Close and Return

Fault Location on Land and Submarine Links (AC & DC)

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ABSTRACT

The increasing number of land and submarine cable assets globally has created a focus on cable fault location capabilities. All faults in cable systems are different and cable fault location depends to a great extent on applying the appropriate technique or combination of techniques. The methods for locating power cable faults require competent engineers and service providers. Guidance is therefore required for engineers on the correct application of the various techniques available. This paper outlines the work that is being undertaken by CIGRE Working Group B1.52 on the topic of Fault Location on Land and Submarine Links (AC & DC).

KEYWORDS

Fault Location, Submarine Cable, Underground Cable.

INTRODUCTION

In 2014, CIGRE SC B1 established WG B1.52 to develop a Technical Brochure on "Fault Location on Land and Submarine Links (AC & DC)".

The terms of reference for the working group are as follows:

- To cover fault location on the following installed cable types: MV/HV/EHV; AC/DC; land and submarine cable systems; single core, 3-core and pipe type cables.
- Focus on main insulation & sheath faults
- Provide overview of existing fault location techniques and underlying principles
- For land and submarine cable systems, provide guidance and strategies for effective fault location for a variety of installation types including but not limited to:
  - Direct buried cable systems
  - Ducted land cable systems
  - Cables between GIS bays
  - Cables installed in horizontal directional drills and tunnels
  - Cables at large burial depths
  - Cable systems with different bonding types
  - Very long cables
- Examine the different methods of pre-location and pinpointing from an accuracy and suitability viewpoint
- Prepare a flowchart to assist in selecting appropriate methods according to fault type and cable type
- Design factors (cable design and installation method) affecting fault location capability
- Safety considerations
- Marine vessel and support requirements for finding submarine cable faults
- Collect case studies of fault location experiences
- Training requirements for fault location personnel
- Assess applicability of on-line methods to support fault location
- Review new and innovative fault location techniques & future developments

The brochure should not cover:

- Leak location in fluid filled cables
- Gas leak location on gas compression cables
- Diagnostic testing
- Defects in cathodic protection systems

For leak location in fluid filled cables, refer to CIGRE TB 652 by CIGRE Working Group B1.37 [1].

FAULT LOCATION STEPS

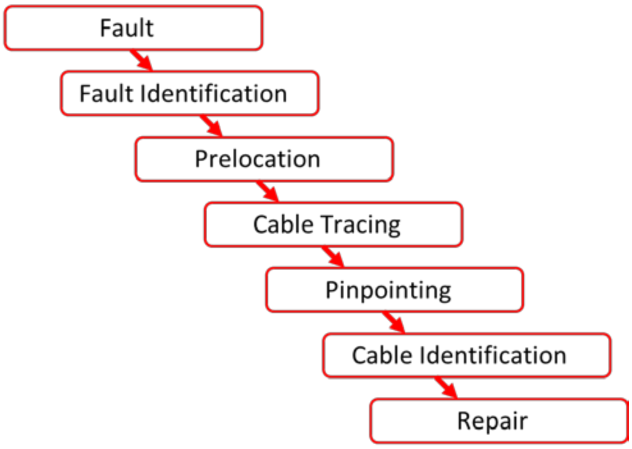

Figure 1: Fault Location Steps

FAULT TYPES

Open Circuit Fault

Also known as a series fault or conductor continuity fault, the current path is broken resulting in the current being completely or partly hindered. They are generally uncommon in submarine cables and land cables. Some open circuit faults have been reported in submarine cables cut by anchors and underground cables in earthquakes where joints connectors are pulled apart.

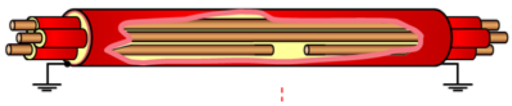

Figure 2: Open Circuit Fault

Shunt Fault

Also known as insulation fault or short circuit fault, two or more main conductors come into contact with each other or with earth. Intermittent shunt faults are nonlinear voltage dependent faults with high resistance until the insulation breaks down. During arcing, they are low resistance.

In XLPE land cables, faults are often high resistance or intermittent. In submarine cables, the arc often penetrates all watertight layers resulting in sea water ingress, resulting in low fault resistance, making the fault a persistent shunt fault.

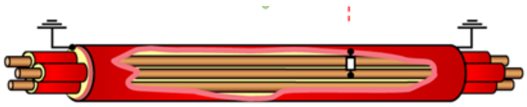

Figure 3: Shunt Fault

Sheath Fault

In cable oversheath & metallic sheath: Damage usually opens a current path from the metallic sheath to earth due to water ingress. It often causes metallic sheath corrosion, leading to further damage in the metallic sheath or eventually in the main insulation. Sheath faults can be low or high resistance.

Figure 4: Sheath Fault

CABLE FAULT LOCATION TECHNIQUES

Prelocation

Prelocation involves testing the circuit from the cable terminations to estimate distance to the fault. It can determine the fault position to within a few percent of the cable length. On very long cables, the margin of error can be significant. Sometimes the fault has to be conditioned to make it detectable e.g. burned to a low resistance fault.

The main prelocation techniques considered are:

- Time Domain Reflectometry (TDR)
- Burn Down Techniques
- Arc Reflection Methods (ARM/SIM/MIM)
- Decay Method and Differential Decay Method
- Impulse Current Method (including Comparison and Differential Modes)
- Frequency Domain Reflectometry
- Bridge Methods

Pinpointing

Pinpointing is a test to confirm the exact position of the cable fault following prelocation. It is carried out directly over the cable.

The main pinpointing techniques considered are:

- Acoustic Method
- Step Voltage Method
- Magnetic Field Methods
  - Impulse magnetometry (primary faults)
  - DC magnetometry (sheath faults)
  - Audio frequency methods
- Sectionalising Methods

Guidelines and examples of the application of these prelocation and pinpointing techniques are provided in the technical brochure.

DESIGN FACTORS AFFECTING FAULT LOCATION

Fault location capability is not always a primary concern in system design. Some effective actions can be taken at the design and project implementation stage to enhance fault location capability including:

- Ensure that a good set of as laid records and cable system information is compiled. This information must be properly stored and readily available to fault location personnel.
- Use link boxes at joints and terminations to enable the circuit to be split the cable into sections to narrow down the fault and to give additional access points to conductor or screen. Ensure link boxes are readily accessible.
- Avoid using cables without an outer semiconducting or graphite sheath as detecting and locating faults requires current flow from the metallic screen or sheath through the fault to earth.
- In the case of hybrid circuits, provide a means of disconnecting cable from the overhead line.
- Some installation types pose particular challenges for fault location:
  - Cables terminated into GIS at both ends
  - Cables in ducts
  - Cables in tunnels

EMERGENCY PLANNING

Attention given to emergency planning aspects of fault location will enable a more efficient fault location campaign to be undertaken, particularly in the case of offshore submarine cable faults. The brochure identifies the key elements of emergency planning which operators should consider in advance of any fault occurring:

- Cable System Records
- Permits
- Preparatory works
- Marine logistics
- Cooperation arrangements if there are different TSO's involved
- Aspects of Repair Preparedness Plans relevant to fault location
- Fault Location Manual:
  - Safety procedures and risk analyses to be performed prior to fault location
  - Steps to follow for fault location (flowchart)
  - Chronological overview of tests and measurements to be performed in different scenarios
  - Testing and measuring equipment needed for fault location which is adapted to the characteristics of the cable connection

Political and legal aspects can have the potential to interfere with fault location activities, but it is vital for successful fault location that that fault location is carried out methodically in an evidence-based and forensic manner.

INNOVATION AND FUTURE DEVELOPMENTS

The brochure describes some of the innovative methods which are currently emerging and being developed within the industry. These methods are covered under three categories:

1. **Fibre Optic Fault Location Methods**
   - Distributed Temperature Sensing (DTS)
   - Distributed Acoustic Sensing (DAS)
   - Distributed Vibration Sensing (DVS)
   - Brillouin Strain Measurements
2. **Electrical/ Conventional Fault Location Methods**
   - Partial Discharge Measurements
   - Advances in conventional fault location Methods
   - Online Fault Location Methods
3. **Submarine Pinpointing Techniques Using ROVs**
   - Visual, tone tracing, step voltage method, use of hydrophones
   - Submersible habitat technique
   - Multibeam equipment

Fibre optic cables enable a wider range of fault pinpointing methods to be applied including Distributed Temperature Sensing, Distributed Vibration Sensing and Distributed Acoustic Sensing through the application of Raman and Brillouin spectroscopy. In Raman spectroscopy, the scattered magnitude is temperature dependent; In Brillouin spectroscopy, the Brillouin shift is temperature and strain sensitive.

The fibre optic cable can be installed externally, directly attached to the cable, or contained in a separate duct. For best fault location results, the fibre optic cable should be installed as close as possible to power cable core. An example of an integrated fibre optic cable is shown in Figure 5.

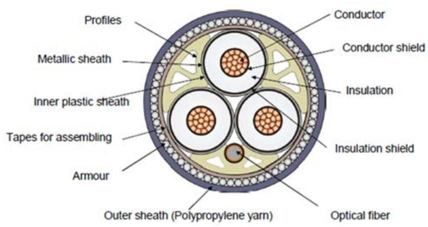

Figure 5: 3-core cable with intrgrated fibre optic

Some failures of submarine cables with embedded fibre optic cables have been reported, so particular attention should be paid to the integrity of the overall cable design in such cases.

Distributed Temperature Sensing (DTS)

With DTS, the fibre acts as a linear sensor to detect hot spots along the cable with high accuracy over long distance. The accuracy of DTS is independent of the laying depth, it is insensitive to electromagnetic interference and can be used from the shore.

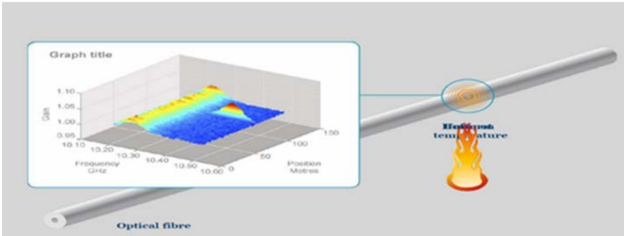

Figure 6: Distributed Temperature Sensing

Distributed Acoustic Sensing (DAS)

Thumping high resistive faults with surge generator creates vibration at the fault. Localised vibrations are captured on the DAS interrogator (onshore) and compared with the initial surge vibration detected at the fault location.

DAS can be undertaken by laying a temporary external fibre optic cable adjacent to cable near the fault. Single mode fibre is generally preferred for DAS applications.

Distributed Vibration Sensing (DVS)

With DVS, the single mode fibre optic cable acts as vibration sensor. A disturbance on the fibre generates a microscopic elongation or compression of the fibre which causes a change in the phase relation.

If there is no integrated FO element, DVS can be undertaken by laying external fibre adjacent to the cable.

SAFETY CONSIDERATIONS

The highest priority should be set for the safety of the fault finding personnel. Fault location should be performed according to the relevant national, international and company safety regulations. Personnel performing fault location shall have appropriate training and authorisation to carry out the works.

Before the execution of cable fault location, it is recommended that a risk assessment is carried out and method statements for the fault location techniques are prepared. Some particular risks apply in fault location, for example:

Particular Risks in Fault Location:

- Maximum allowed test parameters and test voltages
- Stored energy in long and extra-long cables
- Return voltage in DC cable systems
- Induced and impressed voltages
- Impulse voltages
- Touch and step voltages
- Re-energizing the cable

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TRAINING CONSIDERATIONS

Training requirements for working in the high voltage environment are registered in international standards national regulations for electrical operations and company standards. It may also occur that fault location must be performed on industrial plants or other specific areas each with their own specific training and certificates requirements depending on the circumstances. Some examples of general training requirements are listed below.

- General training
  - Electrical safety training
  - Basic safety training
  - Working at height
  - First aid training
  - Fire awareness training
  - Offshore training requirements where necessary
- Specific training
  - Safety rules
  - Understanding fault types and fault behaviour
  - Connection methods
  - Understanding the various pre-location and pinpointing methods
  - Equipment specific training

ACCURACY AND SUITABILITY OF PRELOCATION METHODS

The suitability of the prelocation and pinpointing methods are described in Tables 1 and 2 respectively. The colour codes indicates the suitability.

Method	Fault Type				
	Low Resistance	**High Resistance**	**Open Circuit**	**Intermittent**	**Sheath Fault**
TDR	Land & Submarine 1-3 % accuracy Fingerprint reference helpful Limitations for X bonded & screen interrupted systems	Fault Burning Required	Land & Submarine 1-3 % accuracy Fingerprint reference helpful Limitations for X bonded & screen interrupted systems	Fault Burning Required	
Arc Reflection Methods	No need as TDR will work	Land & Submarine 1-3 % accuracy Length limited Limitations for submarine cables (water ingress). Limitations for X bonded & screen interrupted systems	No need as TDR will work	Land & Submarine 1-3 % accuracy Length limited Limitations for submarine cables (water ingress). Limitations for X bonded & screen interrupted systems	
Decay	No need as TDR will work	Cable cannot be charged to a DC voltage due to low resistance fault.	No need as TDR will work	Land & Submarine 1-10 % accuracy Propagation velocity unknown, no reference points available. Limitations for X bonded & screen interrupted systems	
Differential	No need as TDR will work	Land & Submarine 1-3 % accuracy Access to ref. conductor required	No need as TDR will work	Land & Submarine 1-3 % accuracy Access to ref. conductor required	
Impulse Current	No need if TDR works	Land & Submarine 5-10 % accuracy Limited by breakdown voltage & distance to fault. Limitations for X bonded & screen interrupted systems	No need as TDR will work	Land & Submarine 5-10 % accuracy Limited by breakdown voltage & distance to fault. Limitations for X bonded & screen interrupted systems	
Bridge Methods	Land & Submarine ~ 1 % accuracy Need 1 healthy return conductor	Land & Submarine ~ 1 % accuracy Up to few MW fault resistance, Need 1 healthy return conductor			Land ~ 1 % accuracy Need 1 healthy return conductor
Voltage Drop	Land & Submarine ~ 1 % accuracy Need 1 healthy return conductor	Land & Submarine ~ 1 % accuracy Up to few MW fault resistance, Need 1 healthy return conductor			Land ~ 1 % accuracy Need 1 healthy return conductor
Fibre Optic Methods	Land & Submarine 1-3 % accuracy Vibration from fault spot or magnetic force along route needed	Land & Submarine 1-3 % accuracy DAS & DTS	Land & Submarine 1-3 % accuracy Already OTDR will work	Land & Submarine 1-3 % accuracy Sound/heat needed at fault	Land & Submarine 1-3 % accuracy Vibration from fault spot needed

Table 1 – Accuracy and Suitability of Prelocation Methods

applicable
not applicable
possibly

Method	Fault Type				
	Low Resistance	**High Resistance**	**Open Circuit**	**Intermittent**	**Sheath Fault**
Acoustic	Land & Submarine Limited application. A solid short circuit will not create noise. Can be used for submarine faults with water ingress	Land & Submarine 1-3 m accuracy Not for cables in ducts	Land & Submarine 1-3 % accuracy Earthing of disconnected sections needed Cables in ducts	Land & Submarine 1-3 m accuracy Not for cables in ducts	
Step Voltage	Land 1-3 m accuracy Fault needs soil contact Not for cables in ducts	Land 1-3 m accuracy Fault needs soil contact Not for cables in ducts	Land 1-3 m accuracy Fault needs soil contact Not for cables in ducts	Land 1-3 m accuracy Fault needs soil contact Not for cables in ducts	Land 0.1 m accuracy Fault needs soil contact Not for cables in ducts Galvanic contact of neutral conductor to grounding systems
Audio Frequency	Land & Submarine Land: 1-3 % accuracy Submarine: 10m - several hundred m accuracy		Land & Submarine Land: 1-3 % accuracy Submarine: 10m - several hundred metre accuracy		Land Audio frequency measurement with capacitive probes Step voltage usually preferred
Fibre Optic Methods	Land & Submarine 1-3 % accuracy Vibration from fault spot or magnetic force along cable route needed	Land & Submarine 3-5m accuracy Up to few M ohms fault resistance, Need at least one healthy return conductor	3-5m accuracy	3-5m accuracy Sound or heat production in fault spot needed	Land 1-3 % accuracy Vibration from fault spot needed.

Table 2 – Accuracy and Suitability of Pinpointing Methods

applicable
not applicable
possibly

CONCLUSIONS

This paper has outlined the work that is being undertaken by CIGRE Working Group B1.52 on the topic of Fault Location on Land and Submarine Links (AC & DC). There are many well established techniques available for fault location in cables particularly for buried underground cables. Guidance is provided on the application of different techniques in various scenarios. New and innovative techniques are also being developed which increase the toolkit for fault location.

Many of these techniques use fibre optic cables integrated or in close proximity to the power cable. Appropriate safety measures should be put in place for fault location activities and fault location personnel must be competent and adequately trained for the work being undertaken.

The technical brochure for Working Group B1.52 will be published in 2018.

Acknowledgments

The contribution of the members of CIGRE Working Group B1.52 is hereby acknowledged.

REFERENCES

[1] CIGRE B1.37, Technical Brochure 652 “Guide for the Operation of SCFF Cable Systems”

GLOSSARY

DAS: Distributed Acoustic Sensing
DTS: Distributed Temperature Sensing
DVS: Distributed Vibrations Sensing
FO: Fibre Optic
GIS: Gas Insulated Switchgear
ROV: Remotely Operated Vehicle
TDR: Time Domain Reflectometry