable Fundamentals

Functional Characteristics of Cables

A look inside a typical power cable.



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III. Underground Cable Fundamentals

Types of Cable Insulation

A look at the materials that keep the power contained.



Impregnated Paper

Layers of pure cellulose paper impregnated with thick oil or an oil-resin mixture. A traditional and reliable insulation method.

Used for voltages up to 60 kV.



Solid Insulator

Modern polymers like Cross-linked Polyethylene (XLPE) or Ethylene Propylene Resin (EPR), applied through extrusion.

Used for voltages up to 132 kV.



Oil Fluid Cables

Uses paper layers with low-viscosity oil under pressure. Complex and costly, this technology has been gradually abandoned.

Used for high voltages up to 380 kV.

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III. Underground Cable Fundamentals

Types of Laying

How cables are installed underground.



Direct Laying

Cables are laid directly in an excavated trench. Simple and cost-effective.



Draw-in System

Cables are pulled through pre-installed conduits or ducts. Easy to repair or add to.



Solid System

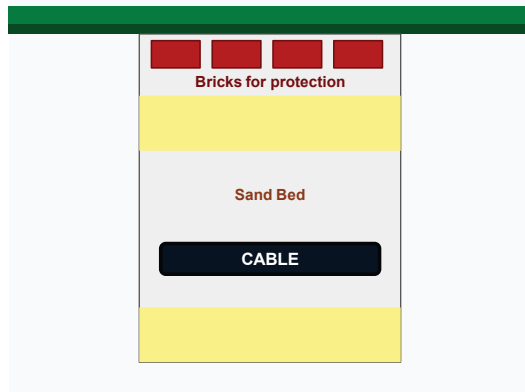
Cables are laid in troughs filled with a bituminous compound. Rarely used today.

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III. Underground Cable Fundamentals

Direct Laying Method

The most common and cost-effective installation technique.



Cross-section of a typical direct-laid cable trench.

Advantages

- ✓ Simple and less costly.
- ✓ Creates ideal conditions for heat dissipation.
- ✓ Clean and safe as the cable is invisible.

Disadvantages

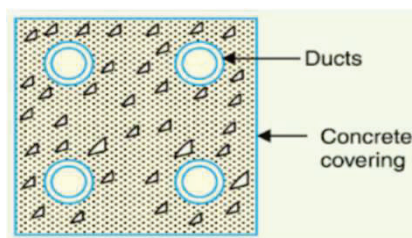
- ✗ Extending or altering the network requires new excavation.
- ✗ Localization of a fault is difficult.
- ✗ Maintenance costs can be very high.

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III. Underground Cable Fundamentals

Draw-in System (Conduit/Duct)

A flexible system for repairs and upgrades.



Cables are pulled through ducts embedded in concrete.

Advantages

- ✓ Repairs and additions can be made without excavation.
- ✓ Strong mechanical protection reduces faults.
- ✓ Simpler cable joints and lower maintenance costs.

Disadvantages

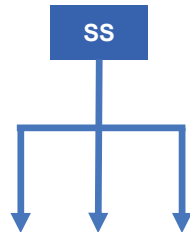
- ✗ The initial cost is very high.
- ✗ Reduced current carrying capacity due to poor heat dissipation.

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III. Underground Cable Fundamentals

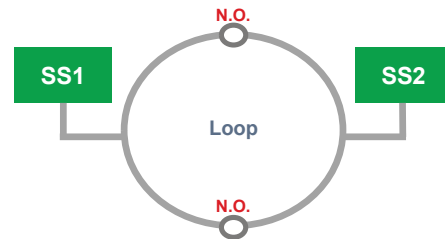
Common Underground Infrastructure

How distribution circuits are configured to deliver power.



Radial Main Feeder

A single power source delivers power along a single path. Simple but less reliable.



Open-Loop Feeder

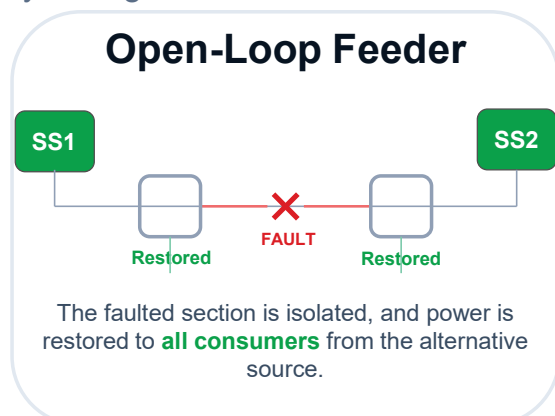
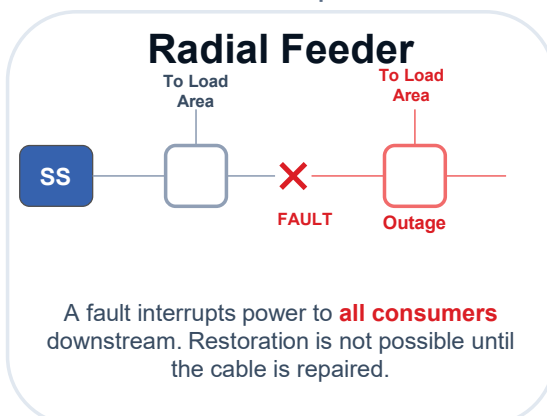
Two sources provide power, allowing for isolation of faults and higher reliability.

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III. Underground Cable Fundamentals

Radial vs. Open-Loop Feeder

A comparison of reliability during a fault event.



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IV. Cable Faults and Failures

What is a "Fault"?

Understanding the official definition of a failure in a power system.

According to the IEEE, a fault is a "partial or total local failure in the insulation or continuity of a conductor."



Short Circuit

An abnormal connection of low impedance between two points of different potential (e.g., phase-to-ground, phase-to-phase). This is a failure of **insulation**.



Open Circuit

A break or interruption in the normal path of the current. This is a failure of **continuity**.

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IV. Cable Faults and Failures

Description of Cable Faults

The three most common types of faults found in underground cables.



1. Open-Circuit Fault

Occurs when there is a **break in the conductor** of a cable. The normal continuity of the circuit is interrupted.



2. Short-Circuit Fault

Occurs when **two conductors** of a multi-core cable come into electrical contact due to insulation failure.



3. Earth Fault

Occurs when the conductor of a cable comes in **contact with the earth** (ground).

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IV. Cable Faults and Failures

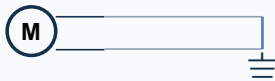
Identifying Faults with a Megger

How to use an insulation tester to diagnose the fault type.

1. Open-Circuit Test

Checks for breaks in the conductor.

Far end shorted & earthed



A broken conductor will show **infinite resistance ($\infty \Omega$)**, while a healthy one will show zero.

2. Short-Circuit Test

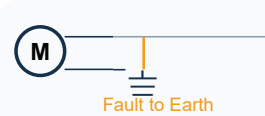
Checks for faults between conductors.



Connecting the megger to two conductors will show **zero resistance (0Ω)** if a short exists.

3. Earth Fault Test

Checks for faults between conductor and ground.



Connecting between a conductor and earth will show **zero resistance (0Ω)** if earthed.

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IV. Cable Faults and Failures

Causes of Faults

Faults are broadly categorized into mechanical and electrical causes.

Mechanical Causes

- ↓ **Digging & Excavation**
Third-party damage from construction work is a primary cause.
- ⚠ **Improper Handling & Installation**
Sharp bends, excessive pulling force, or placing rocks on cables.
- 🐭 **Rodent Damage**
Animals chewing on the cable's outer jacket and insulation.

Electrical Causes

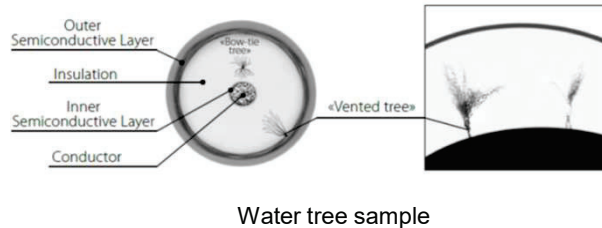
- ⚡ **Lightning Surges**
Over-voltages from lightning strikes can puncture the insulation.
- 🔥 **Overloading & Thermal Failure**
Excessive current leads to overheating, accelerating insulation aging.
- ⚡ **Insulation Aging & Water Treeing**
Natural degradation over time, often accelerated by moisture ingress.

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IV. Cable Faults and Failures

Understanding Water Treeing

A major cause of long-term insulation failure in polymeric cables.



Water treeing is a degradation process in polymeric insulation, caused by the presence of moisture and electrical stress. It forms tree-like channels within the insulation, reducing its dielectric strength and eventually leading to failure.

1 Vented Trees

Start from the semiconductive shields and grow into the insulation. They are considered more dangerous as they can bridge the entire insulation layer.

2 Bow-tie Trees

Start from contaminants or voids within the insulation material itself and grow outwards in a bow-tie shape.

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IV. Cable Faults and Failures

Protection Methods on Underground Lines

Key principles for isolating faults and ensuring system reliability.



Principle: Non-Reclosing Protection

Unlike overhead lines where faults are often temporary, faults on underground cables are almost always **permanent**. Therefore, protection devices should be set for single-shot operation to avoid causing more damage to the cable.



Strategic Placement of Devices

Sectionalizing devices (like fuses or breakers) should be placed at the **start of underground sections**, such as transition points from overhead lines or at the substation. This helps to:

- Quickly distinguish between overhead and underground faults.
- Minimize restoration time by isolating the faulted cable section.

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IV. Cable Faults and Failures

Types of Protective Devices

Fuses

✓ Advantages

- Inexpensive & compact
- Low maintenance
- Current-limiting types reduce equipment damage

✗ Disadvantages

- No reclosing capability (suitable for UG)
- Can cause "single-phasing"
- No low-level ground fault sensing

Circuit Breakers

✓ Advantages

- Highly versatile and adjustable (relays)
- High interrupting capability
- Interrupts all 3 phases simultaneously
- Ground fault protection available

✗ Disadvantages

- Significantly more expensive
- Requires more space and external power
- Complex to operate and maintain

Reclosers

✓ Advantages

- Ground fault sensing available
- Easily adjustable settings
- SCADA compatible for remote control
- Less expensive than breakers

✗ Disadvantages

- Reclosing feature must be disabled ("one-shot" mode) for underground lines.

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V. Cable Testing and Diagnostics

Why Proactive Testing is Crucial

Moving from a reactive to a proactive maintenance strategy.



Prevent Unplanned Outages

Identifying and addressing insulation weaknesses before they lead to a catastrophic failure significantly reduces unexpected downtime.



Increase System Reliability

Regular diagnostic testing provides a clear picture of your cable assets' health, allowing for data-driven decisions on repair or replacement.



Optimize Maintenance Costs

Planned repairs are far less expensive than emergency, after-hours fault location and repair work. Testing helps prioritize where to spend your budget.

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V. Cable Testing and Diagnostics

VLF AC High Voltage Testing

What is VLF Testing?

An AC withstand test performed at a **very low frequency** (e.g., 0.1 Hz) to check the insulation integrity of the cable.

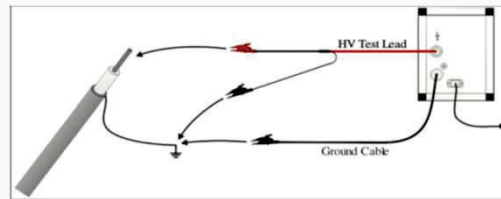
Why Use Such a Low Frequency?

Cables are capacitive. Lowering frequency reduces the required power. Testing at 0.1 Hz requires **500 times less power** than at 50 Hz, allowing for portable test equipment.

Key Advantage

A VLF test is more effective and less damaging than a DC test for detecting certain defects in solid dielectric cables (like XLPE).

Typical VLF Test Connections



The HV lead is connected to the conductor of the phase under test. The other two phases and the cable shield are grounded along with the test set.

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V. Cable Testing and Diagnostics

VLF Test Voltage Levels & Duration

Recommended values based on IEEE 400.2 guidelines.

Cable Rating (phase-to-phase)	Installation Test (phase-to-ground)	Acceptance Test (phase-to-ground)	Maintenance Test (phase-to-ground)
5 kV RMS	9 kV RMS (13 kV peak)	10 kV RMS (14 kV peak)	7 kV RMS (10 kV peak)
8 kV RMS	11 kV RMS (16 kV peak)	13 kV RMS (18 kV peak)	10 kV RMS (14 kV peak)
15 kV RMS	18 kV RMS (25 kV peak)	20 kV RMS (28 kV peak)	16 kV RMS (22 kV peak)
25 kV RMS	27 kV RMS (38 kV peak)	31 kV RMS (44 kV peak)	23 kV RMS (33 kV peak)
35 kV RMS	39 kV RMS (55 kV peak)	44 kV RMS (62 kV peak)	33 kV RMS (47 kV peak)

Recommended Test Duration

The current IEEE recommendation for the duration of a VLF test is from 15 to 60 minutes. Industry experience justifies a **minimum time of 30 minutes**.

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V. Cable Testing and Diagnostics

Tan Delta ($\tan\delta$) Diagnostics

Measuring the level of insulation degradation.

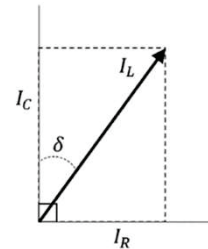
💡 The Principle

- An **ideal** cable's insulation is a perfect capacitor. Current (I_C) leads voltage by 90°.
- A **real** cable has defects, creating a resistive path. This causes a resistive current (I_R) in-phase with the voltage.
- **Tan Delta** is the ratio of this resistive current to the capacitive current.

🔄 What it Tells Us

It provides an **overall assessment** of the cable's insulation health. A higher $\tan\delta$ value indicates more degradation, meaning the insulation is becoming more resistive (lossy).

Current Relationship



$$\tan \delta = \frac{I_R \text{ (Resistive)}}{I_C \text{ (Capacitive)}}$$

As insulation degrades, I_R increases, causing the angle δ and the $\tan \delta$ value to rise.

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V. Cable Testing and Diagnostics

Partial Discharge (PD) Diagnostics

Detecting the small sparks that lead to big failures.

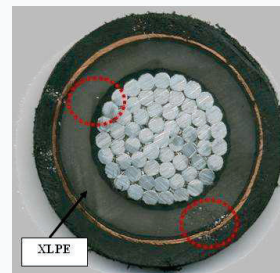
⚡ What is Partial Discharge?

A localized electrical discharge that only **partially bridges the insulation** between conductors. It occurs in voids, cracks, or at interfaces within the insulation material due to high electrical stress.

♥ How it Causes Failure

- The discharge spark is low energy, but its repeated occurrence gradually **erodes the insulation**.
- It creates harmful byproducts (like ozone and nitric acid) that chemically attack the insulation.
- Over time, this erosion process creates a conductive channel, leading to a **catastrophic failure** of the cable.

PD Within Insulation Void



High electrical stress causes tiny sparks within a gas-filled void, slowly damaging the surrounding insulation material.

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V. Cable Testing and Diagnostics

Online vs. Offline PD Testing

Choosing the right method for the right situation.

Offline PD Testing

Outage Required

- ✗ Provides the most detailed results (severity, location, inception voltage).
- ✗ Requires a scheduled outage, which can be disruptive and costly.
- ✗ Uses an external voltage source, allowing for controlled testing conditions.
- ✗ High equipment cost and requires highly skilled operators.
- ✗ Time-consuming (typically >2 hours per test).

Best for detailed diagnostics and commissioning tests.

Online PD Testing

No Outage Required

- ✓ No interruption to service, performed on energized cables.
- ✓ Faster and more economical, ideal for screening large cable populations.
- ✓ Reflects real-world operating conditions (voltage, load, temperature).
- ✓ Lower equipment cost and simpler operation.
- ✓ Quick test time (typically <10 minutes per test).

Best for periodic surveys and continuous monitoring.

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VI. Cable Fault Location Techniques

Challenges in Cable Fault Location

Why finding a fault underground isn't always straightforward.



Invisible Nature

Cables are buried underground, making direct visual inspection impossible.



Time-Consuming

Pinpointing can require walking long distances, which may take hours or even days.



Complex Interpretation

Test results (e.g., TDR traces) can be difficult to interpret, especially on complex networks with many branches.



Stress on Cable

Some locating methods (like thumping) apply high voltage surges, which can stress and potentially harm aged cable insulation.

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VI. Cable Fault Location Techniques

The 3-Step Process of Fault Location

A systematic approach from classification to pinpointing.



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VI. Cable Fault Location Techniques

Thumping a Cable (Acoustic Method)

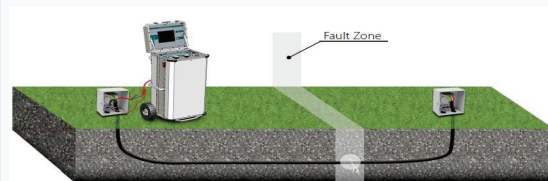
The classic method for pinpointing a fault's exact location.

The Principle

This technique is used for **pinpointing** the fault after its general area has been found (prelocated).

1. A "Thumper" (surge wave generator) sends a powerful **high-voltage surge** into the faulted cable.
2. When the surge reaches the fault, it jumps across the insulation breakdown, creating an **arc**.
3. This arc is like a small underground explosion, producing a distinctive **"THUMP"** sound.
4. Crews walk along the cable route using listening devices (geophones) to find the spot where the sound is loudest.

Acoustic Pinpointing



The surge from the generator causes a flashover at the fault, creating a sound wave that travels to the surface.

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VI. Cable Fault Location Techniques

Thumping: Pros and Cons

Understanding the strengths and weaknesses of the acoustic method.

✓ Advantages (Pros)

- ✓ **Highly Accurate Pinpointing:** When it works, it can identify the exact location to dig with high precision.
- ✓ **Easy to Learn:** The basic concept is straightforward, and the equipment is relatively simple to operate.

✗ Disadvantages (Cons)

- ✗ **Extremely Time-Consuming:** Walking the entire cable route can take hours or even days.
- ✗ **Potentially Harmful:** Repeated high-voltage surges can stress and damage aged cable insulation, possibly causing future faults.
- ✗ **Ineffective on Certain Faults:** It does not work on bolted (dead short) faults or open circuits where no arc can be created.

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VI. Cable Fault Location Techniques

Time Domain Reflectometry (TDR)

Creating a graphical roadmap of the cable for prelocation.

➤ The Principle (Pulse Echo)

1. The TDR instrument sends a **low-voltage, high-frequency pulse** down the cable.
2. The pulse travels along the cable until it hits a **change in impedance** (e.g., a splice, a fault, or the end of the cable).
3. At that point, some or all of the pulse's energy is **reflected** back to the TDR.
4. The TDR measures the time it takes for the reflection to return and calculates the **distance to the impedance change**.

🔍 Used For

TDR is the primary method for **prelocating** faults. It is most effective for:

- **Open circuits** (broken conductors)
- **Short circuits / Low resistance faults**

TDR Trace vs. Cable Events



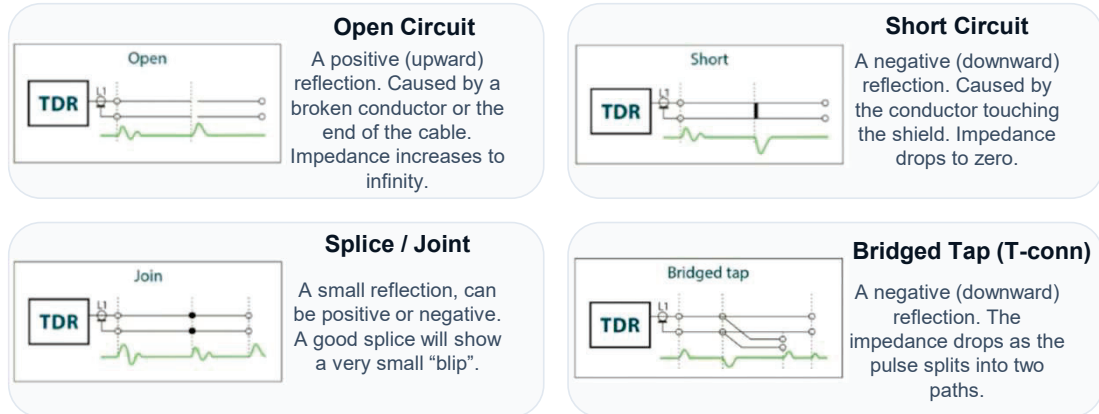
The TDR displays a waveform (trace) where "blips" correspond to physical events along the cable's length.

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VI. Cable Fault Location Techniques

Interpreting TDR Waveforms

Understanding what the reflections mean.



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VI. Cable Fault Location Techniques

Arc Reflection Technique (ARC)

Combining TDR and Thumping to find high-resistance faults.

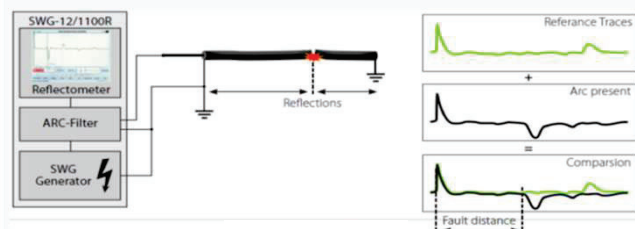
★ The Problem with TDR Alone

A standard TDR's low-voltage pulse cannot "see" a **high-resistance fault** (e.g., a water tree). The pulse simply travels past the fault as if it's not there, only reflecting from the cable end.

🔔 The ARC Solution

1. A **Thumper** sends a high-voltage surge to the cable.
2. This surge has enough energy to flash over the high-resistance fault, creating a **temporary arc** (a momentary short circuit).
3. At the exact same time, the **TDR** sends its low-voltage pulse.
4. The TDR pulse now **reflects off this arc**, revealing the fault's location as a negative "blip".

ARC Method Concept



A filter allows the TDR and Thumper to be connected simultaneously. The Thumper creates the arc, and the TDR sees the reflection from it.

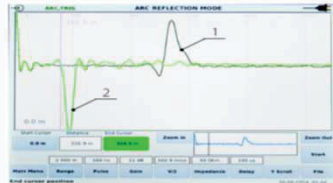
38

VI. Cable Fault Location Techniques

ARC Waveform Analysis

Comparing traces to reveal the fault location.

Step 1: Capture Reference Trace (TDR pulse only, no surge)



Trace description:
1. Positive reflection at the cable end **healthy core**
2. Negative reflection at the faulty point (short circuit) **faulty core**

The low-voltage TDR trace is recorded.
The high-resistance fault is **invisible**.
Only the end of the cable is seen.

Step 2: Capture ARC Trace (TDR pulse + HV surge)



During the surge, a new trace is captured.
The arc at the fault creates a **new, negative reflection**.

The Result: Comparison is Key

By comparing or subtracting the two traces, the **point of difference** clearly shows the distance to the fault.
This is the core principle of the ARC method.

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VI. Cable Fault Location Techniques

Other Prelocation Methods

Specialized techniques for difficult high-resistance faults.

DECAY (Voltage Decoupling)

The cable is charged with DC voltage until the fault breaks down. The energy stored in the cable's capacitance discharges through the fault, creating a traveling wave. The system records this decaying oscillation, and the fault distance is calculated from its period.

Useful for high-resistance faults with a high breakdown voltage.

ICE (Current Decoupling)

A surge from a thumper triggers the breakdown. The system then measures the transient current wave that travels between the fault and the measurement point. This method inductively measures the current pulse.

Effective for faults in the lower kΩ range and over very long distances where ARM may fail.

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VI. Cable Fault Location Techniques

Summary & Q&A

Reviewing the key fault location methods.

TDR PRELOCATION

Your primary tool. It's fast, safe (low voltage), and effective for **low-resistance faults** and **open circuits**.

ARC Method PRELOCATION

The solution for **high-resistance faults**. It combines the TDR with a surge to make invisible faults visible.

Thumping PINPOINTING

The final step. Used to find the **exact spot** to dig after prelocation, by listening for the acoustic "thump".

Questions?

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VII. Practical Session: Hands-on Training

Introduction to Equipment

Meet the Megger STX 40 Cable Fault Locator.



A portable, all-in-one system for cable testing and fault location.

Key Functions We'll Use Today:

- ✓ **Insulation Test**
To classify the fault (high or low resistance).
- > **TDR (Pulse Reflection)**
To prelocate low-resistance faults.
- 🔔 **ARC Method**
To prelocate high-resistance faults.
- ⚡ **Surge Pinpointing**
To pinpoint the fault using the acoustic method (Thumping).

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VII. Practical Session: Hands-on Training

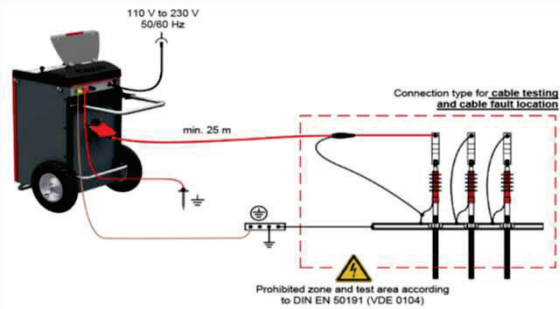
Preparation and Connection

Safety and proper setup are the first priority.

Pre-Test Checklist

- ✓ **Isolate Cable:** Ensure the cable is de-energized and disconnected from both ends.
- ✓ **Wear PPE:** Put on insulated gloves and any other required personal protective equipment.
- ✓ **Proper Grounding:** Connect the STX 40 to a reliable station ground. This is critical for safety and accuracy.
- ✓ **Connect Leads:** Connect the HV lead to the phase conductor under test. Ground the other phases and the cable shield.
- ⚠ **Establish Safety Zone:** Keep a safe distance (min. 2.5m) from all HV components during the test.

Basic Connection Diagram



The diagram shows the connection for both cable testing and fault location. Note the separate grounds for the system and the cable shield.

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VII. Practical Session: Hands-on Training

Practical 1: Measuring a Healthy Cable

Establishing a baseline with a fault-free cable.

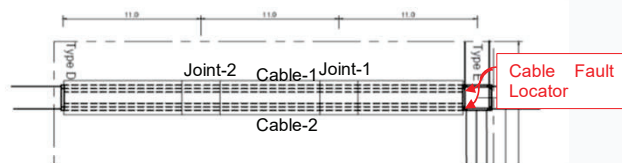
Objective

To understand the TDR signature of a healthy, open-ended cable. This will serve as our reference (or "baseline") trace for comparison in later tests.

Procedure

1. Conduct an **Insulation Test** to confirm the cable is healthy.
2. Perform a **DC Voltage Test** to check for any breakdown.
3. Conduct a **Pulse Reflection (TDR)** measurement.

Test Setup



Expected TDR Result:

A clean trace with a single, large **positive (upward) reflection**, which indicates the open end of the cable.

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VII. Practical Session: Hands-on Training

Practical 2: Locating a Low Resistance Fault

Applying TDR and Surge Pinpointing to a short circuit.

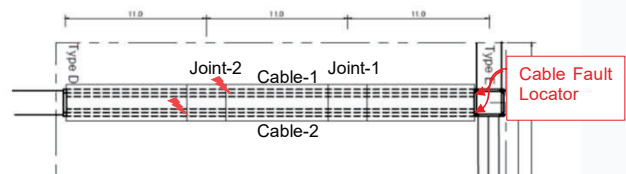
Objective

To prelocate and pinpoint a simulated **low-resistance fault** ($<10\text{ k}\Omega$). Observe the difference in the TDR trace compared to the healthy cable.

Procedure

1. Conduct an **Insulation Test** to confirm a low-resistance fault exists.
2. **Prelocate** the fault's approximate distance using **TDR**.
3. **Pinpoint** the fault's exact location using **Surge Pinpointing** (Thumping).

Test Setup



Expected TDR Result:

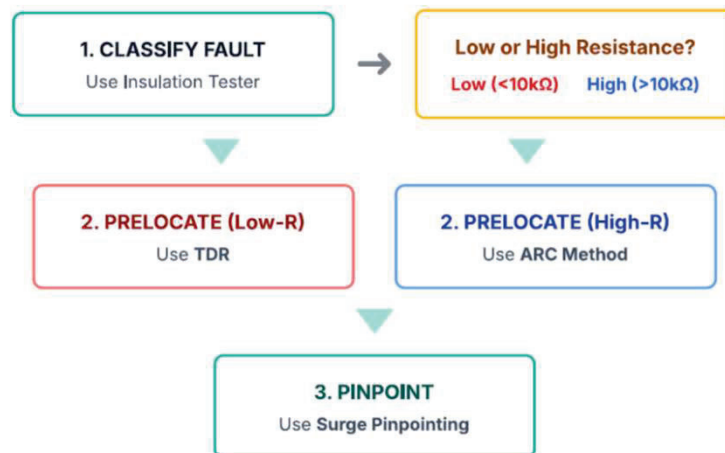
The trace will show a **negative (downward) reflection** at the fault location, indicating a drop in impedance (a short circuit).

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VII. Practical Session: Hands-on Training

Practical Session Summary

Reviewing the fault location workflow.



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VIII. Wrap-up

Course Review: Key Takeaways

A summary of what we've learned.



Fundamentals

Understood the pros and cons of Underground vs. Overhead lines and the basic structure of power cables.



Faults & Protection

Identified common cable faults (Open, Short, Earth), their causes, and the role of protective devices.



Diagnostics

Learned the principles of modern diagnostic tests like VLF, Tan Delta, and Partial Discharge to assess cable health.



Location Workflow

Mastered the 3-step fault location process: Classify, Prelocate (with TDR/ARC), and Pinpoint (with Thumping).

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VIII. Wrap-up



Q & A

Any final questions?

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VIII. Wrap-up

Thank You

For your active participation in this training.

[Instructor's Name]

National Power Training Institute of Nigeria (NAPTIN)
instructor.name@naptin.gov.ng | +234-XXX-XXX-XXXX

Name: Organization:		A AEDC Headquarters		B AEDC Headquarters		C AEDC Saito District office		D AEDC-ECT South Regional Office		E AEDC		MUTIN		MUTIN	
1. Explaination		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?		- The instructor explained technical losses. - How to calculate instantaneous technical losses. - Power system loss calculation using a power system loss calculation program (PSAT - NEPLAN). - Showed that the instantaneous value of losses is different from the annual loss calculation.		Different methods of calculation of power loss, using Excel sheet, NEPLAN and manual calculation.		Power system loss		- Manual calculation for instantaneous technical loss. - Model distribution line for calculation.		- Delivery was excellent. - Clear and concise.		Manual calculation of technical losses.		- Clear outline of objectives of course. - Good diagrams demonstrate the calculation objectives manual. - Good procedures for using the NEPLAN to arrive at the losses.	
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?		- This is just a demo training. - The training should be a bit more detailed.		---		Practical application using NEPLAN Application.		Demonstration more on NEPLAN calculation.		Demonstration tools.		Generalized losses of the distribution system.		---	
2. Configuration and contents of the lecture material		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
2.1 Overall, were configuration and contents of lecture material good? Choose yes or no.		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
2.2 What was (were) good point(s) of the lecture material?		- Explained power losses, distribution losses, technical losses fixed and permanent losses, variable technical losses. - Technical losses. - The fixed and variable losses of the power system, loss calculation.		- Distribution losses. - Technical losses. - The fixed and variable losses of the power system.		Load loss calculation		- Very clear and simple to understand. - The graphics and the pictures are very clear.		Very attractive and readable.		Evaluation of technical losses		Objectives and outline are easy to understand.	
2.3 What was (were) point(s) that should be improved of the lecture material?		---		Practical demonstration using NEPLAN.		Practical demonstration using NEPLAN.		Soft copies should be made available to the trainees.		It should be spiral binded.		Explanation of methods of mitigating losses.		- I suggest block diagrams could be used to simplify and focus on the sequence of the calculations. - Comparison between calculation methods could be explained more.	
3.3 Questions especially about "Loss Reduction"		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
3.1.1 Do you think that, if a 10-year experienced technician takes this course, he/she become to be able to calculate instantaneous technical loss only by himself/herself? Choose yes or no.		Yes		Yes		Yes		Yes		---		Yes		---	
3.1.1.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?		- Technical loss calculation for both instantaneous value and annual loss calculation and factors in loss calculation. - Load distribution factor.		Understanding the parameter or formula in calculating instantaneous technical loss.		He must carry out the loss calculation practically and always overtime, this will enable him understand better.		Manual calculation for instantaneous technical loss.		Manual calculation is explanatory.		Manual calculation is explanatory.		---	
3.2 Do you think that, if a 10-year experienced technician takes this course, he/she become to be able to calculate Annual technical loss only by himself/herself? Choose yes or no.		Yes		Yes		Yes		Yes		Yes		---		---	
3.2.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?		- Manual calculation for annual technical loss. - Using NEPLAN and Excel sheet.		- The steps in calculating annual technical loss and the parameter. - Peak load consumption per Annum, load factor. - Load loss factor.		Same as above (3.1.1)		- Evaluation of technical loss. - How to mitigate them. - Causes.		---		---		---	
3.3 Do you think that, if a 10-year experienced technician takes this course, he/she understands cause of loss increasing and its mitigation and become to be able to plan and carry out the mitigation? Choose yes or no.		Yes		Yes		Yes		Yes		Yes		---		---	
3.3.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?		- Understand that technical losses are caused by in efficiencies of electric power flow through conductors. - Understand that technical losses are caused by in the distribution system. - Understand the major causes of technical losses in the distribution system.		Understanding the root cause of technical loss and equipment to be installed to improve technical loss.		- Low power factor improvement. - Overloading of distribution transformer. - Understate conductor.		Load distribution factor would help.		Evaluation of losses.		---		---	
4 Do you recommend your colleague to take the course or recommend your losses to let subordinates to take the course? Choose yes or no.		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
4.1 Why do you think so?		Learning the knowledge and applying the contents of the courses to practical use will make many changes needed for the standards and specification of our networks for all voltage levels.		Understanding technical loss in the power system and how to calculate the technical losses of annual technical losses.		It's a good one.		It would enable the knowledge be impacted to others quickly.		Technical loss is a major problem in the distribution industry which if not identified will affect the business negatively. Hence the need for this course.		---		This will enable informed decision to be taken as for as course improvement, purchase of teaching aids and purchase of software is concerned.	
5 Do you have any other opinions or observations about this course?		- The course content is good. - Without the regulators enforcement and DISCOs management investment, not much will be achieved.		---		- Practical demonstration is very good. - Other PSAT like PSS SYNCAL could be used, if possible.		There is need for practical demonstration of the loss modeling to enable participants apply the idea in the field.		---		---		---	

Comments Table for 1st Classroom Training Demonstration on Reliability Improvement

A	B	C	D	E	F	G	NAPITN	NAPITN
1. Explanation 1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no. 1.2 What was (were) good point(s) of the instructor's (or instructors') explanation? III. Professional. 1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	Yes I. Concise delivery of the presentation/course. 2. Step by step analysis of the topics/lectures. I. Online Assessment of test questions to attendees/trainees	Yes • Practical application and maintenance on both overhead lines and underground feeders • Specifying some devices and functions for maintenance and fault detection devices	Yes • Very clear and explicit. • More demonstration tools.	Yes • Water tree phenomenon, where water digress into the underground cable, there by grounding the cable. • To give examples for illustration and explanations.	Yes I. Water tree phenomenon II. Cable test methods III. Inclusion of standards in construction III. Inclusion of breaker switch auto recloser to reduce downtime.	Yes • The instructors were very explanatory. • They were able to pass the knowledge in a very simple manner. • The instructors were very professional. I. Duration of the course for at least on physical examples. II. Too much colouring resulting to eye stress. III. The course should improve more on the main topic (Fault Detection) compared to safety and documentation. IV. The use of mobile devices and documentation.	Yes • Underground cable fault detection techniques. • Safety awareness and situational awareness for fault detection documentation. • Emphasis is more on underground cable fault detection techniques. The course should be more attention on the main topic (Fault Detection) compared to safety and documentation. • The use of mobile devices and documentation.	Yes
2. Configuration and contents of the lecture material 2.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no. 2.2 What was (were) good point(s) of the lecture material? I. A deeper look at different scenarios/practices must occur on daily basis for improvement in feeder reliability and reduction of downtime. 2.3 What was (were) point(s) that should be improved of the lecture material?	Yes I. On point technical terminologies 2. Presentation on the Distribution Network component to suit current reality. I. Showcase modern equipment applicable to Nigerian Distribution network. E.g., Modern test equipment.	Yes • Importance of keeping record outage record. • Process of detecting fault before isolating and restoration. • Maintenance processes • Different methods of fault detection.	Yes • Well defined and readable. • Graphic packages are very excellent. Presentations are very easy to understand. • Detailed examples should be emphasised more.	Yes • Graphic packages are very excellent. Presentations are very easy to understand. • Detailed examples should be emphasised more.	Yes I. Inclusion of overhead line fault on physical examples. II. Exclusion of standards in construction III. Inclusion of breaker switch auto recloser to reduce downtime.	Yes • Faults detecting methods Causes of faults; fault detection method, safety, situational awareness, and fault detecting communication). • The course should improve more on the main topic (Fault Detection) compared to safety and documentation. • The use of mobile devices and documentation.	Yes • The use of images in explanation. • Description of the expected learning outcome. • Provision of additional references.	Yes
3. Questions especially about "Reliability Improvement" 3.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand? 3.2 Do you think that, if a 10-year experienced technician takes this course, he/she understands Fault detecting methods and gets able to teach it to his/her colleagues? Choose yes or no. 3.3 Do you think that, if a 10-year experienced technician takes this course, he/she understands Maintenance of overhead lines and gets able to teach it to his/her colleagues? Choose yes or no. 3.4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the pre.	Yes I. Causes of faults on both underground and overhead lines. II. Safety and situational awareness III. Best practices that will improve customer centricity. Yes I. Causes of faults on both underground and overhead lines. II. Safety and situational awareness III. Best practices that will improve customer centricity. Yes I. Causes of faults on both underground and overhead lines. II. Safety and situational awareness III. Best practices that will improve customer centricity. Yes I. Causes of faults on both underground and overhead lines. II. Safety and situational awareness III. Best practices that will improve customer centricity.	No • Practical knowledge of the equipment used for fault detection. • Importance of quick restoration time. • Natural reliability can be achieved when using ring circuit. • Importance of quick restoration time. • Natural reliability can be achieved when using ring circuit. • Importance of quick restoration time. • Natural reliability can be achieved when using ring circuit. • Importance of quick restoration time.	Yes • Practical demonstration and all other parts are essential as they form the major aspects of what we do. • To carry out preventive and corrective maintenance. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines.	Yes • To carry out preventive and corrective maintenance. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines.	Yes • Field work would be beneficial to the frames. • To carry out preventive and corrective maintenance. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines. • To understand the safety components of the overhead lines.	Yes • The areas helpful are: I. Fault detection techniques – Visual inspection, safety measures, and the use of thermovision camera should be captured in the material. • The use of thermovision camera should be captured in the material. • The use of thermovision camera should be captured in the material. • The use of thermovision camera should be captured in the material.	Yes • Most DISCOs still use manual (Visual inspection) for fault detection. • The use of thermovision camera should be captured in the material. • The use of thermovision camera should be captured in the material. • The use of thermovision camera should be captured in the material.	Yes
4. Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the pre.	Yes I. Identify some inspection techniques. II. Routine inspection of overhead lines III. To understand maintenance management. Yes I. Identify some inspection techniques. II. Routine inspection of overhead lines III. To understand maintenance management.	Yes • How to check or inspect overhead line components. • How to identify defective overhead line components. • How to check or inspect overhead line components. • How to identify defective overhead line components.	Yes • Where and what to look at during inspection. • Where and what to look at during inspection. • Where and what to look at during inspection. • Where and what to look at during inspection.	Yes • Identification of faulty components of the overhead lines. • Maintenance cycle implementation. • Identification of faulty components of the overhead lines. • Maintenance cycle implementation.	Yes I. Analysis of gathered outage data and effective countermeasures that recording of systematic outage data and applying appropriate counter measures. II. Classroom examples will be better. Yes I. Analysis of gathered outage data and effective countermeasures that recording of systematic outage data and applying appropriate counter measures. II. Classroom examples will be better.	Yes • Key contributions to reducing outages. • Measures to reduce frequency of outages. • Analysis of forced outage data and applying appropriate counter measures. • Key contributions to reducing outages. • Measures to reduce frequency of outages. • Analysis of forced outage data and applying appropriate counter measures.	Yes • There is need for the list of the major causes of forced outages and their counter measures. • There is need for the list of the major causes of forced outages and their counter measures. • There is need for the list of the major causes of forced outages and their counter measures.	Yes
5. Do you have any other opinions or observations about this course?	Yes I. Every staff should understand the reliability of a feeder. II. The course should be more energy to every home and business 24/7. III. Reliability of feeders will improve the reliability of the network and expand the network/business. • How do you measure Reliability? Comparing the nature of action taken to achieve the intended results to total number of actions taken.	Yes • Especially on record keeping of an equipment and feeder. • Recommend that subordinates should take the course contents for their own maintenance knowledge acquisition.	Yes • I recommend my subordinate colleagues as they are more directly involved in the repair and fault clearing. • There should be advanced level aspect of the course where artificial intelligence aspect of prudent asset management will be discussed.	Yes • I will recommend my colleagues because we will have time to pass it down to my subordinates. • The course should be expanded to include more personnel to attend the course. • The course should be expanded to include more personnel to attend the course.	Yes I. Basic knowledge for every distribution network engineers. II. It is basic knowledge for every distribution network engineers. III. It is basic knowledge for every distribution network engineers. IV. It is basic knowledge for every distribution network engineers.	Yes • All technical staffs should know more about fault detecting methods with their own maintenance professional improvement. • They should know how to reduce forced outages. • They should know more about the causes of forced outages and underground networks. • They should know more about the causes of forced outages and underground networks.	Yes • It serves as upskilling of experienced personnel. • The course should be more professional improvement. • The course should be more professional improvement. • The course should be more professional improvement.	Yes

Comments Table for 1st Classroom Training Demonstration on Quality Improvement

	A	B	C	D	E	F	G	H
1 Explanation								
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	• The instructors are good, being able to elaborate terms to our understanding, which gives birth to free interaction.	• The instructors' explanation was very clear and interactive.	• Communicated effectively. • Very organised in delivering the course content. • Excellent time management skill.	• How to mitigate voltage drop on power distribution network • How to calculate voltage drop on a single and three phase power system.	• The causes of poor power quality mitigation techniques. • Advantages of power quality equipment. • The instructors are very experienced and demonstrated high level of professionalism.	• Necessity of power quality analysis.	• The instructors are very effective and a great communicator. • The instructors are very simple in explaining the concepts. • The instructors are very experienced and demonstrated high level of professionalism.	• The instructors took time to explain about flicker and power quality is well understood.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	• I don't think there is room for any improvement of the lecturer. They are doing a very good and interactive installation and material used.	• The training should emphasis on improvement of the lecturer. They are doing a very good and interactive installation and material used.	• Have there for more challenging opportunities for greater success.	NO ANSWER	• Reduce the speed of delivery.	• Transient: More examples would be needed. • The instructor should introduce more physical examples.	• The instructor's explanation was well understood and more experience was put on the training.	
2 Configuration and contents of the lecture material explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the lecture material?	• How to mitigate line voltage drop for proper system planning.	• It is informative and easy to deliver. • It has a clear content, easy to understand.	• Good presentation of the lecture. • Well-arranged and useful for the trainings.	• Different components of Power Quality and their causes and effects. • Voltage drops calculations.	• Very readable. • Good quality materials.	• Reasons why power quality must be monitored and reduced or eliminated in power network.	• Introduction to power quality analyses, indicators of poor power quality, standards and why. • Components of power quality, such as voltage drop, flicker, harmonics, Transients, voltage drops. • Voltage drop calculation. • Ferrate effect.	• All the lecture materials are ok.
2.3 What was (were) point(s) that should be improved of the lecture material?	• The instructors should be strict for more practical orientation to be able to properly merge with the theoretical teachings for more understanding of the student.	• We are trying to solve problems that were caused due to poor planning and deviation from standards. • We should emphasis and drive from for strict adherence to standard.	• Despite the fantastic presentation, need to widen the scope/course content and necessary to cover other related areas. • Reference to NERC orders (Distribution and safety grid introduced in the course contents)	NO ANSWER	• It should be presented in spiral bound type.	• Transient. • Voltage drop calculation: Reality in Nigeria network should be adopted.	• Load standard and specifications (NERCA and NERC) are not stated in the document. • Protection of life and properties should be included under necessity for power quality analysis.	• The materials are ok.
3 Questions especially about "Quality Improvement"								
3.1 Do you think that, if a 10-year experienced technician takes this course, he/she understands Voltage drop calculation methods and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	• Knowing formulae and being able to deploy when necessary during the calculation to resolve or mitigate system stability.	• Understand the constant and the variable forms on the length of the feeder (L) and the current (I)	• Power quality improvement. • Mitigating technical losses. • Causes of voltage drops in power system and mitigations.	• Knowing the formulae for calculation of voltage drop • Understanding the line parameters.	NO ANSWER	• Least this in the previous class (Reliability Improvement) • The excel part is very important.	• Understanding voltage drop calculation for network planning. • Voltage drops calculation formula using Microsoft Excel. • Understanding the parameters of voltage drop calculation.	• Training and Retraining.
3.2 Do you think that, if a 10-year experienced technician takes this course, he/she understands typical power quality problems and how they affect electrical systems and equipment? And he/she gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.2.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	• Encourage earth improvement exercise to protect customer equipment which is the common problem in many buildings/houses. • Comparing of power improvement quality.	• He or she needs to understand that poor power quality can result to equipment failure, power outages, transients, harmonics, surge and interruptions.	• Causes of power anomalies and mitigations. • Understanding the components of power anomalies. • Voltage drop calculation.	• Damaging of power equipment.	• Component of power quality. • Indication of power quality.	• Solutions to voltage drop. • Ferranitic effect.	• Understanding the concept of power quality. • Determining typical power quality problems and how they affect electrical system. • Explore methods for measuring and monitoring quality parameter. • Mitigation techniques to develop skills and Solutions to improve power quality.	• It will help in carrying out maintenance work on the system or network.
3.3 Do you think that, if a 10-year experienced technician takes this course, he/she understands techniques to mitigate power quality problems and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.3.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	• Consumes the standard to mitigate power quality problems in their homes.	• He or she should understand power quality problems, targeting a combination of techniques, targeting specific components.	• SAME AS ABOVE	• Load balancing • Identification of VAR or reactor where necessary.	• Mitigating transients • Mitigating voltage surge and swells.	• Power factor • Proper grounding requirement for good grounding. • Filters.	• Determining typical power quality problems and how they affect electrical system. • Explore techniques/methods for measuring and monitoring quality parameter. • Mitigation techniques to develop skills and Solutions to improve power quality problem.	• Training and retaining will help improve their work.

Comments Table for 1st Classroom Training Demonstration on Quality Improvement

4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? (Note) Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	A	B	C	D	E	F	G	H
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	Because it will build confidence in the participation to coach or teach people ways to improve quality in their work.	- Taking this course and applying its contents in our network will help to correct issues of power quality and improve the voltage we deliver to our customers. - The contents are good. Again, we must emphasize on the standards and specifications while we coach and teach people ways to move forward, we need to level up to Japanese standards. This will reduce the outages and voltages issues that arise and improve customer satisfaction. Also, the ESCO will earn more revenue.	- The training course should be extended to technical staff in AEDC irrespective of the grade level. - Excellent, helpful and course outlines very satisfactory.	- The person will learn different power quality problems and equipment required to improve power quality. - NO ANSWER	- It is very educative and can help to improve the quality of work and knowledge by colleagues. - There is the need to do more of the training and even move ahead for the advance course. The course is very good for more than two hours without lunch is not a good one.	- It is one of the challenges in Nigeria power supply industry. - I would love some equipment on power quality detection and improvement to be deployed for practical purpose.	- Capacity building - Improve services efficiency - Improve company revenue generation - Improve technical know-how.	- I got a lot of experience during the training. - I will explore MAPTIN to organize this type of training every six month, it will go a long way for our technical staff at AEDC.
5 Do you have any other opinions or observations about this course?	Not at all.							

Comments Table for 2nd Classroom Training Demonstration on Quality Improvement

1 Explanation	A	B	C	D	E	F	G	H	I
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	•Voltage management in distribution networks •Utilization of assets to reduce the voltage drops which could lead to system failure.	Good presentation.	•Power Quality Analysis •The need to monitor power quality. •Components of power anomalies, well detailed and easily understood.	•Clear explanation on components of power quality. •Components of power anomalies are well detailed and easily understood.	•Concise teaching. •Good time management. •On point explanation.	•Components of power anomalies, well detailed and easily understood. •FERBANT Effect.	•They make the made the class very interactive. •They appeared smart and cheerful. •They were very specific.	•Objectives of power quality improvement. •Necessities of power quality analysis. •Factors of poor power quality location.	•Monitoring power quality. •Load profiling. •Optimize power quality remedy location.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	•How the compensator, such as var capacitor, can be used to compensate the voltage drops. •Can be utilized practically in the network system to address the voltage drops which could lead to system failure.	More practical related examples.	Methods for measuring and monitoring power quality parameters.	•More explanation needed on voltage swell/sags.	More practical examples.	•Power quality standards. •Voltage drop calculations should be precise and detailed. •Using excel sheet.	•Improve their knowledge base through more trainings. •Come at the introduction part to allow candidate to understand better.	•Harmonics. •Voltage drop solution. •Network analysis.	
2 Configuration and contents of the lecture material									
2.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the lecture material?	•How to improve the voltage profile and quality of power supply.	Clear print and good organisation.	General materials was direct and well explained.	•The content of the lecture is well explained. •The flow of the content is very good.	Detailed without being too large and bulky.	Materials quality and pictures.	•The materials were discrete and same time detailed.	•Power quality standards. •Voltage drop calculation. •Why monitoring power quality.	Voltage drop solution/mitigation
2.3 What was (were) point(s) that should be improved of the lecture material?	•More about compensators - "FACTS" •To assist the knowledge and awareness of learners in future and modern planning of network systems.	Just okay	•Improvement in the area where the class will be interactive by allowing participants to be engaged. •Voltage drop calculation.	•Introduction of more practical examples.	More diagrams could be introduced.	•Materials should be size edited, not back and front or share soft copy.	•The logical flow of the content should be improved on.	•More practical examples. •Illustrate key concepts. •Introduce more of emerging trends and technologies.	•Dynamic voltage management. •Network security and reliability.
3 Questions especially about "Quality Improvement"									
3.1 Do you understand Voltage drop calculation methods and will you be able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	•Basically, $ee = K \times I$ (length of line $< 100m$) $\times Z \times I$ and excel format $Z = \frac{1}{\text{Impedance}}$ •R (Resistance) $\cos \phi + X$ (Reactance) $\sin \phi$	Calculation using the Microsoft excel sheet.	Voltage drop calculation using Excel.	•Voltage drop calculation for network planning.	The excel activity done by the instructor.	•FERBANT Effect. •Power quality analysis and improvement. •Voltage drop calculations.	•Voltage imbalance % = Minimum voltage deviation from average voltage •Voltage drop calculation using excel.	•Voltage drop calculation using Microsoft excel.	•Conductor cable parameters •Test run the real live ppa meter and see the effect.
3.2 Do you understand typical power quality problems and how they affect electrical systems and equipment? And will you be able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.2.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	•Transients - Slight changes in voltage interruptions. •Voltage sags and surges - Slight lower voltage levels in the system. •Swell/Surges	All the parts makes up the presentation.	•Consumer aspect •The area of identifying the power quality problems.	•Sources of poor power quality. •Why monitor power quality? By consumers	•Voltage surges. •Voltage swell •Voltage sag	•Voltage sag/ Dip/ Swells. •Voltage sags and fluctuations. •Voltage imbalance. •Harmonic distortion •Voltage drop.	•Transients.	•Voltage sag/ Dip/ Swells. •Voltage sags and fluctuations. •Voltage imbalance. •Harmonic distortion •Voltage drop.	
3.3 Do you understand Techniques to mitigate power quality problems and will you be able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.3.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?		All the sub-headings concerning it.	•Voltage swells •Over voltage and under voltage.	•Voltage sag/ Dip/ - some solutions •Increasing the conductor sizes etc. •Voltage drops - solution i.e. tap changes, phase balancing, reinforcement.	•How to balance load effectively and UPS, Capacitors and distributed generation sources to mitigate power quality.	•Tap changing. •Load Management.	•Load management. •Dynamic voltage management.	•Installation of lightning arrester to protect the equipment. •Installation of energy storage device such as SPB. •For voltage swells installation of additional power lines (overrating).	•Indicator of power quality. •Voltage drop solution. •Some mitigation solution to power quality such as lightning arrester.

Comments Table for 2nd Classroom Training Demonstration on Quality Improvement

	A	B	C	D	E	F	G	H	I	L
4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	4. Recommended for other colleagues	It will help them better understand and manage operations.	• Basic training and re-training of staff. • Create a better chance to better service to consumers.	4.1 I strongly recommend my colleagues to take the course, this will help the network. • My colleagues are the ones that have a great impact on the network activities.	4.1 It will be a capacity building course for subordinates and also refresher course for colleagues and bosses.	4.1 The course will help the distribution engineers to understand and learn some of the power quality issues in their network.	4.1 Taking the course will improve problem solving skills, and help personnel to stay up to date with new or emerging technologies in solving power problems.	4.1 I strongly recommend all the distribution company technical staff to take the course in order to close the gap between practical and the theory aspect of the job.	4.1 It reflects our brain on what we were thought.	
5 We are considering changing from face-to-face training to e-learning training for the classroom training that we are introducing here. The reason for this is that some people have said that the cost of lodging, meals, transportation, and other things is too high. We are considering Mr. MARTIN and we would like to encourage as many people as possible to attend from within our limited training budget. Please answer the following questions regarding the conversion of classroom training to e-learning.										
5.1 Is there a problem with converting the training into an e-learning program?	Yes	No	Yes	Yes	No	No	No	No	No	No
Why do you think so?	4.1 It is better for a face-to-face training because it is easier to be able to ask more questions based on field observations.	As explained above, E-learning could not accommodate more people conveniently.	4.1 I believe the face-to-face program is better because it is more interactive and the student because you share ideas generally.	Direct interactions will be okay if practical is involved in the training.	It can be taught effectively virtually without losing its impact.	4.1 Learning is cheaper and time boundaries can be altered according to the convenience.	There is no hands on training for this course, so it could be online.	Classroom interaction and practical aspects should be involved in some of the courses.	4.1 Proper attention may not be given, but there will be lack of administration.	
5.2 Is there any content in this training that should not be converted to e-learning?	No	No	Yes	No	No	No	No	Yes	No	
Why do you think so?	• Practical training is better.	They can all be accommodated.	• For me, all the contents should be maintained face to face training. I would like to move to the advantages of the learners.	• The content of this course is theoretical.	The material is adequate and can be converted to e-learning.	The contents are all relevant to the course.	This is because, there is no practical training in this course.	• Theoretical training.	4.1 It can be converted to e-learning but full concentration will not be given to the course.	
5.3 If this training were to be converted to e-learning, is there any content that you think would be difficult to understand?	Yes	No	No	Yes	No	No	No	Yes	No	
Why do you think so?	• The practical experiences of the teachers would be more helpful.	They are summarised and not too cumbersome to understand.	NIL	The practical aspect will be difficult	4.1 It has been broken down for easy understanding and it relates to practical network activities.	The contents are easy to understand and clear to the students.	The course is quite specific and very explanatory.	Practical Training.	Because most of these were thought.	
6 Do you have any other opinions or observations about this course?	None	Exposing participants to practical training will be very helpful.	NIL	Satisfactory	Good.	• Yes, there is need for tabulation of the difference between surges, swells and sag for more understanding.	None.	Satisfactory	No	

Comments Table for 1st Practical Training Demonstration on Phase Comparison

Name:	A	B	C	D	E	F	JICA Expert Team
	AEDEC	AEDEC	AEDEC	AEDEC	AEDEC	AEDEC	AEDEC
1 Explanation							
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes	Yes	Almost yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	- Indication - Phase balancing - Fault detection	I am happy with the instructors explanation.	All the points were good and well explained.	It was ok and the instructor is very good.	The instructor was nice and understandable.	It was ok and the instructor is very good.	The situation cannot be conveyed without first explaining the difference between the training facility and the actual site. The "Caution" mentioned in "Training manual for phase comparison work" should be explaine more detail.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	Before any connection, you must be able to indicate the light connection.	This lecture should be had 2-3 times a month.	All points was well explained.	The instructor is good.	Many points should be improved for more understanding.	Yes, there is need to improve more in the technical skill.	The examination work is awkward. Further repeated practice is needed.
2 Configuration and contents of the training material							
2.1 Overall, were configuration and contents of lecture material good? Choose yes or no.	Yes	Yes	Yes	Yes	No	Yes	-
2.2 What was (were) good point(s) of the lecture material?	How phase indicator should be handled.	The hand gloves and the lecture.	All the lecture materials were good.	The protection part.	The configuration of the material was not good enough.	The configuration was ok, and carrying out of the test.	-
2.3 What was (were) point(s) that should be improved of the training material?	The improvement in the installation for more student to learn.	Non	More educative materials should be provided.	More educative material should be provided.	Many points should be improved.	Yes, more equipment on megger.	Since it seems that some parts were not sufficiently conveyed only orally, the necessity of phase detection work on distribution lines should be lectured in the actual N training, before the practical training, along with the mechanism of such work.
3 Questions especially about "phase comparison work on distribution line"							
3.1 Do you think that, if a less than 5-year experienced technician takes this course, he/she becomes to be able understands the necessity of phase comparison work on distribution line and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	-	Yes	Yes	Yes	Yes	
3.1.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	Most especially when installing a transformer, phase indicator is very important to avoid explosion.	-	The phase comparison should be done on a live line for a better understanding.	YES	The point should not be difficult for him to understand.	There is necessity of phase comparison to avoid damage of equipment.	Once the energized simulated substation is completed to construct, the operation of the phase comparator should be checked on an energized line at the end of this training demonstration.
3.2 Do you think that, if a less than 5-year experienced technician takes this course, he/she becomes able to conduct overhead fault detection by him/herself, and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	No	Yes	
3.2.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	Must not work without supervision.	Been well suited up in overall and gloves.	All the points.	All the points.	The part of line inspection.	With lecture and practical, they will understand.	
3.3 Do you think that, if a less than 5-year experienced technician takes this course, he/she become able to conduct phase comparison work only by himself/herself? Choose yes or no.	Yes	-	Yes	Yes	Yes	Yes	
3.3.1 If yes, especially what part(s) will help him/her to understand well? If no, what part(s) is (are) difficult.	Subsequent training will help to understand more.	Everyone coming for the training should be happy.	No part is too difficult to understand.	No point was too much to understand.	The hpotronic should be explained better.	Conducting of phase comparison work is very important for more understanding.	
4 Do you recommend your colleagues to take this course or recommend your boss to let subordinates to take this course? Choose yes or no. (Note) Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	-	Yes	Yes	No	Yes	
4.1 Why do you think so?	The training was perfect and ok.	-	Yes, the course is highly recommended.	The course is highly recommended.	-	Everyone needs to know it.	
5 Do you have any other opinions or observations about this course?	I enjoyed every bit of the training.	-	The trainers should be sent abroad for more training abroad.	More training abroad.	Yes, the course should be re-organised again, for more improvement.	The above training is very ok.	

Comments Table for 2nd Practical Training Demonstration on Phase Comparison

Name:		B	C	D	E
Organization:		AEDC	AEDC	AEDC	AEDC
1 Explanation					
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	How to detect a fault in all phases; red, yellow and blue phase on the line by using the machine to test.	How to use the equipment to know the phase to phase connection	Instructor was able to explain how to carry out voltage cables	The transmitter and receiver are electronic devices that gives clear visible indication of status that determine the phase relationship between two points at the same nominal voltage.	The good of the instructors explanation is how to use the phase comparison equipment.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	The instructor is good though a little improvement on the verbal explanation..	Everything about the equipment is good.	NIL	She was perfectly ok both in practical and lecture. She is good to go.	The time limit should be improved.
2 Configuration and contents of the training material					
2.1 Overall, were configuration and contents of training material good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the training material?	The point in the training materials are good and self explanatory.	The equipment used are good.	It explain the theoretical view of what was practicallised on the field.	Training material gives us more details and easy to understand even a layman can understand.	The good point of the training materials how to use safety belt, hand glove, phase comparison devices.
2.3 What was (were) point(s) that should be improved of the training material?	The point is perfect. No area of improvement.	No improvement.	NIL	I recommend a minimal text book.	The diagrams should be improved on the training materials.
3 Questions especially about "Phase comparison work on distribution line"					
3.1 Did you understand the necessity of phase comparison work on distribution line and get able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	The materials used during the practicals, were all okay. The physical view and oversite are well explained.	I understood how you prepare your equipment and wear your belt, gloves and climb the ladder, raising the rod with its connector to detect the phase to phase connection.	I appreciate the importance of phase comparison as it is necessary to ensure 3 phase machine works properly and avoid short circuit of phases.	Mostly when the receiver happens to make a sound to correspond with the transmits the phase is the same.	The practical aspect of the phase comparison is amazing.
3.2 Did you understand the importance of the preparation works for phase comparison work and get able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.2.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	I can teach my colleagues when the machine for detection is provided for practicals.	I understood the importance of connecting each phase to the line is series with each other so as not to cause damage to the equipment.	The use of phase comparator practically to detect each phase.	Assembly of the apparatus or materials to used. Know whether phase are in both side or in a correct point.	The part that helped me understand well is coupling of the component of the phase comparison device.
3.3 Can you conduct phase comparison work only by yourself? Choose yes or no.	Yes	Yes	Yes	No	Yes
3.3.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to conduct it?	Reasons is that when the machine is provided for texting. I can carry out the text because I was showed how to carry out the test.	The raising of testing rod from one phase to the other to confirm a common phase. E.g. Red phase to Red phase.	I was able to conduct it on my own using the phase comparator machine.	Reason are; One person will be at transmitter side while the other person will be at receiver end. It is impossible for one person to be at both end.	The part that make me understand more is testing the devices on our main line, that is life line.
4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	Because the lecture in class and the practical on site given to me was super and well explained.	The training can help the colleague to know how to connect phase to phase e.g. red phase to red phase not red phase to yellow phase.	So that they can understand the application of phase comparator machine before connecting two different feeders.	Because of some machine i.e industrial machines that were wired in three phase, may be affected. It also help in phase balancing.	To improve the use to understand our network more on phase comparison on our area of coverage.
5 Do you have any other opinions or observations about this course?	The only opinion I have is that I will continue attending NAPTIN training whenever I am invited.	NO	The course is quite interesting.	If all our engineers or technicians knows the phase comparison, and we apply it in our network. It will help to boost our network in a healthy condition.	We need more of this training.

Comments from JET members regarding minor things for improvement in your training

- To prepare the training documents in advance
- Please prepare and check all equipment and materials required for the training by the day before.
- A slightly shorter ladder would be better.
- Please practice repeatedly to get closer to the actual work on site.
- Do not throw down insulated gloves or other equipment and materials on the ground.
- Please keep the training facilities area clean and free of trash.
- Please keep the warehouse in NAPTIN building organized and tidy.

Comments Table for 1st Practical Training Demonstration on Overhead Line Fault Location

A	B	C	D	E	F
1 Explanation	1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes
	1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	The explanation was well explained.	All the instructor points were very good and well explained.	All the instructor points were very good and well explained.	The explanation was ok, and well understood.
	1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	It was well explained.	The instructor's points was well understood.	The instructor's points was well understood.	The improvement should be on operating the equipment.
	2 Configuration and contents of the training material				
2	2.1 Overall, were configuration and contents of lecture material good? Choose yes or no.	Yes	Yes	Yes	Yes
	2.2 What was (were) good point(s) of the lecture material?	All the materials were good and on point.	All the materials were good, especially H.V DC tester.	All the points were good.	The preparation of material in connection with the tools to locate the system.
	2.3 What was (were) point(s) that should be improved of the lecture material?	No point.	More training material should be provided for the instructors.	All points was well explained.	To get modern equipment to use on training.
	3 Questions especially about "overhead fault detection"				
3	3.1 Do you think that, if a 5-year experienced technician takes this course, he/she understands the basic procedure and principle of overhead fault location, and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes
	3.1.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	All points were well understood.	He/she should be able to understand all the points.	All points were very informative.	A 5-year experienced technician will understand very well.
	3.2 Do you think that, if a 5-year experienced technician takes this course, he/she becomes able to conduct overhead fault detection by him/herself, and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes
	3.2.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	He/she must understand all the points very well.	All the points were clear and well understood, there was no point that was difficult to understand.	He/she must understand all the points very well.	With constant practice, he/she would grasp the knowledge, and would be able to teach others.
4	4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes
	4.1 Why do you think so?	The course is very informative.	Because it is very informative and will help. He/she to know the modern ways of overhead and underground fault locating system.	It is highly recommended.	It is highly recommended.
	4.2 Why do you think so?	The course is very informative.	Because it is very informative and will help. He/she to know the modern ways of overhead and underground fault locating system.	It is highly recommended.	It is highly recommended.
	4.3 Why do you think so?	The course is very informative.	Because it is very informative and will help. He/she to know the modern ways of overhead and underground fault locating system.	It is highly recommended.	It is highly recommended.
5	Do you have any other opinions or observations about this course?	They should go for more training abroad.	More training of this nature should be organised.	The course is good and help one to improve on him/her way of working.	- More practice on overhead line. - Having technicians to work with, as well as lines men. - Overhead line requires hard work to overcome all obstacles.

Comments Table for 2nd Practical Training Demonstration on Overhead Line Fault Location

	A	B	C	D	E
1 Explanation					
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	The good points of the instructor explanation is the way and manner the instructor taught us physical aspect of the training.	Choose a range of voltage, connect the hipotronic machine to the line one after the other to detect a fault on overhead line. Discharge each hipotronic lead at any point of charging connection.	On how to use hipotronic machine to detect or trace fault. Also know when a particular line is faulty through hipotronic equipment.	The instructor was able to explain how to carry out phase comparator practically. The instructor explain and practicalize overhead fault detection using hipotronics.	On how to detect a fault on all phases on the line. Red phase, Yellow phase and Blue phase.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	The time limit if explanation	Every explanation is good.	The instructor himself explain bit by bit, his explanation was easy to understand. He took his time to make sure everyone follows up. He is ok.	NIL	The instructor is good but still need more improvement in explaining the practical in details.
2 Configuration and contents of the training material					
2.1 Overall, were configuration and contents of lecture material good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the lecture material?	The good points of the lecture material is how to use the hipotronics machine.	The testing equipment and the sample of network is good for the practical.	OK	It captures all the theoretical explanation of what were obtained in the field covering O/H fault detection.	The lecture materials are super good.
2.3 What was (were) point(s) that should be improved of the lecture material?	The points that should be improved on the training material is the diagrams.	Everything about the practical is very good.	He can improve based on his personal knowledge, more advanced in his career.	NIL	No area of improvement as far as this training went.
3 Questions especially about "overhead fault detection"					
3.1 Do you think that, if a 5-year experienced technician takes this course, he/she understands the basic procedure and principle of overhead fault location, and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	The technician will help him/her how to detect fault easily and restored supply to his/her customer.	He will understand how to use the equipment to locate O/H fault.	With the use of hipotronic machine, it's easy to detect a faulty line/phase while difficult point is after locating a faulty phase is to locate or detect where the fault actually is.	He/she should be able to use phase comparator and hipotronics machine in fault detection.	Very well, because once a practical is given in details in explanation. He/she will be able to use this machine and physical explanation to understand.
3.2 Do you think that, if a 5-year experienced technician takes this course, he/she becomes able to conduct overhead fault detection by him/herself, and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.2.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	The part that will help him/her understand well is the aspect of using hipotronic device.	The setting of the hipotronic and selecting of range of voltage that determine the faulty current will make him to understand.	Mostly on how to operate the hipotronic machine and detect the fault on the line.	He/she should be able to explain simulation process of detecting fault. He/she should be able to conduct wireless phase comparator.	Well, I don't think if you are technical grounded in line manager, it will be difficult for you to understand this overhead fault detection.
4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	It will improve easy fault clearing and fault detection on our network.	It will help a subordinate to know how to clear fault on O/H line in a short time.	Knowledge is power. If all the engineers have ideas on this, our timely taken in fault clearing will reduce.	To enable them have more understanding of overhead fault detection process and phase comparison on HV.	Because the training was super, and the organisers and the instructor are good.
5 Do you have any other opinions or observations about this course?	We need the training of this course periodically in order to make us have more knowledge on the course/training.	NO	To give more training on this, mostly to engineers i.e. Operation and line department, i.e. O&M. That comprises. •Service Engineers •Linesmen •PC&M •Faulty men	The course should be extended to other units of technical fields.	No observation than to tell my colleagues that the training is good to attend.

Comments Table for 1st Practical Training Demonstration on Underground Cable Fault Location

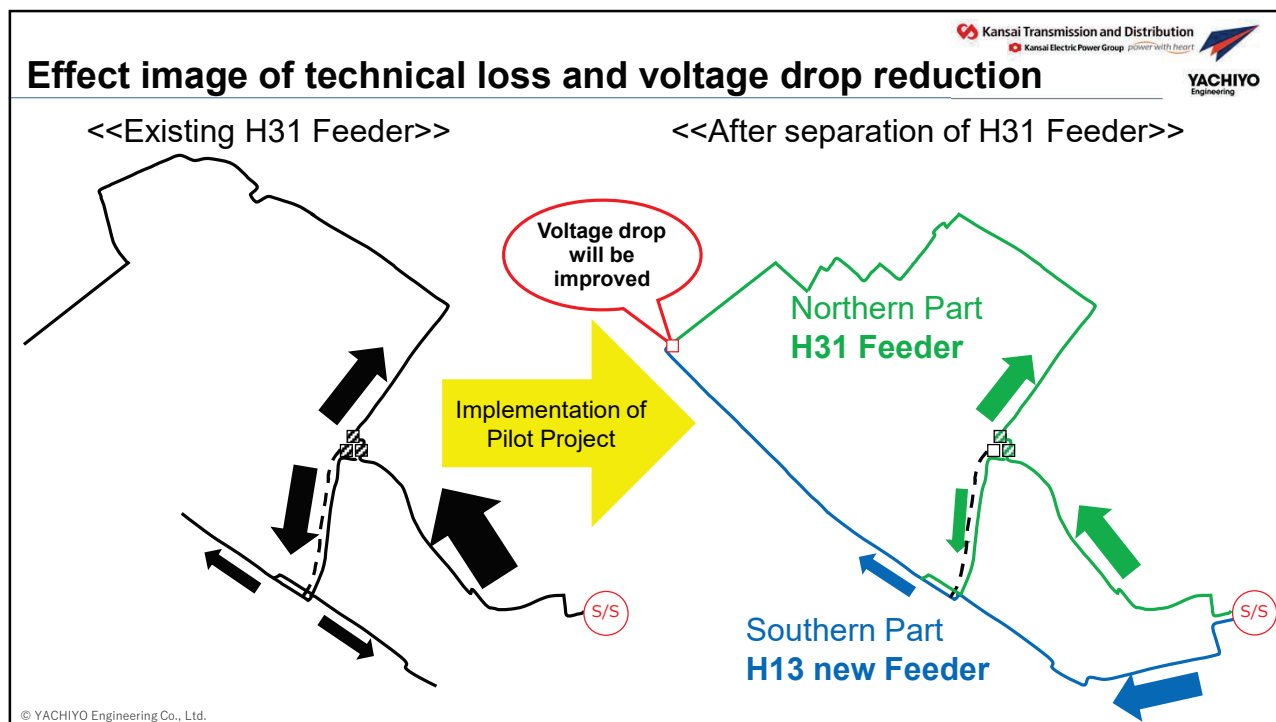
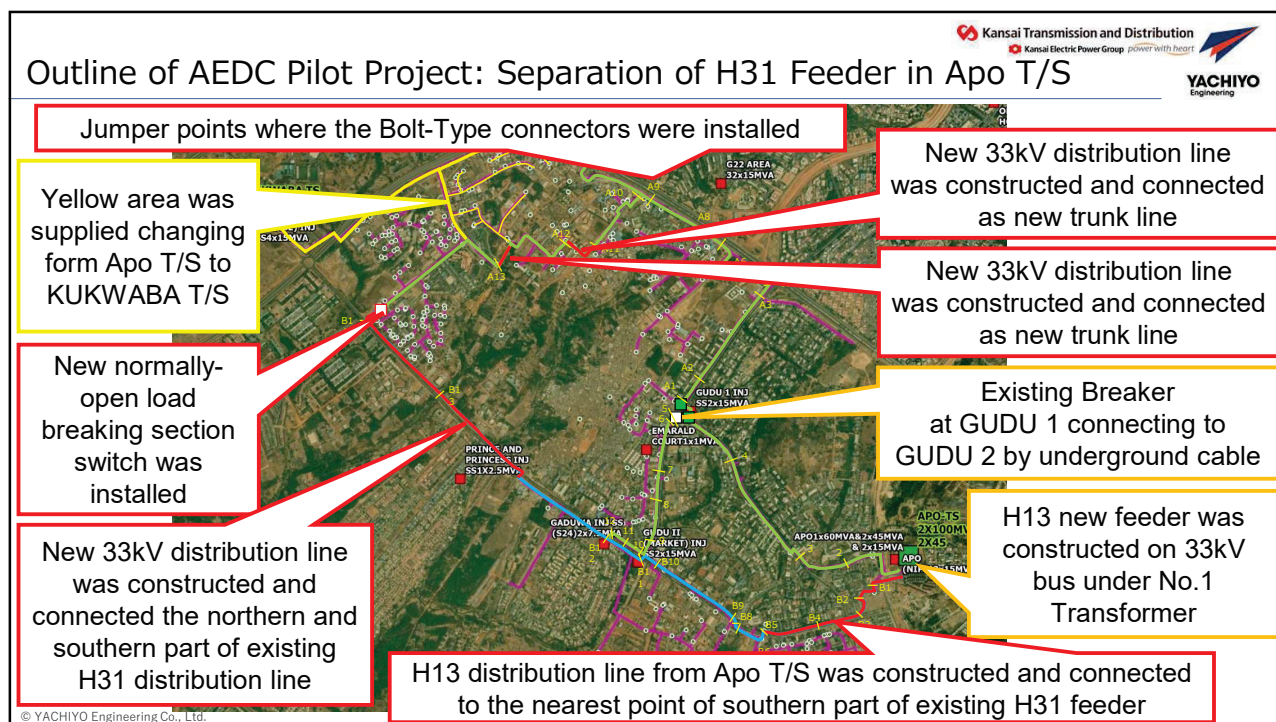
A	B	C	D	E	F
1 Explanation					
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	• All the printouts are very important.	• The explanation on the entire topic was excellent.	• Because is easy.	• All was very good, we need more of it.	• The good point is that I understand.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	• The instructors' points were very ok and explanatory.	• NO ANSWER	• NO ANSWER	• The instructor was very good.	• All explanations were ok.
2 Configuration and contents of the lecture material					
2.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the lecture material?	• All the lecture materials were very ok.	• The hipotronic machine megger.	• The diagram of conductor systems: overall lines.	• Cable fault locator • Generator • Safety	• The good point was about the machine.
2.3 What was (were) point(s) that should be improved of the lecture material?	• More course for line on fault reality.	• NO ANSWER	• To have more than one resource persons.	• I am very ok with the lecture and materials.	• NO ANSWER
3 Questions especially about "Underground cable fault detection and restoration"					
3.1 Do you think that, if a 10-year experienced technician takes this course, he/she understands classroom lecture and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	• He/She will understand the points very well after the lecture.	• The practical aspect of the training	• With more technical diagram and demonstration on how cables runs underground. He/She will definitely pick up.	• Because it is been practicalized and well understood.	• I understand all.
3.2 Do you think that, if a 10-year experienced technician takes this course, he/she becomes to be able to conduct underground cable fault detection and gets able to teach it to his/her colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.2.1 If yes, especially what part(s) will help him/her understand well? If no, what part(s) is (are) difficult for him/her to understand?	• He must understand all the point because, all the points are necessary for the operation of the equipment.	• It will help him or her develop skills.	• With proper guiding teaching, he will be able to do so with proper knowledge.	• NO ANSWER	• He/She will understand the keynote of the training.
4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	• The course will help the person to know how to operate cable fault locator and use it for underground cable fault tracing.	• NO ANSWER	• Because, if you want to do well in electricity industry or technical field, you need to broaden your knowledge, therefore this very course is important.	• All is well for the training.	• Because is a good thing.
5 Do you have any other opinions or observations about this course?	• The course is very important for every engineer that is concerned with underground cable distribution network.	• NO ANSWER	• NO ANSWER	• NO ANSWER	• NO ANSWER

Comments Table for 2nd Practical Training Demonstration on Underground Cable Fault Location

	A	B	C	D	E
1 Explanation					
1.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
1.2 What was (were) good point(s) of the instructor's (or instructors') explanation?	The instructor good point was on how to pinpoint a faulty area in an underground cable fault, that is, how to detect the fault in the underground cable with a megger machine which was shown to us at the site.	- Underground cable manufacturing component. - Underground cable advantage & disadvantages over O/H lines. - Underground cable fault detector location. The explanation on the entire topic was excellent.	The instructor was able to explain different types of faults on HV cables and their respective detection techniques using megger STX 40 cable fault locator.	The safety part was well explained. Also how to detect underground fault and troubleshoot it.	The instructor is very on elaboration.
1.3 What was (were) point(s) that should be improved of the instructor's (or instructors') explanation?	Actually all explanation and practical that was carried out well explained in the class and on the field.	- Every explanation about the instructor was very good. - She's perfect.	The practical aspect should be given more time so that each participant can be opportune to use the machine independently.	Need more knowledge in handling the equipment.	The instructor should be given more time.
2 Configuration and contents of the lecture material					
2.1 Overall, was the instructor's (or instructors') explanation good? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
2.2 What was (were) good point(s) of the lecture material?	The lecture material is a good one and all the training practical on underground cable fault location were shown to us at the site with the megger machine.	The lecture itself is good and the practical.	The lecture material is educative and concise on the underground cable locator information.	Lecture materials were very easy to understand and well explained.	- The good points on the lecture materials are. - Direct laying method - Common underground infrastructure. - Description of cable faults. - Generator - Safety
2.3 What was (were) point(s) that should be improved of the lecture material?	- I am assuming that all the materials so far used for the lecture and practical are good. - Nothing to be improvised otherwise.	There should be more lectures like this on other field of technical.	The real life examples/experience could be incorporated in the material, it would be better.	Hoping they can turn it into simple handout or minimal textbook.	The lecture material is okay.
3 Questions especially about "Underground cable fault location"					
3.1 Did you understand classroom lecture and will you be able to teach it to your colleagues? Choose yes or no.	Yes	Yes	Yes	Yes	Yes
3.1.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	Yes, especially with the help of megger machine, I can teach my colleagues to detect an underground cable fault location, the pointer and when moving it to the direction where the signal is will help to detect that fault.	- I understand the layers that's makes a single core cable and 3 core cable. - Understand advantages and disadvantages of cable compared to O/H lines. - Layering of cables either by direct or conduit.	Practical application of the machine in detecting fault.	Both in lecture room and practical, mostly using the thumping to detect fault by surging or burning method.	The parts that helped me understand well is description of cable faults and causes of cable faults.
3.2 Did you become to be able to conduct underground cable fault location and will you be able to teach it to your colleagues? Choose Yes or no.	Yes	Yes	No	Yes	Yes
3.2.1 If yes, especially what part(s) helped you understand well? If no, what part(s) was (were) difficult for you to understand?	With the help of the megger, I understand the detection or location of a cable fault in an underground cable.	- I understand how to inject a voltage range 0-20kV, 0-25kV on a megger to detect how healthy a cable is. - How we inject voltages to detect point of fault on a cable by distance, burning and vibration.	Operating the machine independently is a bit difficult.	- In fault detection by using thumping machine. - Identify faults. - Locate faults. - Cable diagnoses.	I will be able to teach my colleagues on the aspect, identify the description of cable faults and the cause of cable faults.

Comments Table for 2nd Practical Training Demonstration on Underground Cable Fault Location

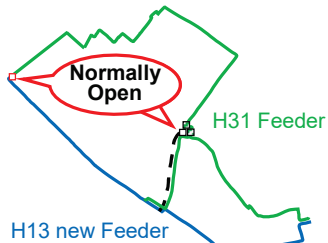
	A	B	C	D	E
4 Do you recommend your colleagues to take this course or recommend your bosses to let subordinates to take this course? Choose yes or no. [Note] Please answer this question only from the perspective of the course contents. This means you are required to ignore the price.	Yes	Yes	Yes	Yes	Yes
4.1 Why do you think so?	• NAPTIN has been a good body of engineering to the society at large, and many class and practical has been carried out by the body. • NAPTIN is a strong body of engineering that makes you improve in engineering practical.	• The course will be good to our colleague too, because they will understand underground cable how it is been prepared, how to detect fault and trace the fault underground.	• To enable colleagues gain more practical understanding of the usage of megger machine.	NO ANSWER	• Because it will help me and my colleagues to understand more to carry out our daily activities in particularly on our area of coverage that cover underground cable.
5 Do you have any other opinions or observations about this course?	NO ANSWER	• The course is perfect.	• Similar training of this nature should be organised more often.	If everyone of us has a little basic ideas on this, • It will limit time taken in troubleshooting or clearing fault in our network. • The training should extend one or two weeks continuously.	• The course is perfect, keep it up.



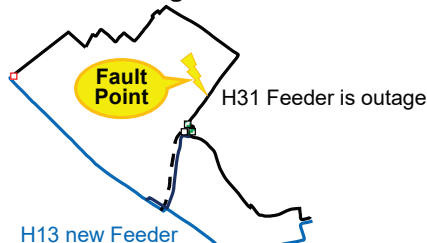
Effect of reliability improvement (2) Reduction of outage duration

Partial charge for healthy sections when outage was occurred

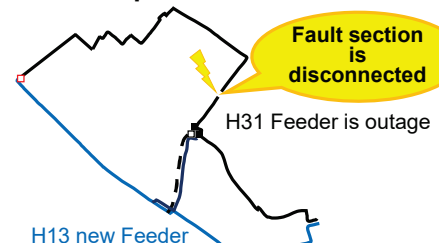
<<0. Normal state>>



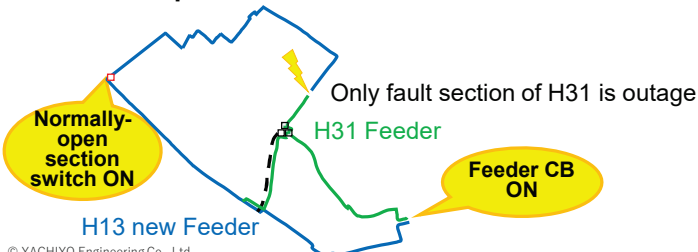
<<1. When outage occurred>>



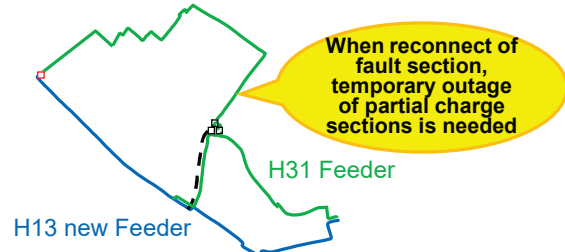
<<2. Fault point was detected>>



<<3. Partial power restoration to health sections>>



<<4. After removal of the cause of fault>>

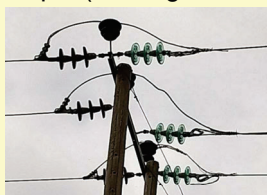


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Outline of AEDC Pilot Project: Installation of Bolt-type connectors

Connection and disconnection of Jumpers by Bolt-type connector

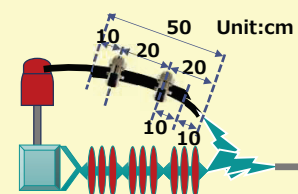
<<Status quo (Binding connection)>>



<<Bolt-type connector>>



Weight: 693g/piece,
Length: 70mm/piece



Bolt-type connectors are installed at two points to connect one phase Jumper

Advantage of Bolt-type connector

- > Repeatedly disconnecting and connecting jumpers is able **without jumper damage**
- > Anyone can do this work (Skill less)
- > Stable the joint quality
- > No special tools required to work

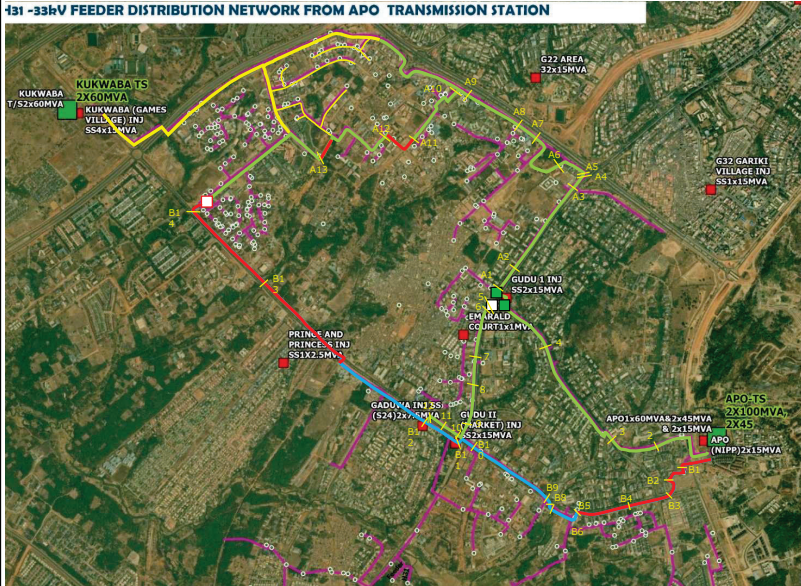


228 Pieces (38 points)
were installed

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Section for H31 Feeder and installation point of Bolt-type connectors

131 -33kV FEEDER DISTRIBUTION NETWORK FROM APO TRANSMISSION STATION

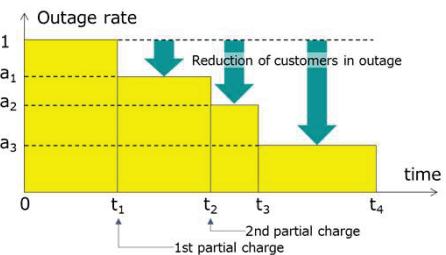


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Compare the converted outage durations (Yellow in the following figure) for the post-construction distribution line with and without partial power charge.

Alternative Outage Rate : =

$$\frac{\text{Subtotal capacity of transformer(s) in outage}}{\text{Total capacity of all transformers in H31 feeder}}$$



Calculating "Converted outage duration time"

Introduction of the new indicator: "Converted outage duration time"

- If some intact sections were energized before the complete restoration, this action does reduce the number of your customers that suffer from the outage. This new indicator "Converted outage duration time" reflects such an action.
- Converted outage duration time is defined as follows:

$$\text{Converted outage duration time} = t_1 + a_1(t_2 - t_1) + a_2(t_3 - t_2) + a_3(t_4 - t_3) + \dots$$

- $a_1, a_2, a_3, \dots$: mean Outage rate

$$\text{Outage rate} := \frac{\text{Number of customers in outage}}{\text{Number of all customers}}$$

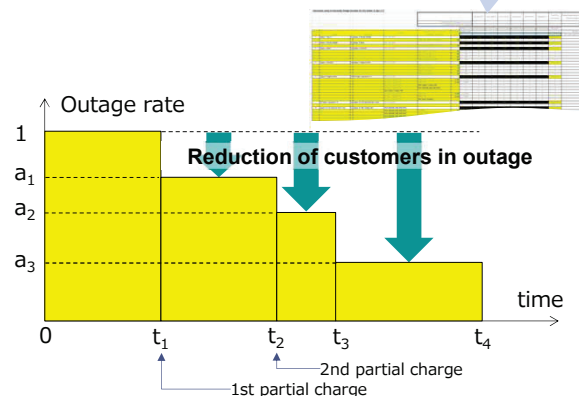
However, as grasping number of customers in outage is difficult in Nigeria, following alternative outage rate will be used.

Alternative Outage Rate : =

$$\frac{\text{Subtotal capacity of transformer(s) in outage}}{\text{Total capacity of all transformers in the feeder}}$$

- $t_1, t_2, t_3, \dots$: mean the time of energizing partially
- Converted outage duration time is equal to the area of the yellow region in the right graph.

Calculation sheet for the Converted outage duration



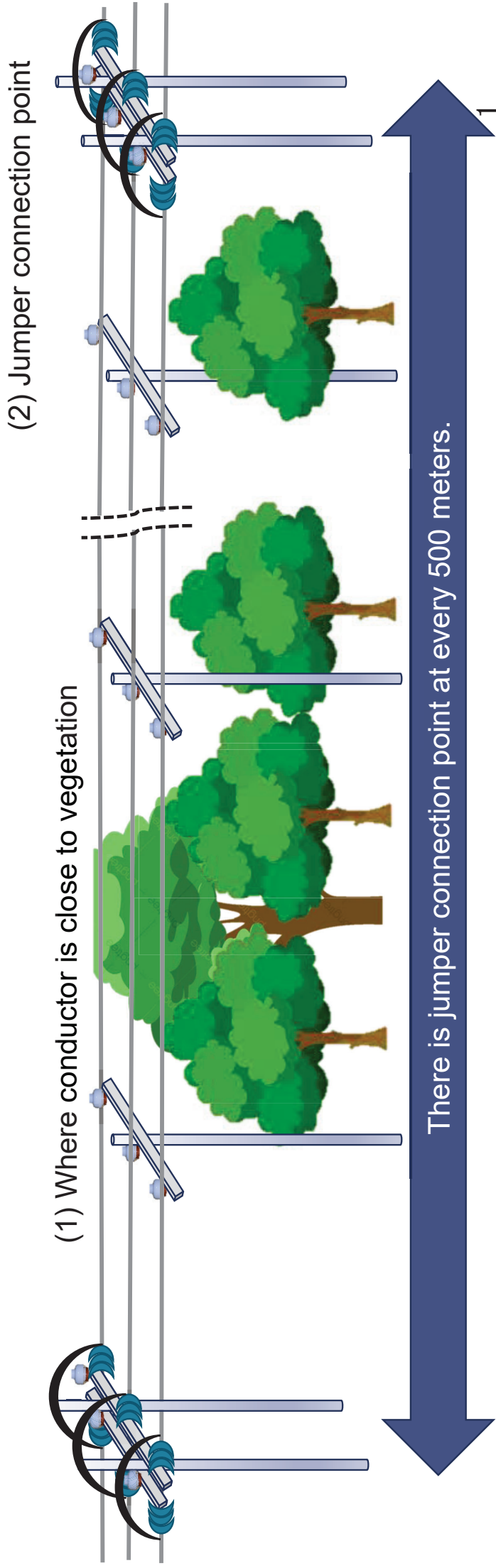
© YACHIYO Engineering Co., Ltd.

Effect of reliability improvement (1) Reduction of outage frequency

Our proposal is... to install some equipment which will help to improve the reliability at

(1) Where conductor is close to vegetation

(2) Jumper connection points

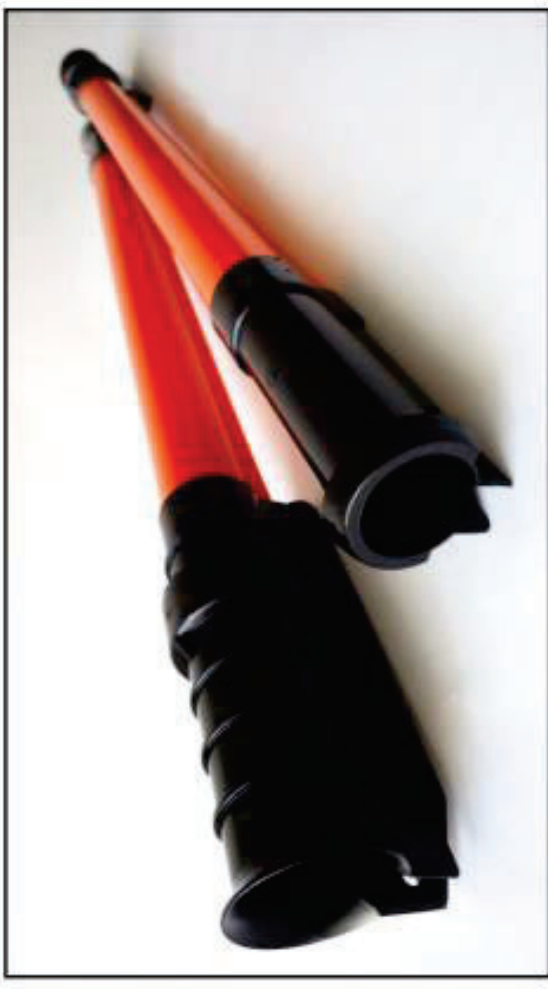


Effect of reliability improvement (1) Reduction of outage frequency

Polyethylene cover for conductor close to vegetation

[What is it?]

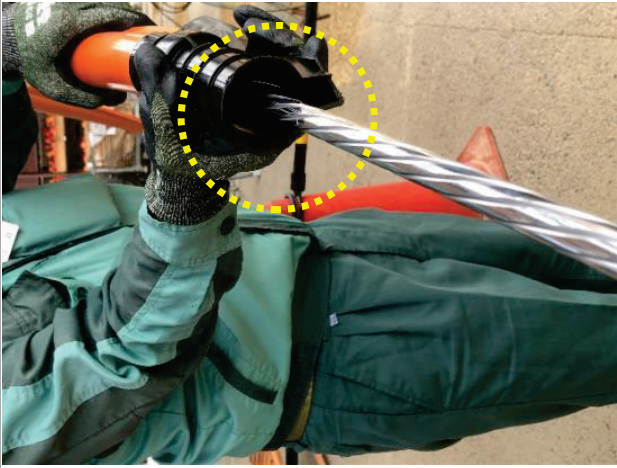
- This cover prevents conductor from hitting or making contact with the vegetation or branches of trees.
- 1 piece of it can be tightly connected to another one.
- Made of polyethylene, it is light and robust.
 - Weight: 1kg/piece
 - Length: 3m/piece



In Japan, this kind of cover is also used to inform that there is high voltage conductor at construction sites and to prevent workers or cranes from getting closer to the conductor.

Effect of reliability improvement (1) Reduction of outage frequency

[How to install]

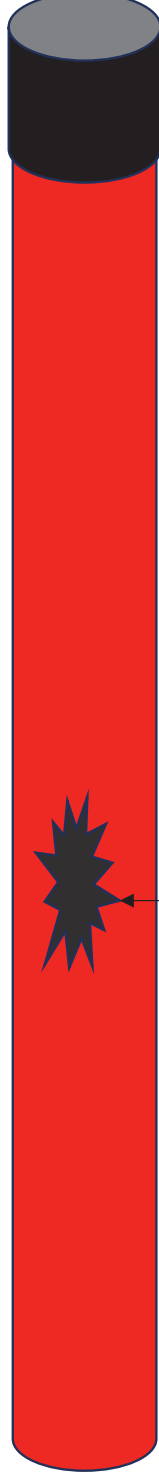
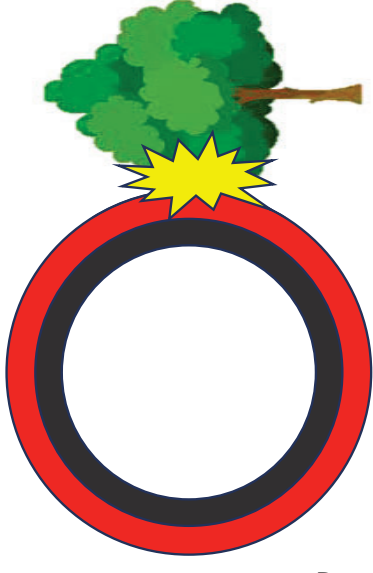
Step	1) Make it “bite”	2) Install	3) Connect	4) Finish
Photo				
Remark	Open the insertion point wide, and make it “bite” the conductor	Install the cover to the conductor, like holding the conductor with the cover.	Connect them tightly.	Inner diameter is 35mm, which is enough for 150mm ² conductor.

Effect of reliability improvement (1) Reduction of outage frequency

Polyethylene cover for conductor close to vegetation

[When it has to be replaced]

- Since this cover has “double-layer” structure (as shown on the right), and they are colored differently.
- The outer layer will be worn out due to friction with vegetation.
- When inner layer, of which color is different from that of outer layer, can be seen from outside (as shown below), it means the insulation performance is significantly reduced. Therefore it is time for the cover to be replaced.



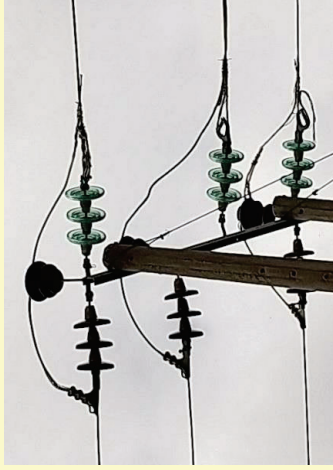
Inner layer that can be
seen from outside

4

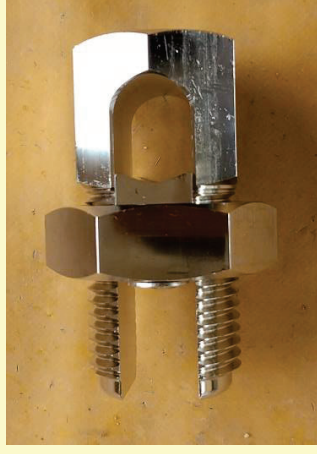
Effect of reliability improvement (1) Reduction of outage frequency

Connection and disconnection at Jumpers by bolt type connector

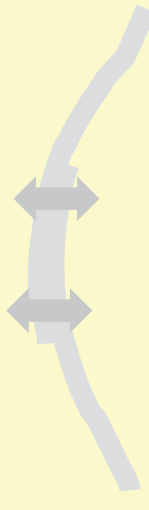
<<Status quo (Binding connection)>>



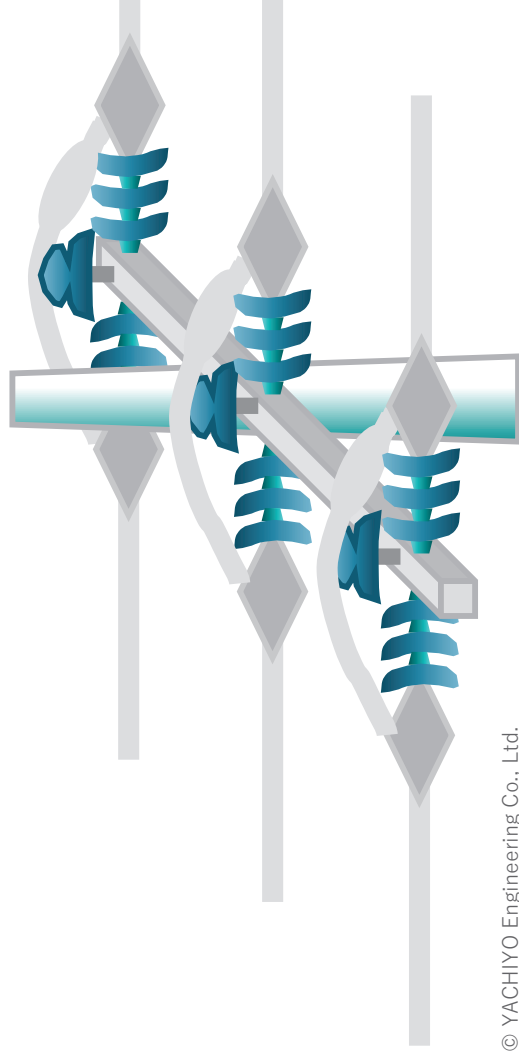
Using at all
or part
jumpers



<<Bolt type connector>>



Bolt type connectors are installed at two points to connect Jumpers



Advantage of Bolt type connector

- > Can repeatedly disconnect and connect without replacing a jumper
- > Anyone can do this work (Skill less)
- > Stable the joint quality
- > No special tools required to work
- > Specification

Weight: 693g/piece, Length: 70mm/piece

5

Effect of reliability improvement (1) Reduction of outage frequency

End protection cover (“cap”)

[What is it?]

- End protection cover (“cap”) is installed to the jumper disconnection points on the source side, preventing conductor from touching or injuring the workers, or from making them get electric shock.

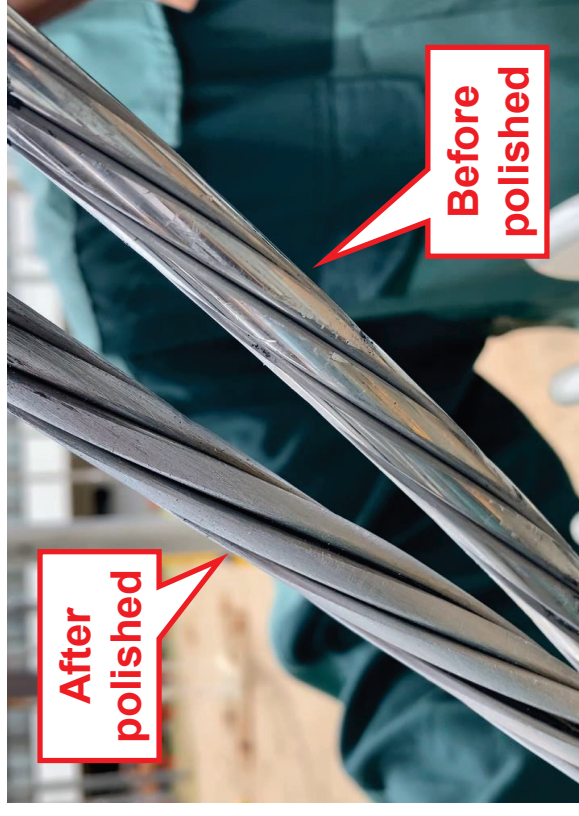


Effect of reliability improvement (1) Reduction of outage frequency

[What is Wire polisher?]

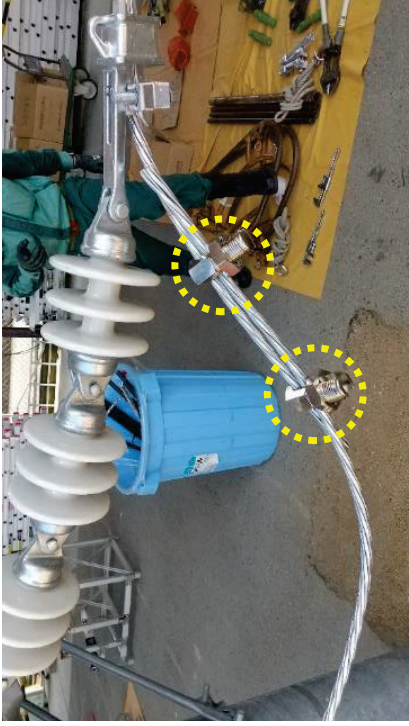
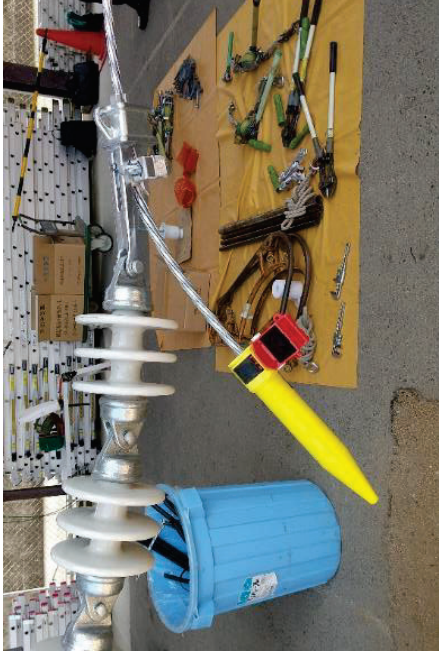
[Why is it desirable for conductors to be polished before connection?]

- Aluminum forms a tough “oxide film” on its surface as soon as it comes into contact with air.
- The oxide film must be removed completely, otherwise it will increase the contact resistance.



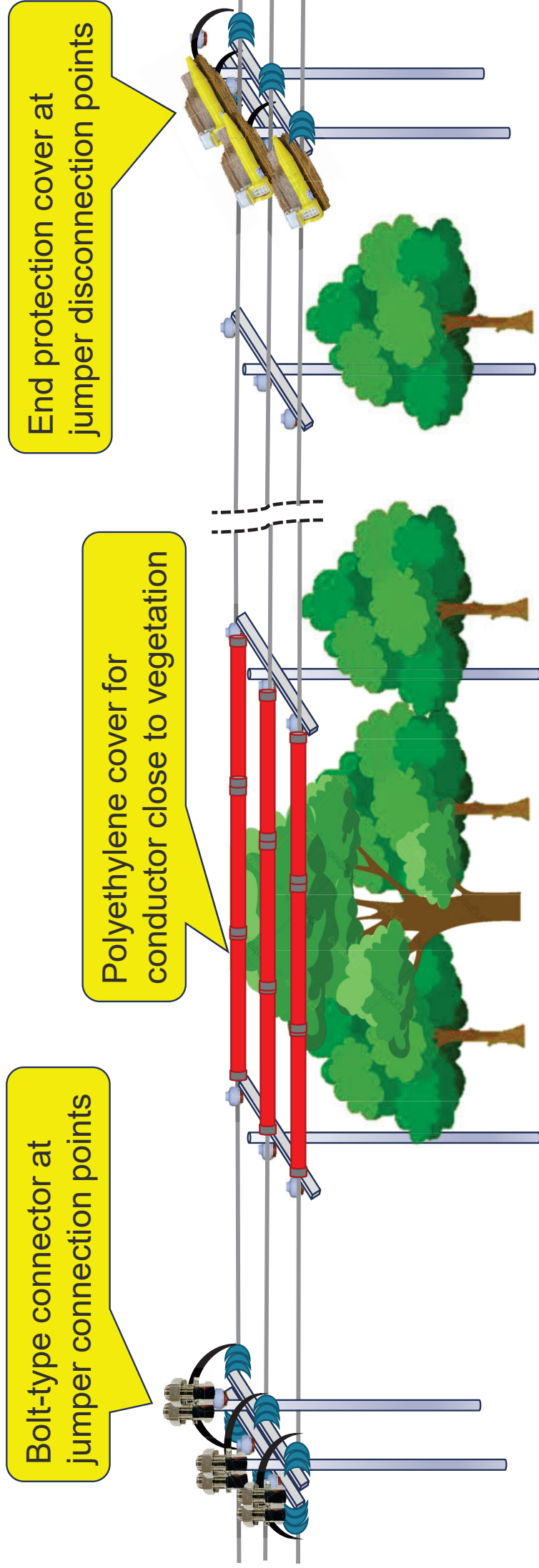
Effect of reliability improvement (1) Reduction of outage frequency

[How to install]

Step	1) Temporarily install the connectors	2) Determine the position and tighten firmly	3) Install the end protection cover
Photo			
Remark	■ Whichever to be installed first. ■ Fasten them to a certain extent by hand. ■ It is desirable for conductors to be polished before the connection.	■ Check and determine the right position of connectors. ■ Tighten them firmly.	■ Install the end protection cover to the jumper disconnection points, preventing conductor from touching or injuring the workers.

Effect of reliability improvement (1) Reduction of outage frequency

Image of installation



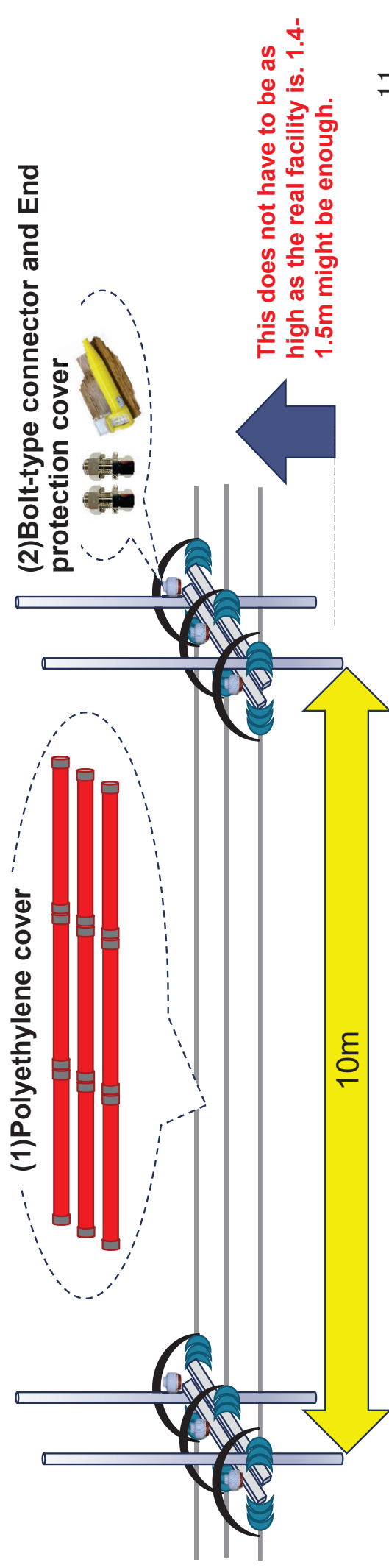
Workability verification in Gwagwalada

(4) Confirmation of workability of New installed equipment

Since we need to make sure that it is easy enough for AEDC colleagues to install the equipment that we proposed, [we request you to create the model structure of your distribution line](#). It has to have at least...

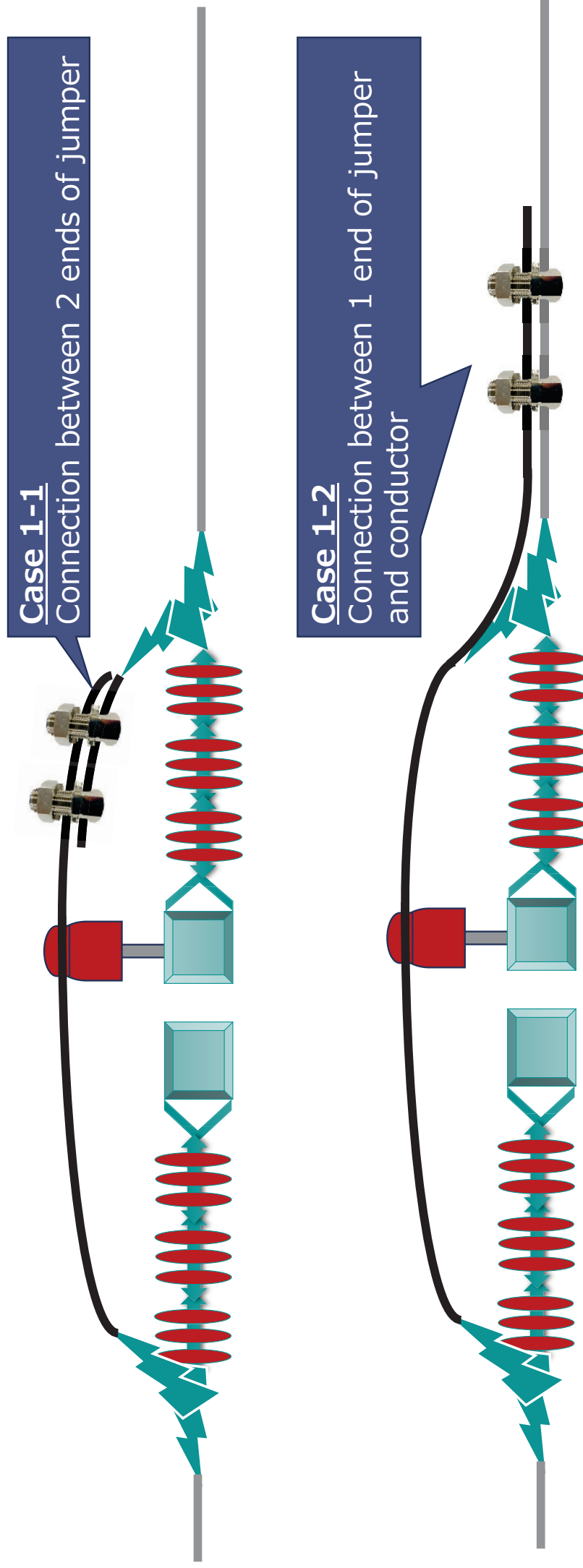
- 1 span that is 10m long to install (1)Polyethylene cover and
- 1 jumper connection point to install (2)Bolt-type connector and End protection cover.

Please note that the conductor does not have to be as high as the real one is (1.4-1.5m might be enough).



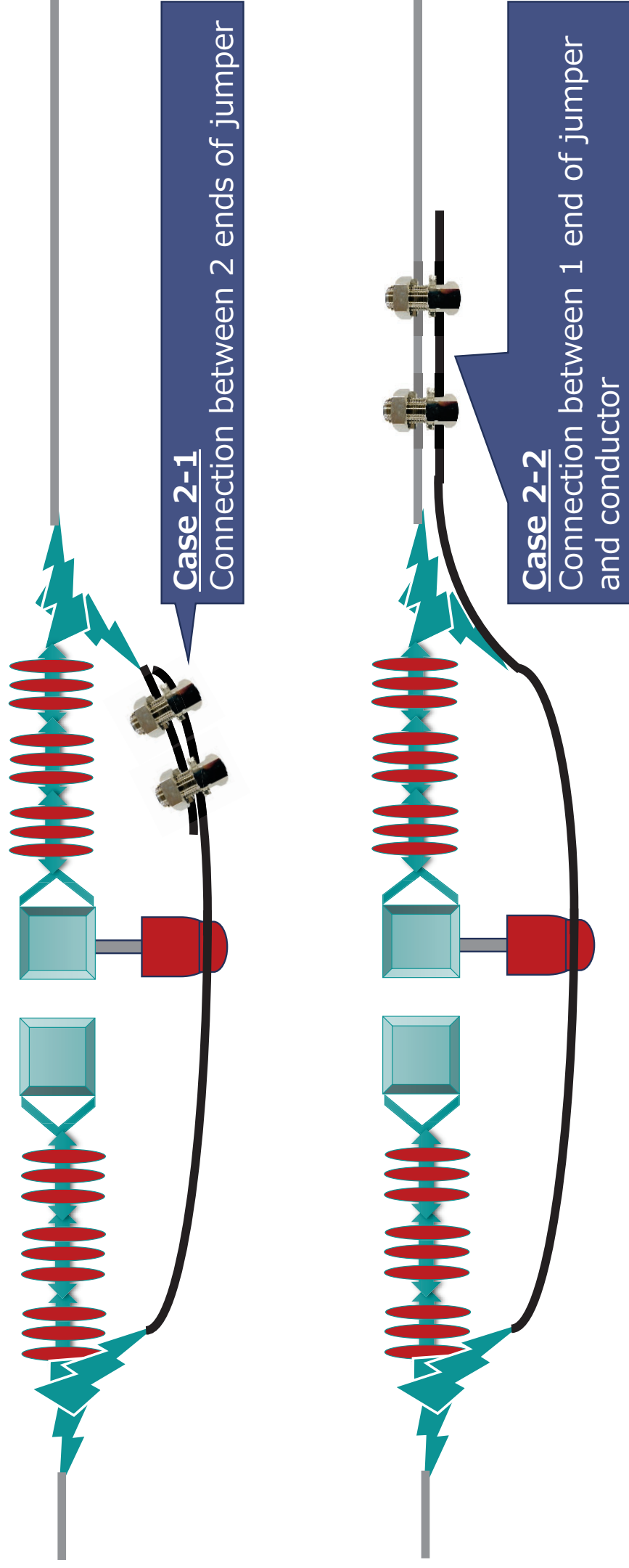
(4) Confirmation of workability of New installed equipment

[The position of connection] Case 1: Above the cross arm



(4) Confirmation of workability of New installed equipment

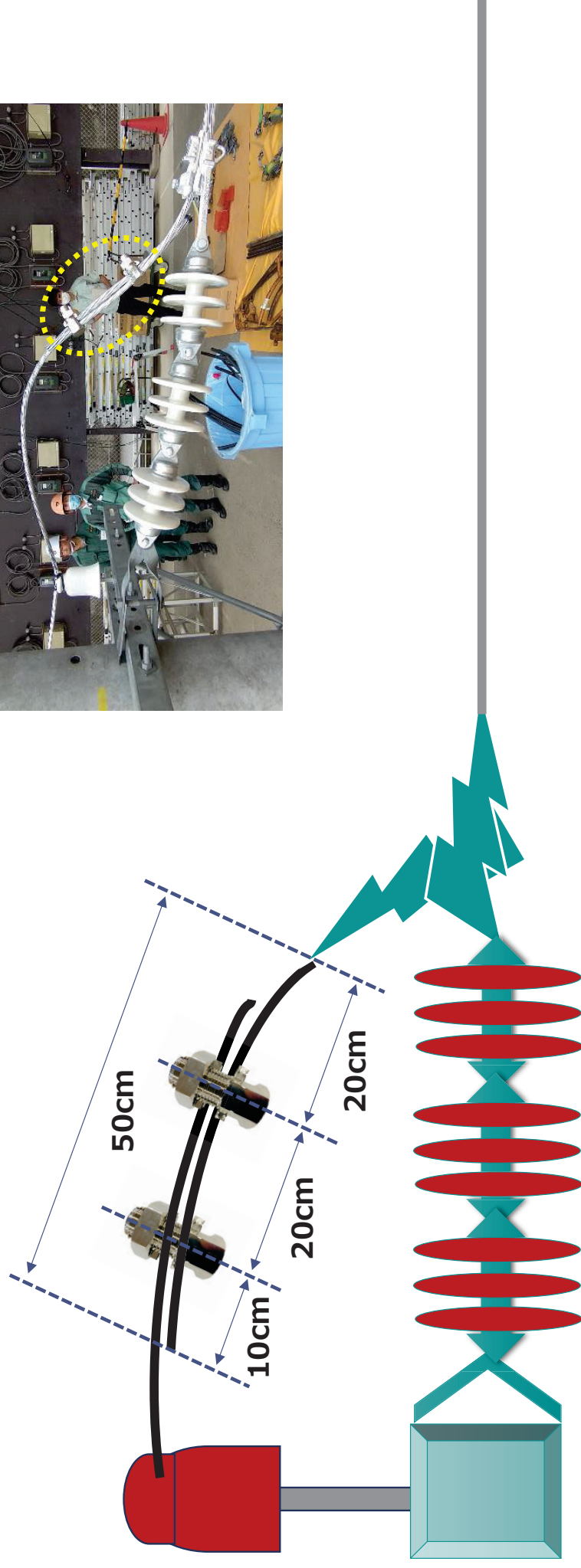
[The position of connection] Case 2: Under the cross arm



(4) Confirmation of workability of New installed equipment

[The tentative dimension of connection (1)]

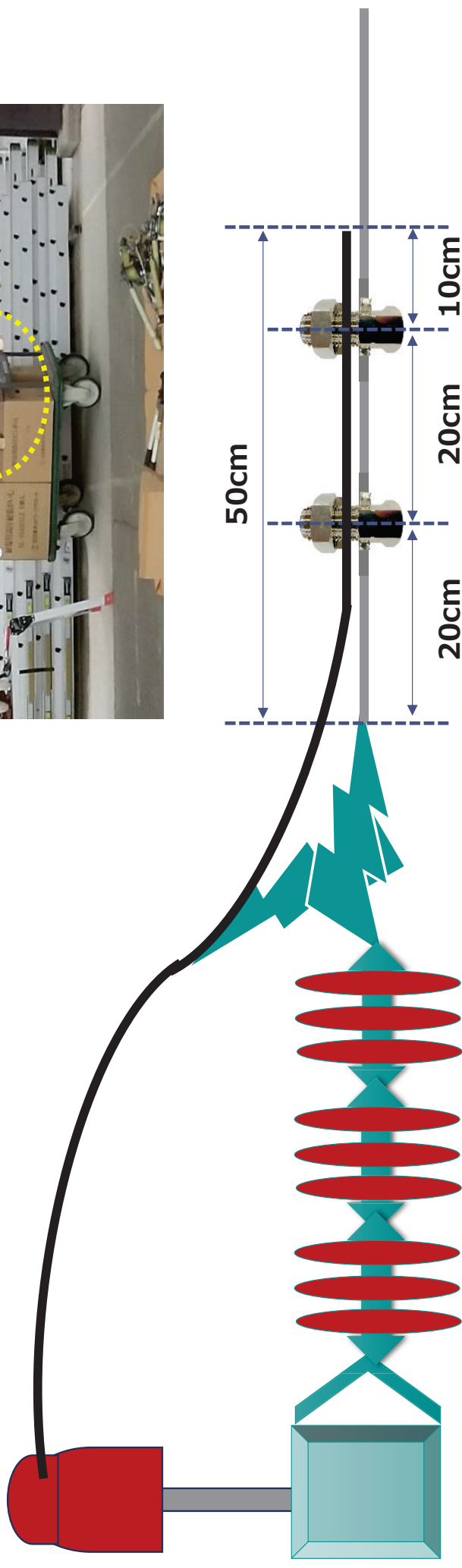
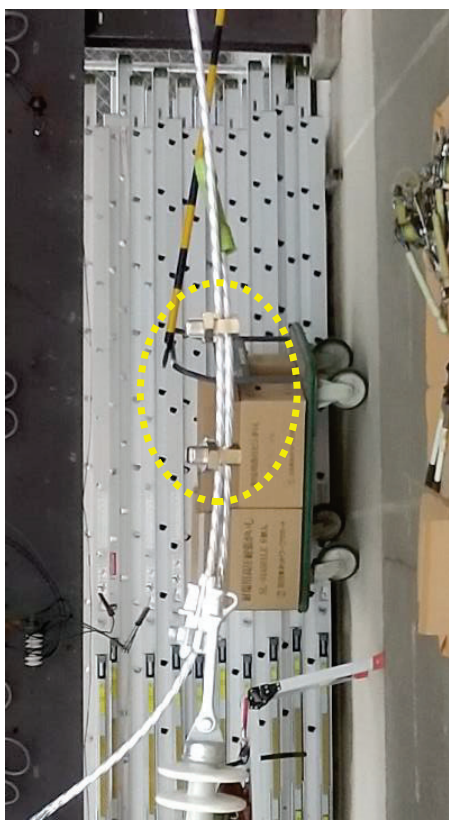
- Connection between 2 ends of jumper



(4) Confirmation of workability of New installed equipment

[The tentative dimension of connection (2)]

- Connection between 1 end of jumper and conductor



Tasks for grasping and understanding the effect of the Pilot Project

1. Voltage measurement for grasping the improvement effect on voltage drop	
☐ Check when finished <u>After completion of changing work to ring shape network.</u>	<u>Fill out all items in the sheet</u> , "Measuring the voltage at 2nd side of transformers", <u>must containing the following data</u> after measurement of the voltage at the transformers. > Measurement Date and Time > Voltage at the Second Side of the Transformer > Source Voltage of the feeder, H13, H31 or L33, at T/S substation > Source Current of the feeder, H13, H31 or L33, at T/S substation
☐ Check when finished	<Spot1> Not yet (0 of 5)
☐ Check when finished	<Spot2> 3 of 4 is completed, but only voltage data at Transformer
☐ Check when finished	<Spot3> 3 of 4 is completed, but only voltage data at Transformer
☐ Check when finished	<Spot4> Not yet (0 of 4)
☐ Check when finished	<Spot5> Not yet (0 of 4)
☐ Check when finished	<Spot6> 3 of 4 is completed
2. Calculating "Converted outage duration time" for grasping the reduction effect of downtime	
☐ Check when finished <u>Please implement immediately.</u>	<u>Confirmation</u> of the matching between the distribution network data in the "Calculation sheet of Converted Outage Duration time" and the status of actual distribution network and <u>modify and correct</u> it to match the actual distribution network status.
☐ Check when finished <u>When outages are occurred and if partial charging (energizing) is carried out, please be sure to implement.</u>	<u>Record the data of restoring outage</u> such as the time of power outage occurrence, partial power charging and all recover, and partial power charging area for each. And then, <u>this restoring outage data will be informed to dispatch section.</u>
☐ Check when finished <u>When outages are occurred and if partial charging (energizing) is carried out, please be sure to implement.</u>	<u>Calculating "Converted Outage Duration time"</u> using "Calculation sheet of Converted Outage Duration time". <u>Sending this "Calculation sheet of Converted Outage Duration time" file to JET members each time</u> an outage with partial energizing is occurred.
3. Organizing the network data for grasping the improvement effect on loss reduction	
☐ Check when finished <u>Please implement immediately.</u>	<u>Organizing the distribution network data</u> of Apo T/S H31 and H13 before and after the Pilot project in the template sent by Engr. Taofeeq. <u>Sending this Template</u> to Engr. Taofeeq and JET members.

Distribution line loss calculation sheet on very simple network model of H13 and H31

H31 separated feeder (North side)

Actual max load of existing H31 feeder at substation: 327 A (= 15.9MW/33kV/0.85/√3)

Before Pilot Project

Section No.	Jumper	to	next Jumper	Distance between Jumpers (km)	Kind of conductor	Resistance (Ω/km)	Section resistance R (Ω)	Capacity (kVA)	Rated Current (A)	Section current (A)	Converted section current I (A)	Technical loss I ² × R (W)
1	Circuit breaker of H31 feeder	to	Jumper 2-Garden Delight	0.726779867	Wolf (150mm ²)	0.1828	0.13285536	300	5,249	2,752.089	327.000	42,618.272
2	Jumper 2-Garden Delight	to	Jumper 3-Didas	0.401244207	Wolf (150mm ²)	0.1828	0.073347441	300	5,249	2,746.840	326.376	23,439.245
3	Jumper 3-Didas	to	Jumper 4-2nd Gate	0.697400163	Wolf (150mm ²)	0.1828	0.12748475	1,800	31,492	2,741.591	325.753	40,584.071
4	Jumper 4-2nd Gate	to	Jumper 5-Anglican Girls	0.844271347	Wolf (150mm ²)	0.1828	0.154332802	350	6,123	2,710.100	322.011	48,008.778
5	Jumper 5-Anglican Girls	to	Jumper 6-AP FILLING STATION	0.06772105	Wolf (150mm ²)	0.1828	0.012379408	30,000	524.864	2,703.976	321.283	3,833.518
6	Jumper 6-AP FILLING STATION	to	Jumper 7-Rahamaniya Estate	0.338842061	Wolf (150mm ²)	0.1828	0.061940329	0	0.000	152.211	18.085	60.779
7	Jumper 7-Rahamaniya Estate	to	Jumper 8-Adisa Junction	0.332963861	Wolf (150mm ²)	0.1828	0.060865794	1,300	22,744	152.211	18.085	59.725
8	Jumper 8-Adisa Junction	to	Jumper 9-Three Palm Fortunes	0.295097197	Wolf (150mm ²)	0.1828	0.053943768	1,600	27,993	129.466	15.383	38.295
9	Jumper 9-Three Palm Fortunes	to	Jumper 10-Opp. MKK Plaza	0.188491218	Wolf (150mm ²)	0.1828	0.034456195	5,800	101.474	101.474	12.057	15.027
10	Jumper 10-Opp. MKK Plaza	to	Jumper 11-Next MKK	0.157164597	Wolf (150mm ²)	0.1828	0.028729688	0	0.000	0.000	0.000	0.000
11	Jumper 11-Next MKK	to	Jumper 12-Opp. S24 Inj. Substation	0.227732592	Wolf (150mm ²)	0.1828	0.041629518	0	0.000	0.000	0.000	0.000
12	Jumper 12-Opp. S24 Inj. Substation	to	End of distribution line at GUDU II	0.056689011	Wolf (150mm ²)	0.1828	0.010362751	0	0.000	0.000	0.000	0.000

A1	Jumper A1-S22 Injection Sub. Fence	to	Jumper A2-War College Qtrs	0.236713043	Wolf (150mm ²)	0.1828	0.043271144	5,400	94,475	997.241	118,491	1,822.598
A2	Jumper A2-War College Qtrs	to	Jumper A3-Nass Qtrs	0.798241473	Wolf (150mm ²)	0.1828	0.145918541	0	0.000	902.766	107,266	5,036.776
A3	Jumper A3-Nass Qtrs	to	Jumper A4-Next APO Bridge	0.176451841	Wolf (150mm ²)	0.1828	0.032255596	1,000	17,495	902.766	107,266	1,113.383
A4	Jumper A4-Next APO Bridge	to	Jumper A5-APO Bridge	0.09297722	Wolf (150mm ²)	0.1828	0.016996236	500	8,748	886.270	105,187	564.153
A5	Jumper A5-APO Bridge	to	Jumper A6-JohnHolt	0.257302746	Wolf (150mm ²)	0.1828	0.047034942	500	8,748	876.523	104,147	1,530.519
A6	Jumper A6-JohnHolt	to	Jumper A7-Nkwegu Plaza	0.462508936	Wolf (150mm ²)	0.1828	0.084619746	7,950	139,089	867.775	103,108	2,698.844
A7	Jumper A7-Nkwegu Plaza	to	Jumper A8- Rajab Plaza	0.099232282	Wolf (150mm ²)	0.1828	0.018139661	1,200	20,995	728.686	86,582	407.945
A8	Jumper A8- Rajab Plaza	to	Jumper A9-Water Resources	0.474068325	Wolf (150mm ²)	0.1828	0.08665969	7,550	132,091	707.691	84,087	1,838.218
A9	Jumper A9-Water Resources	to	Jumper A10-Bt ConOil & Fed Sec	0.098073884	Wolf (150mm ²)	0.1828	0.017927906	9,900	173,205	575.601	68,392	251.573
A10	Jumper A10-Bt ConOil & Fed Sec	to										
A11		to		2.63741172	Wolf (150mm ²)	0.1828	0.482118862	9,900	173,205	398.897	47,396	3,249.126
A12		to										
A13		to	Jumper A14-AISA									
A14	Jumper A14-AISA	to	Jumper A15-US Embassy Qtrs	0.290890403	Wolf (150mm ²)	0.1828	0.053174766	10,100	176,704	402.396	47,812	364.673
A15	Jumper A15-US Embassy Qtrs	to	End of H31 distribution line	0.611150186	Wolf (150mm ²)	0.1828	0.111718254	12,900	225,691	225.691	26,816	241.016

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	GUDU I Injection substation	to	GUDU II Injection substation	1.223115387	Wolf (150mm ²)	0.1828	0.223585493	0	0.000	1,029.660	122,343	10,039.766
	GUDU II Injection substation	to	Jumper B11-Evergreen Garden Adjacent S23		0	0.1828	0	0	0.000	1,029.660	122,343	0.000
B11	Jumper B11-Evergreen Garden Adjacent S23	to	Jumper B5-Kasa De Lucy	1.585500629	Wolf (150mm ²)	0.1828	0.289792955	25,353	443,562	1,029.660	122,343	13,012.711
B5	Jumper B5-Kasa De Lucy	to	Jumper B6-Torch Alive Ministry	0.047244678	Wolf (150mm ²)	0.1828	0.008636327	2,300	40,240	586.098	69,639	125.650
B6	Jumper B6-Torch Alive Ministry	to	Jumper B7-Next Sharia Junction	0.307564593	Wolf (150mm ²)	0.1828	0.056222808	100	1,750	545.858	64,858	709.520
B7	Jumper B7-Next Sharia Junction	to	Jumper B8-Sharia Junction	0.023862576	Wolf (150mm ²)	0.1828	0.004362079	0	0.000	544.109	64,850	54.696
B8	Jumper B8-Sharia Junction	to	Jumper B9-Oceanic Centre	0.397080199	Wolf (150mm ²)	0.1828	0.07258626	23,150	405,020	544.109	64,650	910.160
B9	Jumper B9-Oceanic Centre	to	Jumper B10-Shafa F/Station	0.485167887	Wolf (150mm ²)	0.1828	0.08868869	5,750	100,599	139.089	16,526	72.668
B10	Jumper B10-Shafa F/Station	to	Jumper B12-Gaduwa junction	0.562275791	Wolf (150mm ²)	0.1828	0.102784015	600	10,497	38.490	4,573	6.449
B12	Jumper B12-Gaduwa junction	to	Jumper B12.5-Bush Part	0.872224603	Wolf (150mm ²)	0.1828	0.159442657	1,600	27,993	27.993	3,326	5.292

Total Current Outage Capacity 16

167,203

202,713 W (パイロットプロジェクト前の全ロス)

Distribution line loss calculation sheet on very simple network model of H13 and H31

H31 separated feeder (North side).

Actual max load of existing H31 feeder at substation: 327 A (= 15.9MW/33kV/0.85√3)

After Pilot Project

Section No.	Jumper	to	next Jumper	Distance between jumpers (km)	Kind of conductor	Resistance (Ω/km)	Section resistance R (Ω)	Capacity (kVA)	Rated Current (A)	Section current (A)	Converted section current I (A)	Technical loss 3×I ² ×R (W)
1	Circuit breaker of H31 feeder	to	Jumper 2-Garden Delight	0.726779867	Wolf (150mm ²)	0.1828	0.13285536	300	5,249	1,722.428	204.657	16,693.726
2	Jumper 2-Garden Delight	to	Jumper 3-Didas	0.401244207	Wolf (150mm ²)	0.1828	0.073347441	300	5,249	1,717.180	204.033	9,160.271
3	Jumper 3-Didas	to	Jumper 4-2nd Gate	0.697400163	Wolf (150mm ²)	0.1828	0.12748475	1,800	31,492	1,711.931	203.410	15,824.232
4	Jumper 4-2nd Gate	to	Jumper 5-Anglican Girls	0.844271347	Wolf (150mm ²)	0.1828	0.154332802	350	6,123	1,680.439	199.668	18,458.471
5	Jumper 5-Anglican Girls	to	Jumper 6-AP FILLING STATION	0.06772105	Wolf (150mm ²)	0.1828	0.012379408	30,000	524.864	1,674.316	198.940	1,469.828
6	Jumper 6-AP FILLING STATION	to	Jumper 7-Rahamaniya Estate	0.338842061	Wolf (150mm ²)	0.1828	0.061940329	0	0.000	152.211	18.085	60.779
7	Jumper 7-Rahamaniya Estate	to	Jumper 8-Adisa Junction	0.3329363861	Wolf (150mm ²)	0.1828	0.060865794	1,300	22,744	152.211	18.085	59.725
8	Jumper 8-Adisa Junction	to	Jumper 9-Three Palm Fortunes	0.295097197	Wolf (150mm ²)	0.1828	0.053943768	1,600	27,993	129.466	15.383	38.295
9	Jumper 9-Three Palm Fortunes	to	Jumper 10-Opp. MKK Plaza	0.188491218	Wolf (150mm ²)	0.1828	0.034456195	5,800	101.474	101.474	12.057	15.027
10	Jumper 10-Opp. MKK Plaza	to	Jumper 11-Next MKK	0.1577164597	Wolf (150mm ²)	0.1828	0.028729688	0	0.000	0.000	0.000	0.000
11	Jumper 11-Next MKK	to	Jumper 12-Opp. S24 Inj. Substation	0.227732592	Wolf (150mm ²)	0.1828	0.041629518	0	0.000	0.000	0.000	0.000
12	Jumper 12-Opp. S24 Inj. Substation	to	End of distribution line at GUDU II	0.056689011	Wolf (150mm ²)	0.1828	0.010362751	0	0.000	0.000	0.000	0.000

A1	Jumper A1-S22 Injection Sub Fence	to	Jumper A2-War College Qtrs	0.236713043	Wolf (150mm ²)	0.1828	0.043271144	5,400	94,475	997.241	118.491	1,822.598
A2	Jumper A2-War College Qtrs	to	Jumper A3-Nass Qtrs	0.798241473	Wolf (150mm ²)	0.1828	0.145918541	0	0.000	902.766	107.266	5,036.776
A3	Jumper A3-Nass Qtrs	to	Jumper A4-Next APO Bridge	0.176451841	Wolf (150mm ²)	0.1828	0.032253396	1,000	17,495	902.766	107.266	1,113.383
A4	Jumper A4-Next APO Bridge	to	Jumper A5-APO Bridge	0.09297722	Wolf (150mm ²)	0.1828	0.016996236	500	8,748	885.270	105.187	564.153
A5	Jumper A5-APO Bridge	to	Jumper A6-JohnHolt	0.257302746	Wolf (150mm ²)	0.1828	0.047034942	500	8,748	876.523	104.147	1,530.519
A6	Jumper A6-JohnHolt	to	Jumper A7-Nkwegu Plaza	0.462908896	Wolf (150mm ²)	0.1828	0.084619746	7,950	139,089	867.775	103.108	2,698.944
A7	Jumper A7-Nkwegu Plaza	to	Jumper A8- Rajab Plaza	0.099232282	Wolf (150mm ²)	0.1828	0.018139661	1,200	20,995	728.686	86.582	407.945
A8	Jumper A8- Rajab Plaza	to	Jumper A9-Water Resources	0.474068325	Wolf (150mm ²)	0.1828	0.08665969	7,550	132,091	707.691	84.087	1,838.218
A9	Jumper A9-Water Resources	to	Jumper A10-Bt ConOil & Fed Sec	0.098073884	Wolf (150mm ²)	0.1828	0.017979706	2,650	46,363	575.601	68.392	251.573
A10	Jumper A10-Bt ConOil & Fed Sec	to	Jumper A11-Word of Faith Church	0.647461031	Wolf (150mm ²)	0.1828	0.119358877	3,200	55,985	529.238	62.883	1,404.052
A11	Jumper A11-Word of Faith Church	to	Jumper A12-Police Station Junction	0.383112217	Wolf (150mm ²)	0.1828	0.070032913	0	0.000	473.252	56.231	664.323
A12	Jumper A12-Police Station Junction	to	Jumper A13-End of AISA	0.821425785	Wolf (150mm ²)	0.1828	0.150156633	4,050	70,857	473.252	56.231	1,424.367
A13	Jumper A13-End of AISA	to	Jumper A14-AISA	0.349739345	Wolf (150mm ²)	0.1828	0.063922352	0	0.000	402.396	47.812	438.449
A14	Jumper A14-AISA	to	Jumper A15-US Embassy Qtrs	0.290890403	Wolf (150mm ²)	0.1828	0.053174766	10,100	176,704	402.396	76.394	930.983
A15	Jumper A15-US Embassy Qtrs	to	End of H31 distribution line	0.611150186	Wolf (150mm ²)	0.1828	0.111718254	12,900	225.691	225.691	42.847	615.303

26 Total Current Outage Capacity 10 98,450 W 82,522 W

H13 new feeder (South side)

Section No.	Jumper	to	next Jumper	Distance between jumpers (km)	Kind of conductor	Resistance (Ω/km)	Section resistance R (Ω)	Capacity (kVA)	Rated Current (A)	Section current (A)	Converted section current I (A)	Technical loss 12×R (kW)
B1	Circuit breaker of H13 new feeder	to	Jumper B1-Connection to tower	0.27275925	Wolf (150mm ²)	0.1828	0.049860391	0	0.000	1,029.660	122.343	746.302
B2	Jumper B1-Connection to tower	to	Jumper B2-Former Apo Village	0.211548531	Wolf (150mm ²)	0.1828	0.038671071	0	0.000	1,029.660	122.343	578.822
B3	Jumper B2-Former Apo Village	to	Jumper B3-Opposite Stick & Stones	0.100032023	Wolf (150mm ²)	0.1828	0.018285854	0	0.000	1,029.660	122.343	273.699
B4	Jumper B3-Opposite Stick & Stones	to	Jumper B4-Opposite Creative learning	0.335365115	Wolf (150mm ²)	0.1828	0.061304743	0	0.000	1,029.660	122.343	917.599
B5	Jumper B4-Opposite Creative learning	to	Jumper B5-Kasa De Lucy	0.445281233	Wolf (150mm ²)	0.1828	0.081397409	0	0.000	1,029.660	122.343	1,218.342
B6	Jumper B5-Kasa De Lucy	to	Jumper B6-Torch Alive Ministry	0.047244678	Wolf (150mm ²)	0.1828	0.008636327	27.653	483.802	1,029.660	122.343	129.267
B7	Jumper B6-Torch Alive Ministry	to	Jumper B7-Next Sharia Junction	0.307564593	Wolf (150mm ²)	0.1828	0.056222808	100	1,750	545.858	64.858	236.507
B8	Jumper B7-Next Sharia Junction	to	Jumper B8-Sharia Junction	0.023862576	Wolf (150mm ²)	0.1828	0.004362079	0	0.000	544.109	64.650	18.232
B9	Jumper B8-Sharia Junction	to	Jumper B9-Oceanic Centre	0.397080199	Wolf (150mm ²)	0.1828	0.07258626	23.150	405.020	544.109	64.650	303.387
B10	Jumper B9-Oceanic Centre	to	Jumper B10-Shafa F/Station	0.485167887	Wolf (150mm ²)	0.1828	0.08868869	5,750	100,599	139.089	16.526	24.223
B11	Jumper B10-Shafa F/Station	to	Jumper B11-Evergreen Garden Adjacent S23	0.324380695	Wolf (150mm ²)	0.1828	0.059296791	600	10,497	38.490	4.573	1.240
B12	Jumper B11-Evergreen Garden Adjacent S23	to	Jumper B12-Gaduwa junction	0.237895096	Wolf (150mm ²)	0.1828	0.043487224	0	0.000	27.993	3.326	0.481
B13	Jumper B12-Gaduwa junction	to	Jumper B13-Durumi Recreation Park	2.20599284	Wolf (150mm ²)	0.1828	0.403255491	1,600	27,993	27.993	3.326	4.461
B14	Jumper B13-Durumi Recreation Park	to	Jumper B14-Durumi International School Junction	0.424919314	Wolf (150mm ²)	0.1828	0.077675251	0	0.000	0.000	0.000	0.000
B14	Jumper B14-American international School Junction	to	End of H13 distribution line	0.087377241	Wolf (150mm ²)	0.1828	0.01597256	0	0.000	0.000	0.000	0.000

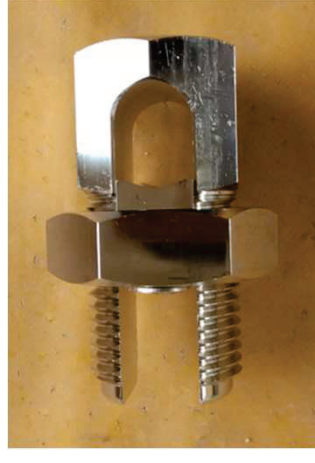
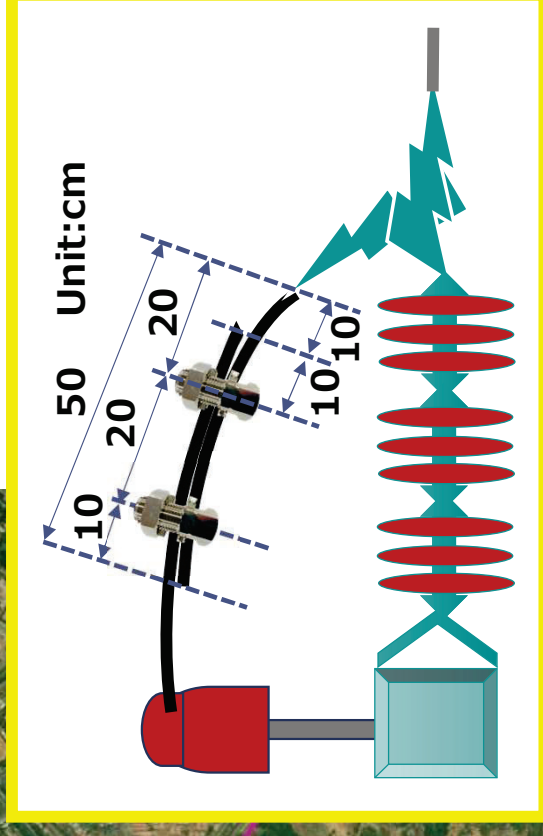
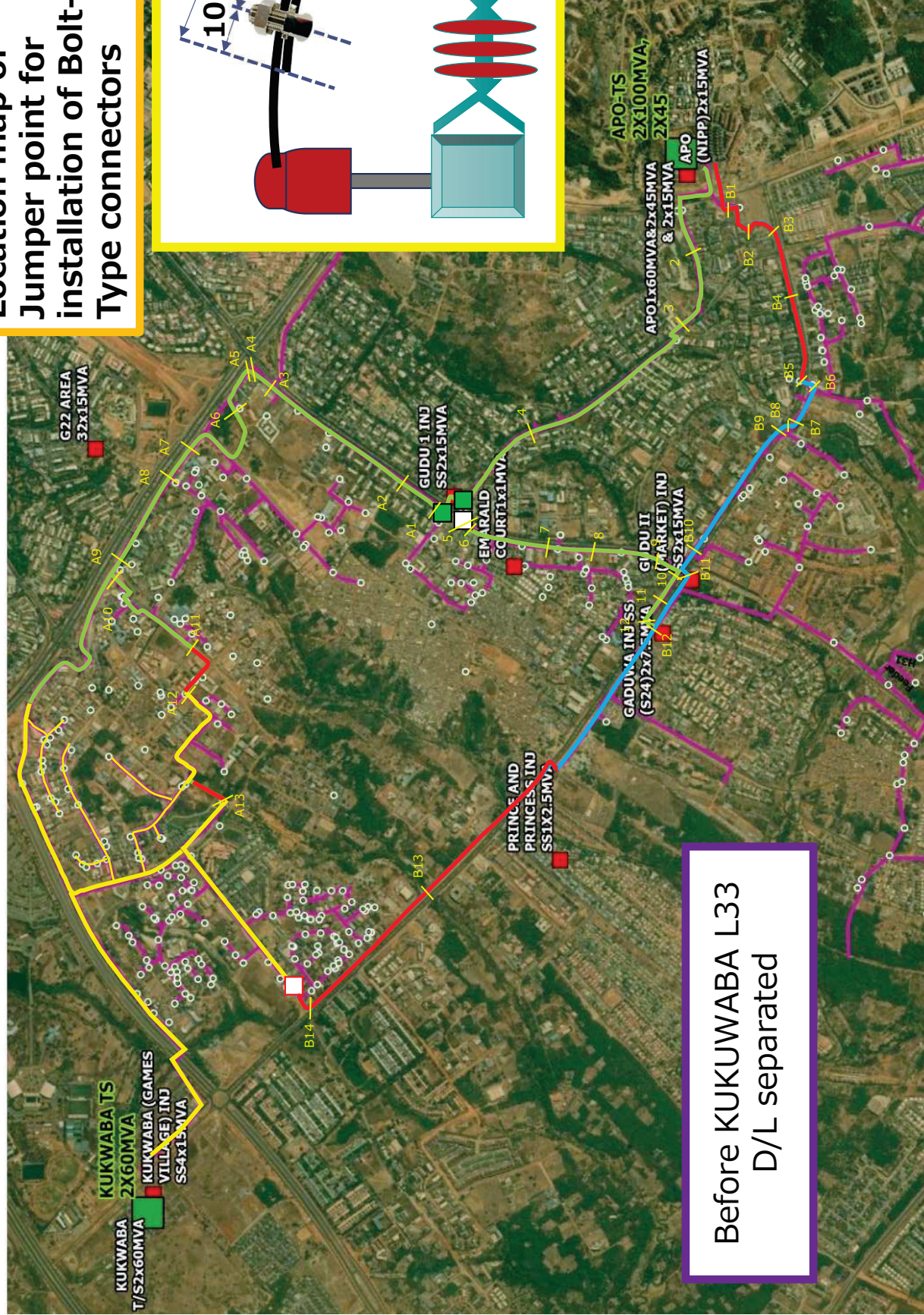
14 Total Current Outage Capacity 6 58,853 W 4,453 W

86,974 W (パイロットプロジェクト後の全ロス)

ロス低減効果 57.09%



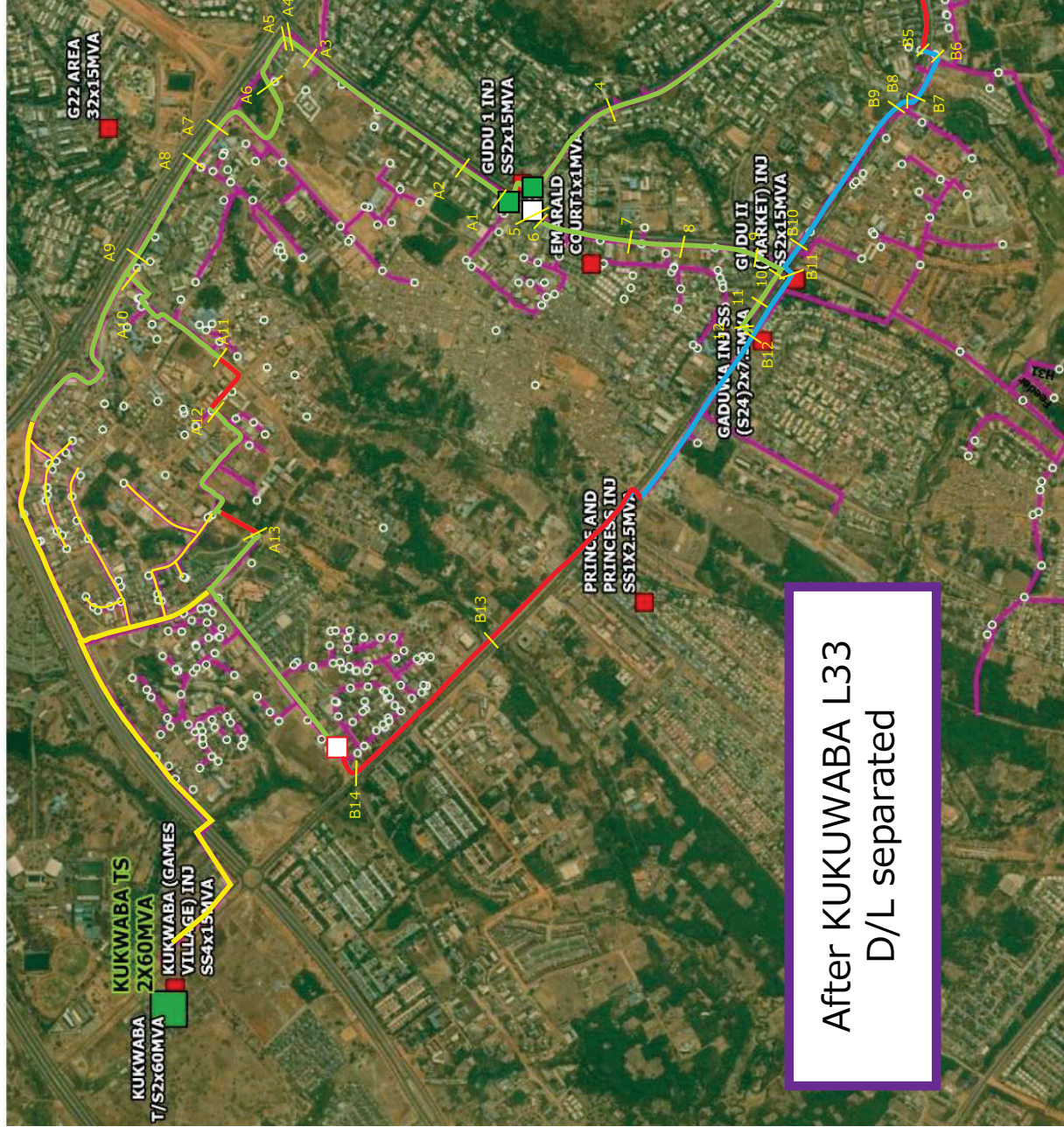
431 -33kV FEEDER DISTRIBUTION NETWORK FROM APO TRANSMISSION STATION



228 Pieces (38 points)
were installed

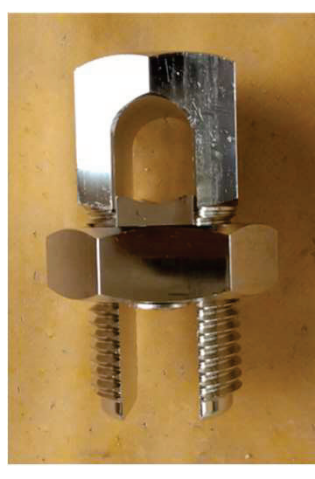
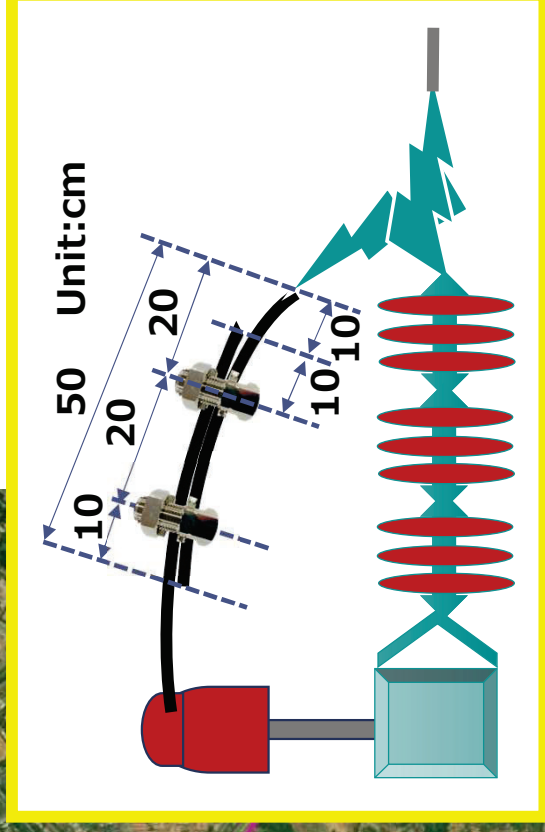
Before KUKUWABA L33
D/L separated

131 -33kV FEEDER DISTRIBUTION NETWORK FROM APO TRANSMISSION STATION



After KUKUWABA L33
D/L separated

Location map of
Jumper point for
installation of Bolt-
Type connectors



228 Pieces (38 points)
were installed

Attachment 1. Deliverables
No.12-6: Installation result of Bolt-type connectors

Jumper location list for installation of the Bott-type connectors

Jumper No.			Randmark	GIS location		Jumper style
Plan		Final		N Latitude	E Longitude	
Jumper 1	→	Non	Apo Ts	8.9998	7.4889	
Jumper 2	→	2	Garden Delight	9.0003	7.4853	Straight-way (Unbranched)
Jumper 3	→	3	Didas	9.0006	7.4827	Straight-way (Unbranched)
Jumper 4	→	4	2nd Gate	9.0052	7.4788	Straight-way (Unbranched)
Jumper 5	→	5	Anglican Girls	9.0110	7.4741	Straight-way (with custmer branch)
Jumper 6	→	6	AP FILLING STATION	9.01107	7.47361	Angle-way (with customer branch)
Jumper 7	→	7	Rahamaniya Estate	9.00829	7.47246	Straight-way (with customer branch)
Jumper 8	→	8	Adisa Junction	9.0053	7.4722	Straight-way (Unbranched)
Jumper 9	→	9	Three Palm Fortunes	9.0026	7.4720	Straight-way (Unbranched)
Jumper 10	→	10	Opp. MKK Plaza	9.0011	7.4714	Angle-way (Unbranched)
Jumper 11	→	11	Next MKK	9.0013	7.4707	Three-way branch
Jumper 12	→	12	Opp. S24 Inj. Substation	9.0025	7.4690	Angle-way (Unbranched)
Jumper A1	→	A1	S22 Injection Sub Fence	9.01162	7.47462	Connect to cable
Jumper A2	→	A2	War College Qtrs	9.01365	7.47532	Straight-way (Unbranched)
Jumper A3	→	A3	Nass Qtrs	9.01930	7.47947	Straight-way (Unbranched)
	→	A4	Next APO Bridge	9.02041	7.48062	Straight-way (with customer branch)
Jumper A4	→	A5	APO Bridge	9.02057	7.48057	Straight-way (Unbranched)
Jumper A5	→	A6	John Holt	9.02124	7.47857	Straight-way (with customer branch)
Jumper A6	→	Non	Vines Hotels	9.02145	7.47634	
Jumper A7	→	A7	Nkwegu Plaza	9.02389	7.47627	Straight-way (Unbranched)
Jumper A8	→	A8	Rajab Plaza	9.02444	7.47552	Straight-way (with branch)
Jumper A9	→	A9	Water Resources	9.02662	7.47184	Straight-way (Unbranched)
Jumper A10	→	A10	ConOil & Fed Sec	9.02711	7.47116	Multi-level crossing
Jumper A11	→	A11	Word of Faith Church	9.02369	7.46802	Three-way (Unbranched)
Jumper A12	→	A12	Police Station Junction	9.02362	7.46563	Three-way branch
Jumper A13	→	Non	HSM Junction	9.02412	7.46227	
Jumper A13.5	→	Non	Metrotile	9.02345	7.46189	
Jumper A14	→	A13	End of AISA	9.02164	7.46072	Near-next pole connecting
Jumper A15	→	Non	AISA	9.02348	7.45821	
Jumper A16	→	Non	US Embassy Qtrs	9.02192	7.45608	
Jumper B1	→	B11	Evergreen Garden Adjacent S23	9.00071	7.47051	Straight-way (with branch)
Jumper B2	→	B5	Kasa De Lucy	8.99558	7.47999	Multi-level crossing
Jumper B3	→	B6	Torch Alive Ministry	8.99495	7.47987	Angle-way (Unbranched)
	→	B7	Next Sharia Junction	8.99576	7.47746	Multi-level crossing
Jumper B4	→	B8	Sharia Junction	8.99598	7.47752	Straight-way (Unbranched)
Jumper B5	→	B9	Oceanic Centre	8.99784	7.47588	Angle-way (with branch)
Jumper B6	→	B10	Shafa Filling Station	8.99997	7.47280	Straight-way (with customer branch)
Jumper B7	→	B12	Gaduwa junction	9.00204	7.46874	Straight-way (Unbranched)
Jumper B8	→	Non	MRS F/Station	9.00466	7.46519	
Jumper B9	→	Non	Bush Part	9.00674	7.46231	
Jumper B10	→	Non	Smokey House GRILLS & CHILL	9.00719	7.46246	
Jumper B11	→	B13	Durumi Recreation Park	9.01532	7.45395	Straight-way (Unbranched)
Jumper B12	→	B14	American international School Junction	9.01796	7.45117	Angle-way (Unbranched)
Jumper B13	→	B1	Connection to tower	8.99905	7.48778	Straight-way (Unbranched)
Jumper B14	→	B2	Former Apo Village	8.99784	7.48699	Angle-way (Unbranched)
Jumper B15	→	B3	Opposite Stick & Stones	8.99694	7.48690	Straight-way (Unbranched)
Jumper B16	→	B4	Opposite Creative learning	8.99618	7.48395	Straight-way (Unbranched)