

## 1. SCOPE

This Safety Instruction applies the principles established by the ScottishPower Safety Rules (Electrical and Mechanical) and the **Company** Safety Instructions to achieve **Safety from the System** for personnel working on **High Voltage Direct Current (HVDC) Plant and Apparatus**.

**Persons** when working or testing on **HVDC Apparatus** within the scope of this document shall be authorised specifically for the **Location** where the **Apparatus** is installed.

This document covers the following:

- **Safety Distance(s)** for approach to **HVDC Apparatus**
- Access to **HVDC Apparatus** within a **HVDC Converter Station**
- Work or testing on **HVDC Apparatus** within a **HVDC Converter Station**
- Work or testing on **HVDC** cables
- Specific **Switching** instructions for work on a **HVDC System**
- Main auxiliary systems critical to the operation of the **HVDC System**

This Safety Instruction addresses specific **Dangers** associated with **HVDC Apparatus** and related systems. This does not negate any need for compliance with the existing ScottishPower Safety Rules (Electrical and Mechanical), the **Company** Safety Instructions or other PSSIs unless explicitly stated.

## 2. ISSUE RECORD

This is a **Reference** document. The current version is held on the EN Document Library.

**It is your responsibility to ensure you work to the current version.**

Issue Date	Issue No.	Author	Amendment Details
02/12/2016	1	Dave Naylor, Stephen Olson, Willie Falconer	Initial issue

## 3. ISSUE AUTHORITY

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## 4. REVIEW

This is a **Reference** document which has a 5 year retention period after which a reminder will be issued to review and extend retention or archive.

## 5. DISTRIBUTION

This Energy Networks' Safety Instruction is maintained by EN Document Control and is part of the ScottishPower Safety Rules which is published to the SP Energy Networks Internet site.

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## 7. DEFINITIONS

Terms printed in bold type are as defined in the ScottishPower Safety Rules (Electrical and Mechanical). For the purpose of this Safety Instruction the following definitions apply:

<i>Bipole</i>	Two poles connected such that they operate together as one energy transfer unit. Normally consists of two poles having opposing direct voltages with respect to earth.
<i>Converter Unit</i>	Operative unit comprising <i>Valves</i> , converter transformer(s), control and protection equipment, <b>Switching</b> devices and auxiliaries used for conversion between AC and DC.
<i>DC Current Measuring Device</i>	This equipment uses laser light technology to read the voltage across a known resistance (shunt) in the <b>HVDC</b> circuit.
<i>DC Voltage Divider</i>	<b>DC Voltage Dividers</b> are used to measure the voltage of a <b>HVDC</b> circuit. They may include capacitors, resistors and/or laser light technology.
<i>DC Hall (DC Area / DC Compound)</i>	Restricted room or <b>Location</b> in which DC <b>Apparatus</b> associated with the <b>HVDC Converter Station</b> is located.
<i>Heating, Ventilation and Air Conditioning (H-VAC)</i>	Equipment used to control the air temperature within a building (e.g. <i>Valve Hall</i> or <i>DC Hall</i> ) and can also create a pressure differential within that building with respect to atmospheric pressure. (N.B. in a <i>Valve Hall</i> positive pressure is used to limit dust ingress into the <i>Valve Hall</i> ).
<b>HVDC</b>	<b>High Voltage Direct Current.</b>
<i>HVDC Converter Station</i>	Part of a <b>HVDC System</b> which consists of one or more <i>Converter Units</i> installed in a single <b>Location</b> together with buildings, reactors, filters, reactive power supply, control, monitoring, protective measuring and auxiliary <b>Plant</b> .
<b>HVDC System</b>	<b>Apparatus</b> which transfers energy in the form of <b>High Voltage Direct Current (HVDC)</b> between two or more alternating current buses.
<i>DC Neutral Bus</i>	A conductor connecting the neutral terminals of two poles.
<i>PLCF (Power Line Carrier Filter)</i>	A device that may be used to impose and/or block a high frequency signal onto a conductor which can then be used for communications between <b>HVDC Converter Stations</b> .
<i>Valve</i>	Complete <i>Valve</i> device assembly used for conversion which is connected between an AC terminal and a DC terminal.
<i>Valve Hall</i>	Restricted room or <b>Location</b> in which the <i>Valves</i> are located.
<i>Valve Cooling Equipment</i>	The means by which heat is transferred from the <b>HVDC Valves</b> to atmosphere to maintain the <b>HVDC Valves</b> within their operating temperature limits. This may comprise a closed loop liquid cooling system or other system.

## 8. PLANT & APPARATUS IDENTIFICATION

**Plant** and **Apparatus** on which work or testing is to be carried out shall be readily identifiable or have fixed to it a means of identification which will remain effective throughout the course of the work or testing.

## 9. DANGERS

The main **Dangers** when working on **HVDC Apparatus** and their associated components are electric shock, burns and / or other injuries arising from:

- Inadvertently infringing **Safety Distance**.
- The mistaking of **Apparatus** on which it is unsafe to work, from that which it is safe to work.
- Inadequate precautions, or security of those precautions, to suppress or safely discharge stored, impressed or induced electrical energy.
- Inadequate precautions, or security of those precautions, to suppress or safely discharge stored mechanical energy.
- Inadequate precautions, or security of those precautions, to suppress or safely discharge pressurised cooling systems.
- Contact with electrical test supplies at dangerous voltages / energy levels.
- Contact with an unearthed **System**.
- Inadequate precautions against laser light sources e.g. fibre optic light signals.
- Inadvertent access to **Apparatus**, such as air core reactors, that are **Live** and generating high magnetic fields.
- Contact with **Plant** or **Apparatus** that may be at a high temperature.
- Specific **Dangers** arising from work on *H-VAC* are:
  - Positive or negative differential air pressure across access doors and hatches
  - Rotating **Plant**
  - Heater elements
  - Confined spaces
  - Sources of **Low Voltage** electrical energy

**10. APPROACH TO EXPOSED HVDC CONDUCTORS AND INSULATORS**

**10.1 Objects**

When exposed **HVDC** conductors are not **Isolated**, the only objects which shall be caused to approach them, or insulators supporting them, within the **Safety Distance(s)** specified in section 10.3 for the appropriate **Location**, shall be **Approved** measuring devices or insulated devices.

When exposed **HVDC** conductors are **Isolated** but could be subject to **High Voltage**, the only objects which shall be caused to approach them, or insulators supporting them, within the **Safety Distance(s)** specified in section 10.3 for the appropriate **Location**, shall be **Approved** measuring devices, insulated devices, discharge devices or **Earthing Devices**.

**10.2 Persons**

**Persons** shall not allow any part of their body to approach **HVDC** conductors designed for, and operated at, **High Voltage**, or insulators supporting such conductors, within the **Safety Distances** specified in section 10.3 for the appropriate **Location**, unless the conductors have been **Isolated**, **Earthed** and **Danger** has been excluded.

**10.3 Safety Distance(s)**

The nature of **HVDC Apparatus** dictates that there are multiple **Safety Distances** applicable and these are specific to each **Location**. Refer to Appendix A for further detail on the derivation of **Safety Distance**.

<b>Location</b>	<b>HVDC Safety Distance (metres)</b>	<b>DC Neutral Bus Safety Distance (metres)</b>
Hunterston <i>HVDC Converter Station</i>	4.4	0.8

A distance of 300mm shall also be maintained from that part of the insulators supporting exposed unearthed **High Voltage** conductors which are outside the appropriate **Safety Distance**.

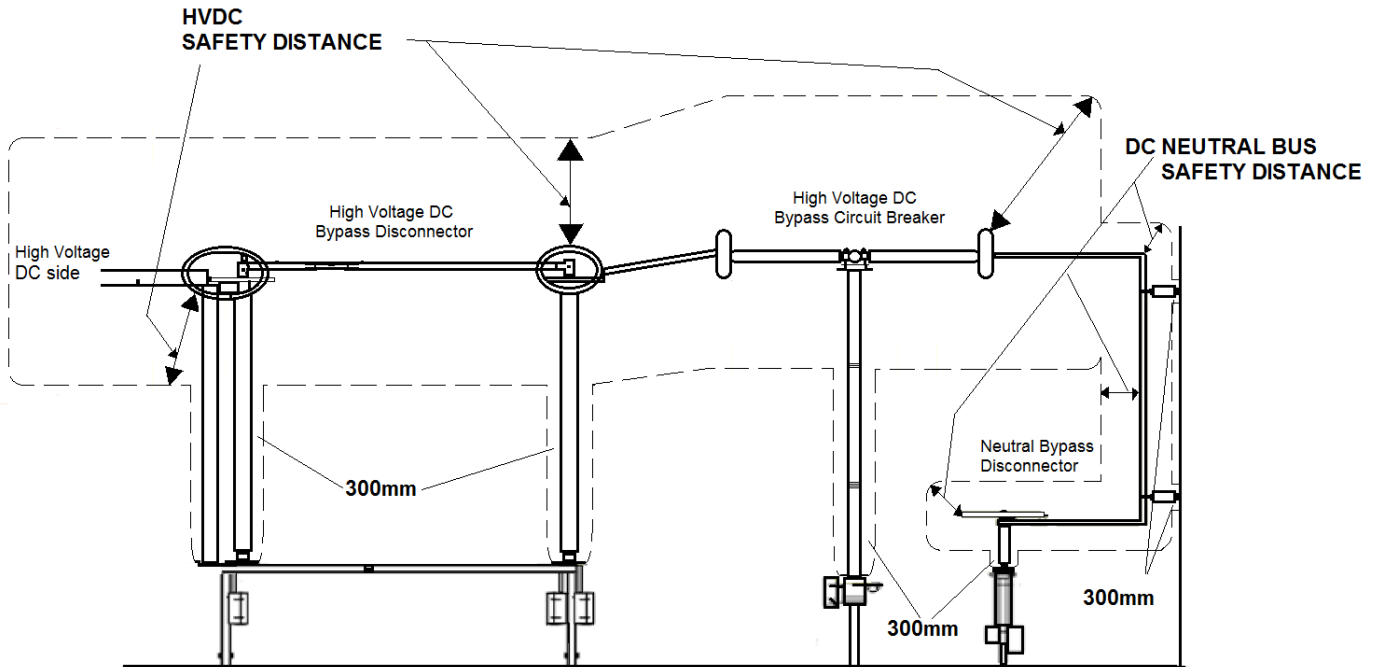
**10.4 Application of Safety Distance to HVDC Bypass Circuits**

Some **HVDC** Bypass Circuits comprise **Apparatus** of different rated voltages which are connected together.

Those conductors which directly connect **DC Neutral Bus** switchgear to **HVDC** switchgear shall be treated as **DC Neutral Bus** conductors. The **Safety Distance** to be applied relates to the design voltage of the **Apparatus** itself, not its configured running voltage, see diagrams overleaf for guidance.

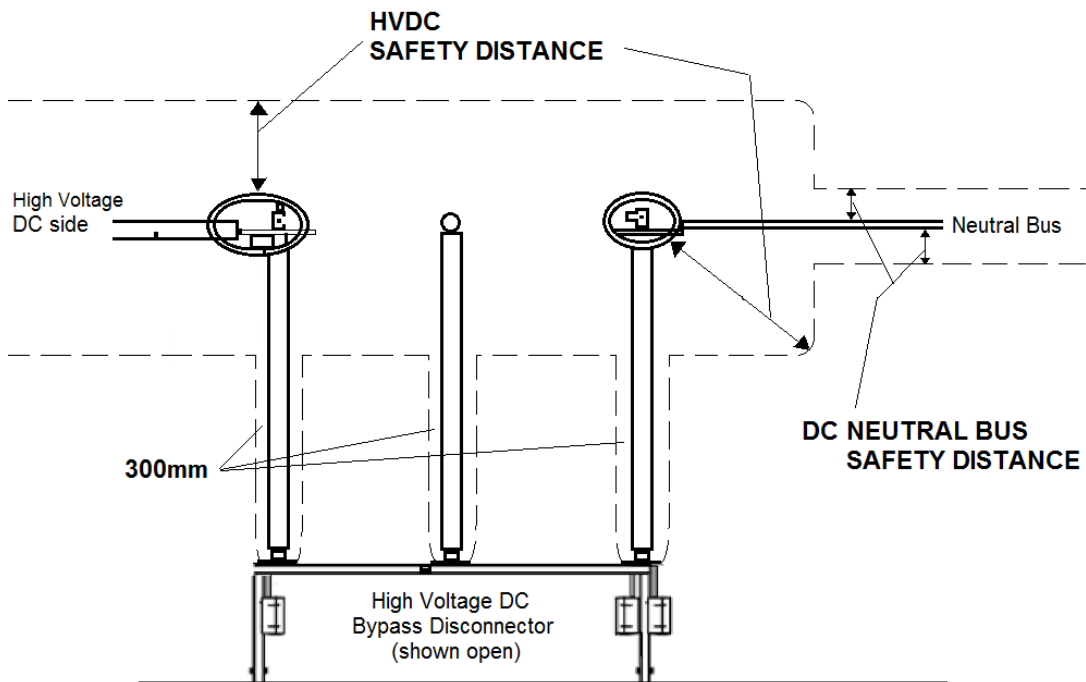
The following diagrams indicate the application of **Safety Distance(s)** for different **Apparatus** layouts.

Diagram 1: Typical **HVDC Apparatus**, where the **HVDC** bypass circuit includes a 'Bypass Switch' or circuit breaker performing the function of a 'Bypass Switch', illustrating combinations of **Safety Distance**



Note: Diagram not to scale. For indicative purposes only

Diagram 2: Typical **HVDC Apparatus**, where the **HVDC** bypass circuit includes only a bypass disconnector, illustrating combinations of **Safety Distance**



Note: Diagram not to scale. For indicative purposes only

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- 10.5 All **HVDC** conductors shall be considered to be operating at their designated voltage regardless of DC operating configuration.
- 10.6 Application and removal of **Earthing Device(s)** when full isolation is not practicable for specific testing purposes shall be done in accordance with an **Approved** procedure, prepared in accordance with OPSAF-11-015 (MSP 2.4).
- 10.7 **Live Apparatus** within *HVDC Converter Stations* may emit magnetic fields. *HVDC Converter Stations* are designed so that harmful exposure to strong magnetic fields is managed by appropriate positioning of **Apparatus** and by access control and barriers while the **Apparatus** is **Live**. Site-specific procedures and training shall ensure personnel are not exposed to harmful magnetic fields – either by magnitude or duration of exposure. Reference shall be made to ScottishPower policy [UKHS-GSP-SMS3029](#) 'Electromagnetic Fields Procedure' for guidance.

## 11. SPECIFIC REQUIREMENTS FOR WORKING IN HVDC CONVERTER STATIONS

### 11.1 All Areas

#### High Temperatures

Where work is to take place on or near to **Apparatus** that may have been operating at a high temperature, the risk shall be assessed and adequate control measures put in place. Control measures may include taking measurements, allowing time for **Apparatus** to cool or leaving *H-VAC* or other ventilation / cooling systems in service. The control measures may need to be observed whilst establishing **Safety from the System**. No **Safety Document** shall be issued where the presence of high temperatures may be a hazard that is not adequately controlled.

### 11.2 Valve Halls

Access to a *Valve Hall* may be prevented by interlocks whilst the *HVDC Converter Station* is in operation. Access shall not be permitted until the pole has **Points of Isolation** and earthing established, in accordance with OPSAF-10-001 and OPSAF-10-002 (PSSIs 1 and 2) and the ScottishPower Safety Rules (Electrical and Mechanical), and a **Permit for Work** or **Sanction for Test** issued.

Where **Earthing Device(s)** are located inside the *Valve Hall*, correct engagement of the **Earthing Device(s)** shall be confirmed as far as reasonably practicable. Where such **Earthing Device(s)** fail to operate or cannot be confirmed as fully closed, an alternative means of earthing, either external and/or internal to the *Valve Hall*, shall be established in accordance with an **Approved** procedure.

Testing of **Apparatus** within the *Valve Hall* could introduce **High Voltage** hazards that need to be controlled. A risk assessment shall be undertaken during the work planning stage to ensure the provisions of OPSAF-10-009 (PSSI 9) can be complied with.

### 11.3 Other HVDC Apparatus

There may be neutral earthing capacitors used as part of the *HVDC* connections scheme within a *Valve Hall* or connected to a *DC Neutral Bus* between two poles of a *Bipole*. For work on or testing of these capacitors they shall be considered as **HV Apparatus** and OPSAF-10-011 (PSSI 11) shall apply.

*PLCF Apparatus* have specific hazards such as: charged capacitors, power amplifiers, local and remote amplifier infeeds. This equipment shall be made safe for work in accordance with a site-specific **Approved** procedure.

*DC Voltage Dividers* are not based on wound transformer technology and are therefore not considered as a **HV** infeed in a similar way as wound metering voltage transformers on a **High Voltage AC System**. Therefore it is not necessary to establish **Point(s) of Isolation** on this **Apparatus**.

*DC Current Measuring Devices* can exhibit unique hazards such as laser power and signalling. This equipment shall be made safe for work in accordance with an **Approved** procedure.

#### 11.4 **Auxiliary Equipment**

*Valve Cooling Equipment* may contain liquid cooling systems comprising pipework, *Valves*, pumps, heat exchangers and control systems. When working on the *Valve Cooling Equipment*, it may need to be **Vented** or **Purged** and isolation or draining may be required, in which case a **Safety Document** shall be issued prior to work commencing.

The *Valve Hall*, *DC Hall* and Filter Halls may have an air management system (*H-VAC*). When working in a pressurised hall or the *H-VAC* air ducting or air handling unit(s), the work shall be risk assessed prior to starting and suitable control measures adopted.

When working on the *H-VAC* system, it may need to be **Vented** or **Purged** and isolation or draining may be required to achieve a safe system of work, in which case a **Safety Document** shall be issued prior to work commencing.

#### 11.5 **Additional General Safety Hazards associated with HVDC Apparatus**

For guidance on how to manage these risks, reference shall be made to the **Approved** operational procedure for the particular **Location**. All work or testing shall be done under a **Permit for Work** or **Sanction for Test**.

#### 11.6 **High Voltage AC Filters and Reactive Equipment**

Where access into individual filter compounds is controlled by interlock arrangements, such access shall only be possible when an earth switch has been closed to earth the filter busbars.

For access to, or for work or testing on, the filter capacitors, reactors, resistors and other associated equipment, additional **Primary Earths** or **Drain Earths** shall be applied in accordance with an **Approved** procedure. A **Permit for Work** or **Sanction for Test** shall be issued.



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## 12. HVDC CABLES

- 12.1 For work or testing on on-shore *HVDC* cables, a safe system of work shall be established in accordance with the ScottishPower Safety Rules (Electrical and Mechanical), the **Company** Safety Instructions and PSSI documents that apply to **High Voltage** AC cables.

It is a requirement of OPSAF-10-005 (PSSI 5) Appendix 1 that the insulation condition of the cable cores shall be established before and after spiking using an insulation tester. This requirement shall be met where reasonably practicable. It may not be reasonably practicable to use an insulation tester e.g. on particularly long and/or heavily insulated cables. Where it is found not to be reasonably practicable, an alternative method shall be used (e.g. time-domain reflectometry – TDR).

- 12.2 For cable work being undertaken off-shore, a procedure provided by the competent Contracted Service Provider shall be used for the identification of the cable and this shall be referenced by the **Senior Authorised Person** issuing the **Safety Document**.

- 12.3 A **Senior Authorised Person** shall ensure a written risk assessment for work on or near to *HVDC* cable **Systems** is undertaken and related control measures are identified and implemented. The assessment shall consider whether the cable **System(s)** to be worked on, including any cable accessories, are subject to induced or impressed voltage conditions.

The **Senior Authorised Person** does not approve the Contractor's risk assessment or method statement as it is a legal duty of the Contractor to provide a suitable and sufficient risk assessment and method statement to manage the work being undertaken. The work methodology shall incorporate the use of insulated and/or non-insulated cable working techniques, where applicable, to manage induced or impressed voltage conditions.

- 12.4 The safe system of work devised following the risk assessment shall include the following:
- Co-ordination meetings between a ScottishPower **Senior Authorised Person**, a ScottishPower control room representative and the competent contractor undertaking the cable works.
  - Requirement for the advance submission of a risk assessment and method statement for cable identification, cable maintenance or repair to the ScottishPower **Senior Authorised Person** by the competent contractor.
  - Positions of **Points of Isolation**, **Primary Earths**, and **Drain Earths**.

### 13. APPENDIX A: HVDC CLEARANCES

#### Defining Electrical Clearances and Safety Distance(s) for HVDC Apparatus

The clearance in air required to provide adequate insulation for **HVDC Apparatus** in *HVDC Converter Stations* is usually governed by the level of switching impulse voltage to which the **Apparatus** might be exposed.

*HVDC Converter Stations* tend to be of a bespoke design in order to achieve an optimum solution for a given application and a number of design-related factors influence the switching impulse voltage. Consequently, the switching impulse voltage and hence the electrical clearance is not directly related to the DC operating voltage.

The level of switching impulse is determined by the manufacturer in the insulation coordination studies which are performed at the design stage of a *HVDC* scheme. The value is rounded up to the nearest standard switching impulse level and the necessary air clearance determined from values given in the international standards. **Safety Distances** are determined from the electrical clearances by the addition of a safety margin. Values of **Safety Distance** for *HVDC Converter Stations* are given in section 10.3.

Note that, since the **Safety Distance** is not directly related to *HVDC* operating voltage, it is necessary to specify **Safety Distances** by **Location**.

#### Changes to System Configuration or Apparatus and its Effect

During the life of a *HVDC System*, a major change to the **Apparatus**, such as a *Valve* replacement, may be necessary. In such circumstances, a new insulation coordination study will be required as it may be found that the standard switching impulse withstand level has changed. Where any work is planned that requires a new insulation coordination study, it will be necessary to confirm whether the existing **Safety Distance(s)** remain applicable and, where necessary, to derive new **Safety Distance(s)**.

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## 14. APPENDIX B: SPECIFIC SWITCHING INSTRUCTIONS

The control system of *HVDC Converter Stations* features a high degree of automation, including operational and safety **Switching** sequences.

This Appendix describes a safe method of implementing such automation.

### Use of Automated Switching Sequences

Prior to the issue of any automated **Switching** instruction, the **Control Person** and **Authorised Person** shall familiarise themselves with the status of **Apparatus** at the *HVDC Converter Station* and where appropriate, the remote end. They shall agree with reference to site-specific documentation, exactly which **Apparatus** is both desired and expected to operate when the automatic sequence is executed. This **Apparatus** shall be listed individually on the **Switching** instruction, along with reference to the execution of the desired automatic sequence.

### Automated Operational Switching Instructions

Automated **Switching** sequences may be used to operate **Apparatus** for the purposes of operational reconfiguration. Reference to site-specific documentation may be necessary to determine which sequence is required.

The **Switching** instruction shall take the form:

On Pole 1, execute Connected command.

The **Authorised Person** shall ensure that the **Switching** sequence was successful (with reference to the site control system) before reporting back the **Switching** instruction.

### Automated Safety Switching Instructions

Automated **Switching** sequences may be used to operate earth switch(es) for the purposes of safety **Switching**, provided that adequate safeguarding of earth switch(es) is achieved during the same **Switching** instruction.

The **Switching** instruction shall take the form:

On Pole 1, execute **Earthed** command.

Check closed and apply lock to earth switches x, y, z.

When opening earth switch(es), the **Switching** instruction shall take the form:

On Pole 1, render operative earth switches x, y, z.

Execute **Isolated** command.

Check open earth switches x, y, z.

If either party is unable to agree what **Apparatus** is expected to operate when automatic sequences are commanded, **Switching** shall be carried out manually using the method described in OPSAF-10-001 (PSSI 1). This section serves only to facilitate the use of automatic **Switching** sequences. Manual **Switching** may still be carried out where preferred.

Where a **Switching** sequence fails to complete, the cause shall be evaluated and the **Switching** instruction cancelled. Manual **Switching** may then be required to resolve the problem.

Where **Points of Isolation** cannot be created because it is not safe to enter the vicinity in order to apply a **Safety Lock** and **Caution Notice**, the required procedure for the specific **Location** will be found within an MSP 2.4 sub-document.

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## 15. APPENDIX C: ADDITIONAL GUIDANCE FOR IDENTIFICATION OF HVDC CABLES

If the cable records are insufficient to identify a cable, the cable shall be positively identified by using the submitted Contracted Service Provider's procedure. The procedure must be suitable and sufficient to ensure absolute identification of the cable to be worked on, as confirmed by the **Senior Authorised Person**.

It is the Contracted Service Provider's responsibility to provide the risk assessment and method statement for the identification before testing or working upon cables off-shore. The ScottishPower **Senior Authorised Person** shall agree the methodology being used by the Contracted Service Provider to ensure **Safety from the System** is maintained throughout the course of the work.

The procedure for identifying the cable may include, but is not limited to using:

- Signal / tone generator cable locator
- The cable route GPS markers marked on charts
- Physical cable identification

### Signal / Tone Generator Cable Locator

To locate the position on the sea bed and to measure the burial depth of the submarine cables, one of the methods most used is to inject a signal of suitable amplitude and frequency into the cable.

A suitable device (for example a Remote Operated Vehicle in deep waters) will be moved close to the sea bed and (by suitable probes installed on it) will detect the magnetic field created by the injected signal. Then a signal conditioner will analyse the detected field and will evaluate the position of the cable and its burial depth.

### GPS Markers and Systems

For off-shore operations, it may be appropriate to refer to satellite-based positioning systems such as GPS. GPS systems are now accurate to within a few metres. It is usual to use the GPS markers attached to the cable to identify the cable's route and in conjunction with the signal / tone generator establish positive identification of an off-shore cable.

### An Example of Pole Identification

For the Western Link – the outer most layer of the marine cable is covered with a black polypropylene serving. Woven into the serving for the Pole 1 cable is a single yellow stripe and two yellow stripes in the serving for Pole 2.

N.B. The spare cable has completely black serving and depending on the cable repair i.e. length inserted, one pole or two pole cable repair, the inserted sections are to be marked during the repair process as appropriate.

For the Western Link – submarine cable installation comprises bundled (paired) installation in shallow waters and segregated installation in deeper water. The routing, method of installation and location of segregated cables are defined on the cable records.

### Other Fault Location Techniques

The methods for locating an insulation fault are directly related to the resistance of the fault path, water depth, cable length and to the needed precision. Typically, two methods are considered as described below:

Echo-meters (Time Domain Reflectometers):

This kind of equipment is particularly useful for pre-localisation of faults with precision of a few percent of the cable length.

In most cases this is enough to allow the choice of the repair method and the relevant vessel and equipment.

Electroding:

The electroding method is particularly useful if used after a pre-localisation with other land-based methods.

Methodologies for fault locations will be evaluated depending on circumstances, in order to find the best solution to be adopted. All viable solutions will be considered.