

Document No: MDI 0045

Amendment No: 1
(Supersedes MDI 0045.am0)

Mains Design Instruction

Cable sheath bonding design

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Mains Design Instruction

ASSET STANDARDS & DESIGN

Document No : MDI 0045
 Amendment No : 1
 Approved By : MASD
 Approval Date : 30/10/2017

MDI 0045 CABLE SHEATH BONDING DESIGN

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1.0 PURPOSE

To set out the minimum sheath bonding design requirements for single core cables installed in Endeavour Energy's transmission and sub-transmission networks.

2.0 SCOPE

This document provides the design requirements for all end-point, mid-point and cross bonded 33 kV, 66 kV and 132 kV single core cables.

The end-point and mid-point bonding requirements within this standard covers cables connected:

- within the premises of a single substation;
- between a substation and a UGOH; and
- between two UGOHs.

The cross bonding requirements within this standard covers cables connected:

- between substations;
- between a substation and a UGOH; and
- between two UGOHs.

3.0 REFERENCES

Internal

- Company Policy 9.2.5 Network Asset Design
- Earthing Design Instruction EDI 0001 Earthing design risk assessment
- Mains Design Instruction MDI 0011 Underground distribution cables - continuous current ratings
- Mains Design Instruction MDI 0046 Transmission underground cables - continuous current ratings
- Network NSW Specifications – 33kV cables specification (V9.2)
- Network NSW Specifications – 66kV cables specification (V7.2)
- Network NSW Specifications – 132kV cables specification (V10.2)

External

- ENA National Electricity Network Safety Code (Doc 01-2008)

4.0 DEFINITIONS AND ABBREVIATIONS

4.1 Abbreviations

CSA

Cross sectional area

ECC

Earth continuity conductor

GIS

Gas insulated switchgear

OHEW

Overhead earth wire

SVL

Sheath voltage limiter

UGOH

Underground to overhead

4.2 Definitions**Cross bonding**

A method for managing the metallic sheath voltage by designing the cable installation to have three (3) sections where the metallic sheath is transposed between the sections and earthed at each end.

Earth Continuity Cable (ECC)

A cable used to provide a conductive path for fault current.

Floating end

The end of the cable where the metallic sheath is unearthed.

Maximum cable length (L)

The maximum allowable length of cable that satisfied the design requirements in Section 5.1. The cable length may include straight through joints, in addition to the joints required for the bonding method, where the sheath is bonded continuously through the joint.

Metallic sheath

Metallic covering over the cable insulation designed to carry fault current. This metallic sheath may be a copper wire screen, corrugated copper or aluminium laminate.

Mid-point bonding

A method for managing the metallic sheath voltage by earthing the metallic sheath at one point along the cable length, usually in the middle.

Mixed bonded cable

A continuous length of cable where multiple bonding systems are used. The bonding systems are usually sectionalised from each other

Detailed sheath bonding design

A detailed engineering design process, taking into consideration all aspects of the cable construction, layout and fault current return paths, that complies with the design criteria listed in Section 5.1. Generally transient analysis software such as ATP or PSCAD should be used.

Sheath Voltage Limiter (SVL)

A device designed to restrict excessive transient voltages on the metallic sheath.

End-point bonding

A method for managing the metallic sheath voltage by earthing the metallic sheath at one end of the cable, also known as single-point bonding.

Substations

Zone and transmission substations.

5.0 ACTIONS

If the requirements and assumptions of this standard are satisfied, a detailed sheath bonding design is not required. If the requirements and assumptions of this standard are not satisfied, a detailed sheath bonding design must be submitted to the Mains Assets Manager for review, demonstrating compliance with the design criteria listed in Section 5.1.

5.1 Design criteria

The requirements of this standard were established using the following criteria:

- the maximum standing voltage on the metallic sheath under balanced load conditions must not exceed 160 V;
- the maximum voltage on the metallic sheath under a single line to ground through fault condition must not exceed 90% of the SVL rated voltage; and
- if the cross bonding has unequal minor section lengths, the de-rating effect from the circulating current in the metallic sheath must not exceed 1% of the cable rating calculated in Mains Design Instruction MDI 0011 Underground distribution cables - continuous current ratings or Mains Design Instruction MDI 0046 Transmission underground cables - continuous current ratings. If the de-rating exceeds 1%, the cable current rating must be updated to include the effects of unequal minor sections.

5.2 Design assumptions

The requirements specified in this document are only valid if the following assumptions are satisfied in the design.

Overall

- the single core cables used in the design comply with applicable NNSW cable specifications;
- only one cable circuit (of any voltage) is installed within the trench;
- SVLs have a 7.5 kV rating;
- the UGOH footing impedance is less than or equal to 10 Ω whilst meeting the requirements of EDI 0001; and
- the substation earth grid impedance, obtained from the Substation Primary Design Manager, is less than or equal to 0.5 Ω (if the cable bonding is directly connected to the substation).

End-point or mid-point bonded cable

- a minimum of two (2) km of OHEW connected to the UGOH. However, the OHEW can be less than two (2) km if connected directly to a substation; and
- the cable and ECC are installed in the configurations illustrated in Section 5.9.

Cross bonded cable

- The cable is installed in the configurations illustrated in Section 5.9 without an ECC.

5.3 Safety considerations

Under normal operating conditions, a voltage will be induced onto the metallic sheath. The metallic sheath must be treated as live low voltage and be adequately insulated to prevent inadvertent contact.

Under fault conditions, there is a risk of an earth potential rise occurring at the link boxes. Therefore, the risk must be managed in accordance with the requirements of Earthing Design Instruction EDI 0001 Earthing design risk assessment.

5.4 Bonding system selection considerations

The following must be considered (but not limited to) when selecting the bonding system:

- the number of joints required (costs of the joints and reliability impacts);
- costs associated with purchasing and installing an ECC for end-point and mid-point bonded systems;
- compatibility of the bonding system with future cable extensions and associated bonding; and
- if three (3) or more cable drums are required for the cable installation, cross bonding should be used.

5.5 End-point bonded cable

5.5.1 Connectivity

End-point bonded cables must have one end of the metallic sheath connected to earth. The floating end of the metallic sheath must be connected to an SVL to manage voltage transients on the metallic sheath.

End-point bonded cables connecting a substation to a UGOH must be connected as shown in Figure 1. The link box with the SVLs must be installed at the substation to assist with future maintenance.

End-point bonded cables connecting a UGOH to another UGOH must be connected as shown in Figure 2. The SVLs are to be installed on the side of the cable with the most accessible UGOH.

The maximum lengths of the cables (L) are outlined in Section 5.5.2.

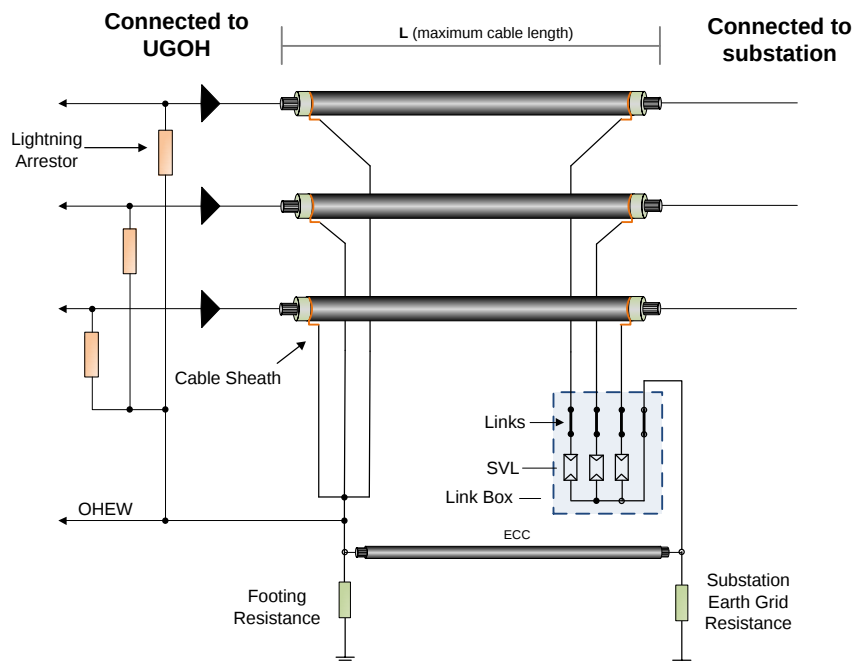


Figure 1 - Connectivity of an end-point bonded system, connecting a substation to a UGOH.

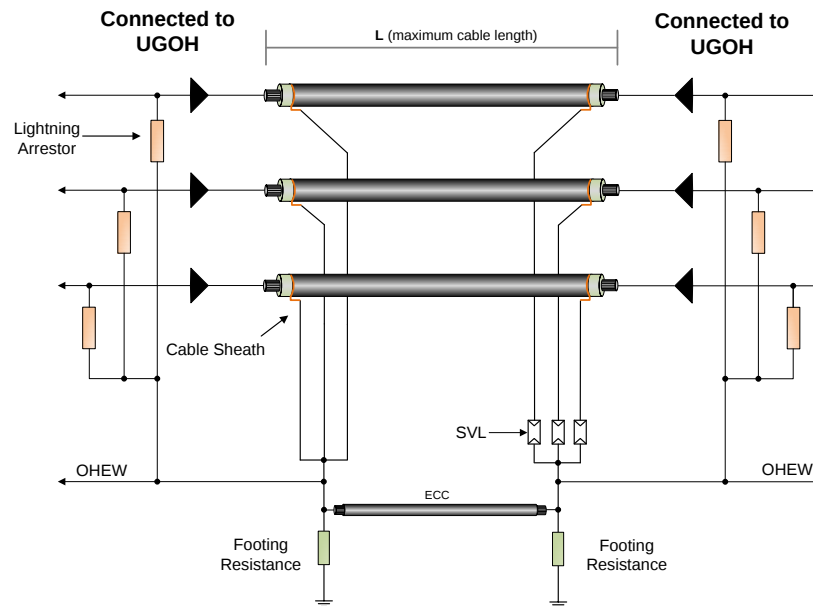


Figure 2 - Connectivity of an end-point bonded system, connecting a UGOH to a UGOH.

5.5.2 Maximum length requirements

The maximum cable lengths (L) for end-point bonded systems are listed in Table 1.

The maximum cable length varies depending on the location of the ECC with respects to the cable cores. The standard trench profile (outlined in Section 5.9.1) is the preferred arrangement however the alternative trench profile (outlined in Section 5.9.2) may be used if the maximum cable lengths are insufficient.

Table 1 – Maximum cable length for end-point bonding systems.

Cable details		Maximum prospective fault current (kA)	Maximum cable length L (m)			
Voltage (kV)	CSA (mm ²)		Standard trench profile (Section 5.9.1)		Alternative trench profile (Section 5.6.2)	
			Substation - UGOH	UGOH - UGOH	Substation - UGOH	UGOH - UGOH
33	300	31.5	1100	1500	1500	1800
	630					
	800					
	1200					
66	630	31.5	800	1300	1300	1800
132	400	31.5	950	1300	1200	1500
	630					
	800					
	1200					
	400	40	750	1100	950	1400
	630					
	800					
	1200					

5.6 Mid-point bonded cable

5.6.1 Connectivity

Mid-point bonded cables must have the metallic sheath, at the mid-point, connected to earth via an earthing link box. The floating ends of the metallic sheath must be connected to an SVL to manage voltage transients. Cable bonding connecting a substation to a UGOH must be connected as shown in Figure 3, whereas a UGOH to UGOH connection must be connected as shown in Figure 4.

The maximum lengths of the cables (L) are outlined in Section 5.6.2.

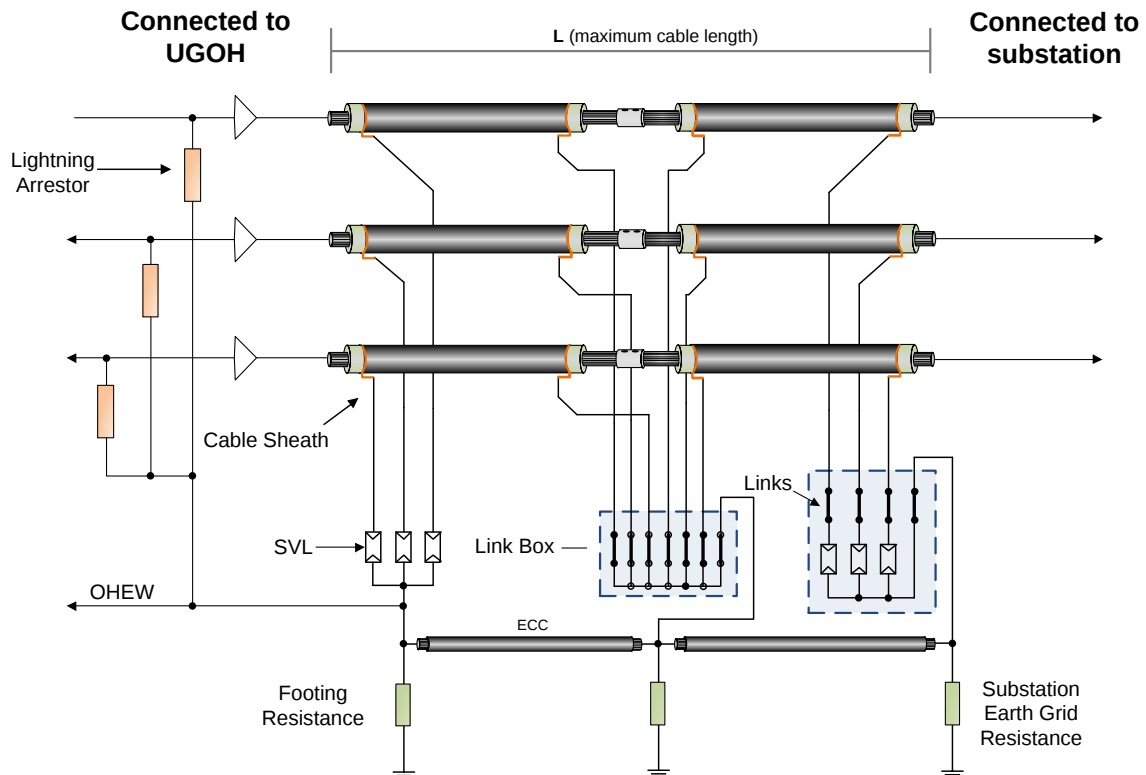


Figure 3 - Connectivity of a mid-point bonded system, connecting a UGOH to a substation.

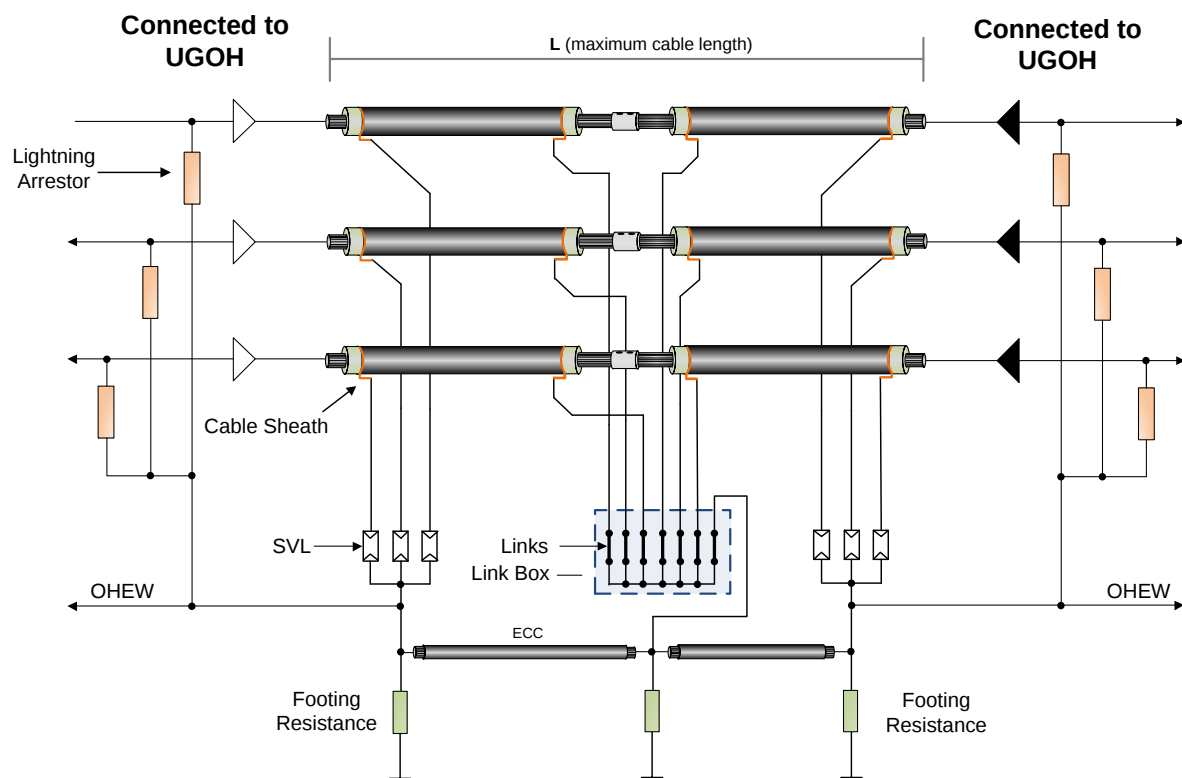


Figure 4 – Connectivity of a mid-point bonded system, connecting a UGOH to a UGOH.

5.6.2 Maximum length requirements

The maximum cable lengths (L) associated with mid-point bonding is the total length of the underground cable, including the midpoint joint, and is listed in Table 2.

If the location of the mid-point joint (where the metallic sheath is connected directly to earth) is not at the middle of the cable run, the maximum cable length on either side of the mid-point joint must be no greater than half of the maximum cable lengths listed in Table 2.

The maximum cable length varies depending on the location of the ECC with respects to the cable cores. The standard trench profile (as outlined Section 5.9.1) is the preferred arrangement however the alternative trench profile (as outlined in Section 5.9.2) may be used if the maximum cable lengths are insufficient.

Table 2 – Maximum cable length for mid-point bonding system.

Cable details		Maximum prospective fault current (kA)	Maximum cable length L (m)			
Voltage (kV)	CSA (mm ²)		Standard trench profile (clause 5.9.1)		Alternative trench profile (clause 5.9.2)	
			Substation - UGOH	UGOH - UGOH	Substation - UGOH	UGOH - UGOH
33	300	31.5	2200	3000	3000	3600
	630					
	800					
	1200					
66	630	31.5	1600	2600	2600	3600
132	400	31.5	1900	2600	2400	3000
	630					
	800					
	1200					
	400	40	1500	2200	1900	2800
	630					
	800					
	1200					

5.7 Cross bonded cable

Unlike end-point and mid-point bonded systems, cross bonded systems do not require an ECC but uses the metallic sheath to provide earthing continuity.

5.7.1 Single major section

Cross bonded cables consisting of one major section, made up of smaller minor sections, have the metallic sheath earthed at each end of the major section. The metallic sheath must be transposed between the minor sections and is connected to SVLs to manage voltage transients. However, the cable cores are jointed straight though as illustrated in Figure 5.

The minor section lengths and allowable differences between minor section lengths must not exceed the values stated in Section 5.7.4 and Section 5.7.5 respectively.

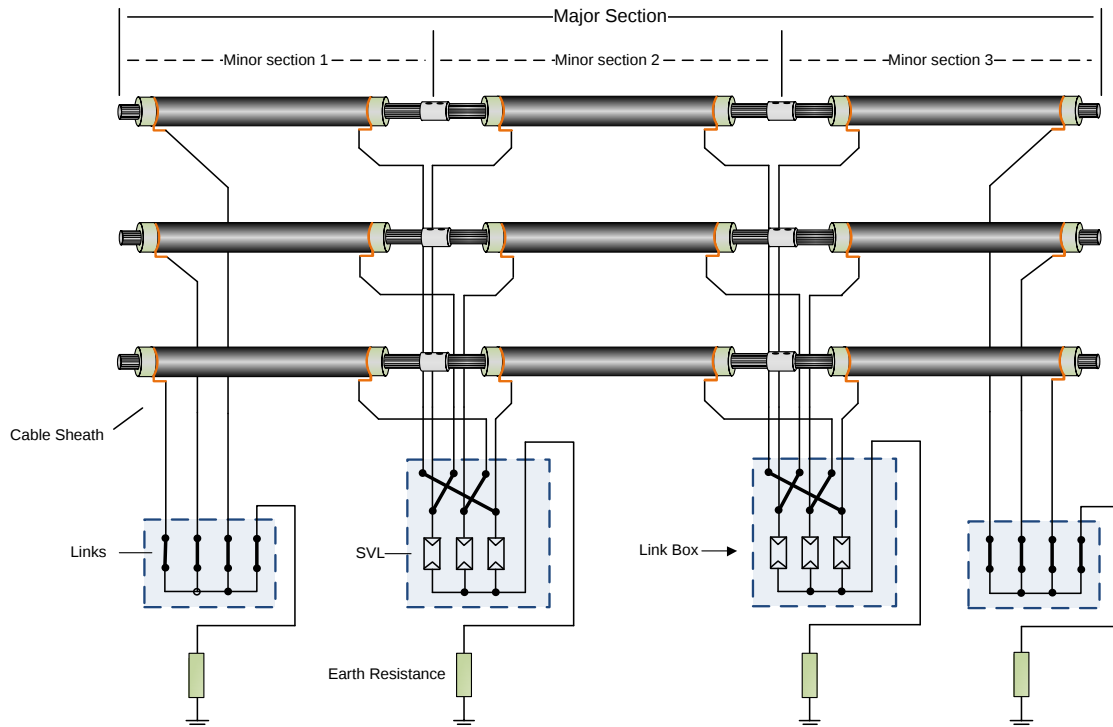


Figure 5 - Connectivity of a cross bonded cable system with one (1) major section.

5.7.2 Multiple major sections

The cross bonded major sections can be combined to achieve long cable lengths. The connectivity of multiple cross bonded systems is illustrated in Figure 6 and there is no limit to the number of major sections permitted in a cable run.

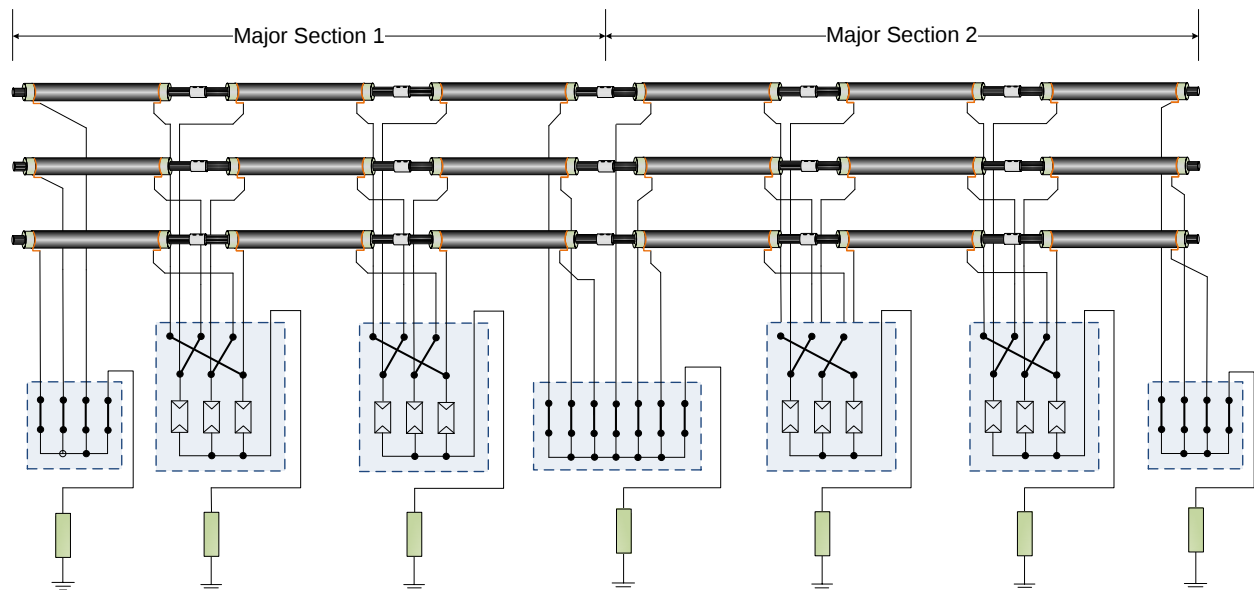


Figure 6 - Connectivity of a cross bonded cable system with two (2) major sections.

5.7.3 Connectivity

A cross bonded cable connecting a substation to a substation, a substation to a UGOH and a UGOH to a UGOH are to be connected as shown in Figure 7, Figure 8 and Figure 9 respectively. The maximum minor section lengths are outlined in Section 5.7.4.

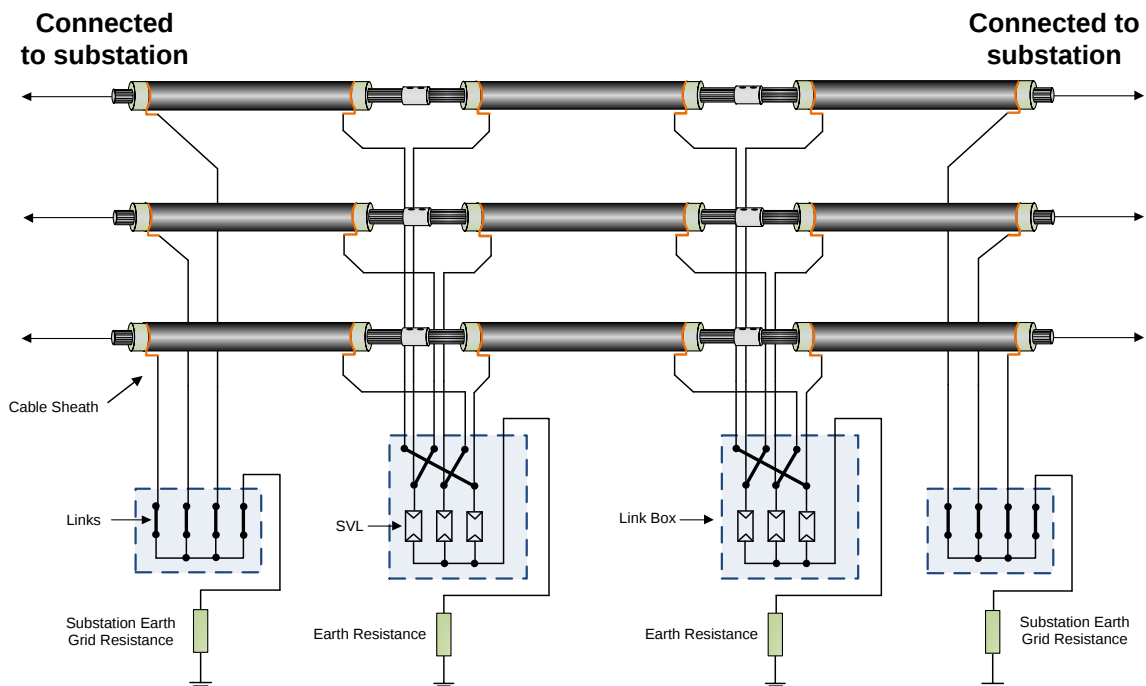


Figure 7 – Connectivity of a cross bonded system, connecting a substation to a substation.

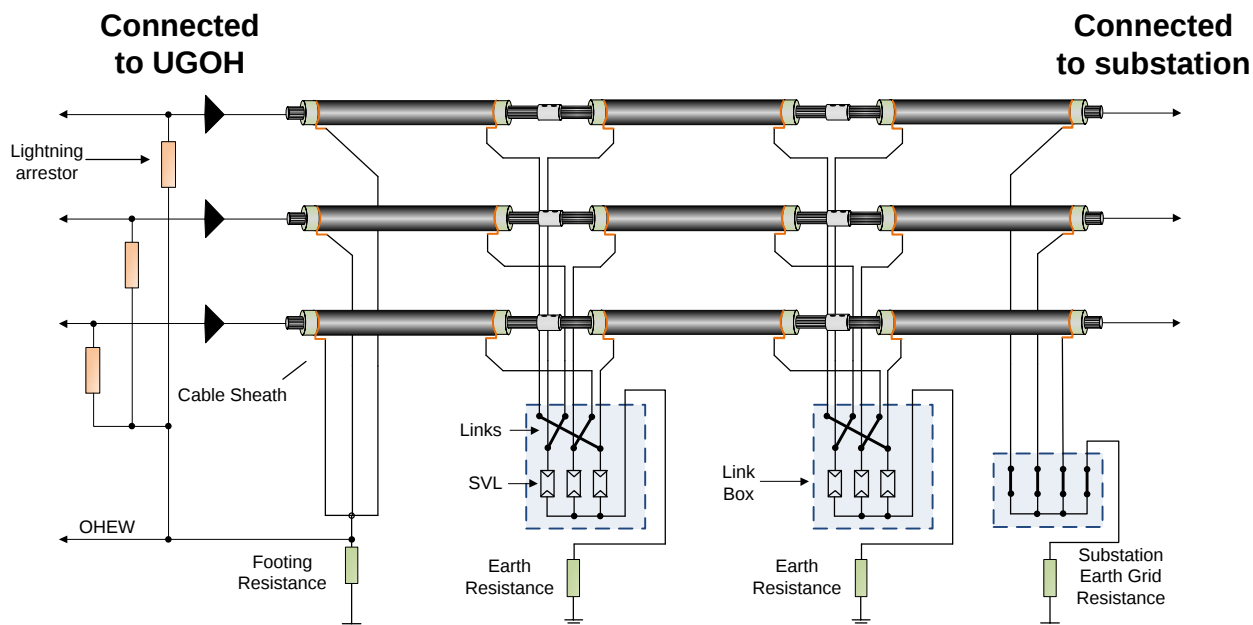


Figure 8 - Connectivity of a cross bonded system, connecting a UGOH to a substation.

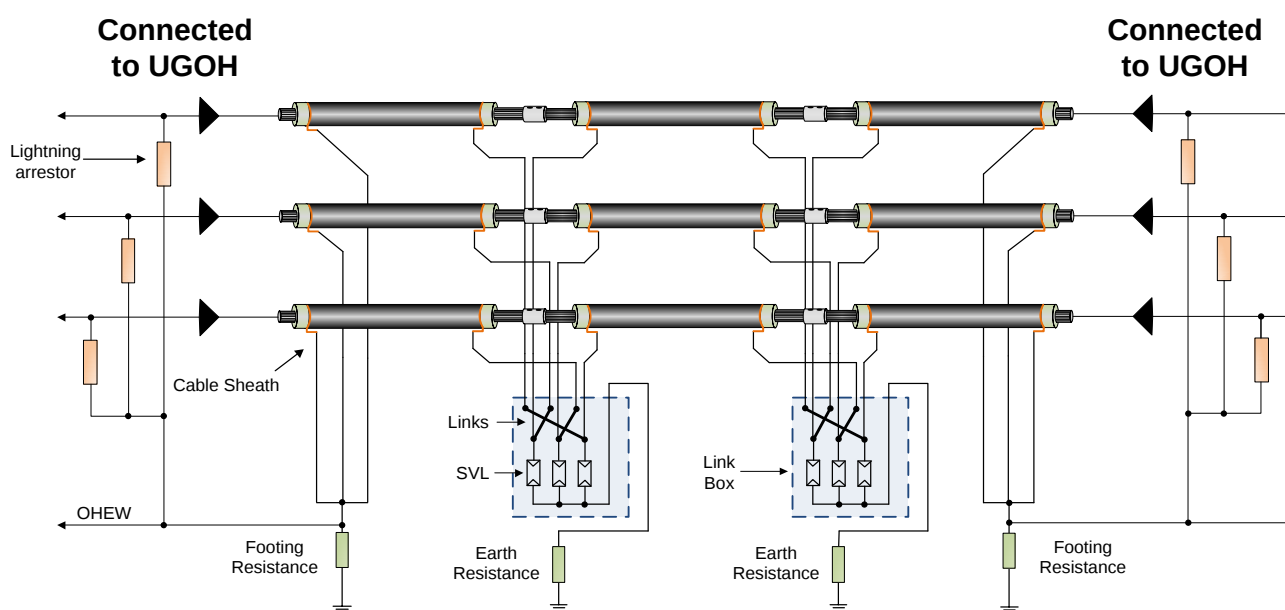


Figure 9 - Connectivity of a cross bonded system, connecting a UGOH to a UGOH.

5.7.4 Maximum minor section length requirements

The maximum minor section lengths for cross bonded systems are listed in Table 3. As cross bonded systems do not require an ECC, the trench profiles outlined in Section 5.9.1 and 5.9.2 result in the same maximum minor section lengths.

Table 3 - Cross bonding maximum minor section lengths.

Cable details		Maximum prospective fault current (kA)	Maximum minor section length (m)
Voltage (kV)	CSA (mm ²)		
33	300	31.5	1200
	630		
	800		
	1200		
66	630	31.5	1500
132	400	31.5	1300
	630		
	800		
	1200		
	400	40	1300
	630		
	800		
	1200		

5.7.5 Maximum minor section imbalance

For a given major section, the length of the minor sections should be as close to equal as possible, i.e. the minor section length should ideally be the length of the major section divided by three (3). If the minor section lengths are not equal, circulating currents will exist in the metallic sheath which may de-rate the cable. Refer to Annexure A – concepts, for an explanation of this effect.

The magnitude of circulating current is dependent on the difference in minor section lengths (within a given major section) and can be represented as a ratio. The difference ratio is listed below and must be less than 1.3.

$$\text{Difference Ratio} = \frac{\text{Longest minor section}}{\text{Shortest minor section}} \leq 1.3$$

5.8 Mixed bonded cable

Where a new bonding system is to be installed adjacent to an existing bonding system, the designer must consider whether it is more practical to convert the existing bonding system to suit the additional cable length or to create a mixed bonded system (multiple bonding systems are used on a continuous length of cable).

If a mixed bonded system is used, separate link boxes are required for each bonding system and must be connected to earth as shown in Figure 10 so that:

- the sheath is not continuous between bonding systems where an SVL is installed; and,
- the cable metallic sheath can be isolated for testing purposes.

However, one (1) link box is permitted where no SVLs are connected between the mixed bonding systems and if the link box can isolate the metallic sheath of each cable independently (i.e. a link box with seven (7) links – six (6) for the bonding leads and one (1) for the earth connection).

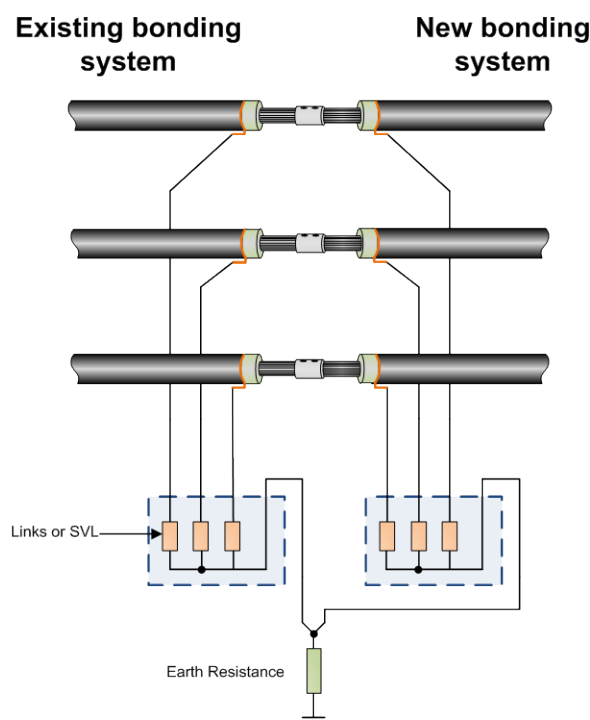


Figure 10: Where SVLs are connected between mixed bonding systems, separate link boxes are required to be installed.

5.9 Cable trench profiles

5.9.1 Standard trench profile

The following configuration is based on Endeavour Energy's standard trench profile. The ECC must be installed in a conduit 50 mm from the edge of the trench, as shown in Figure 11 below. If cross bonding is used, the ECC is not required.

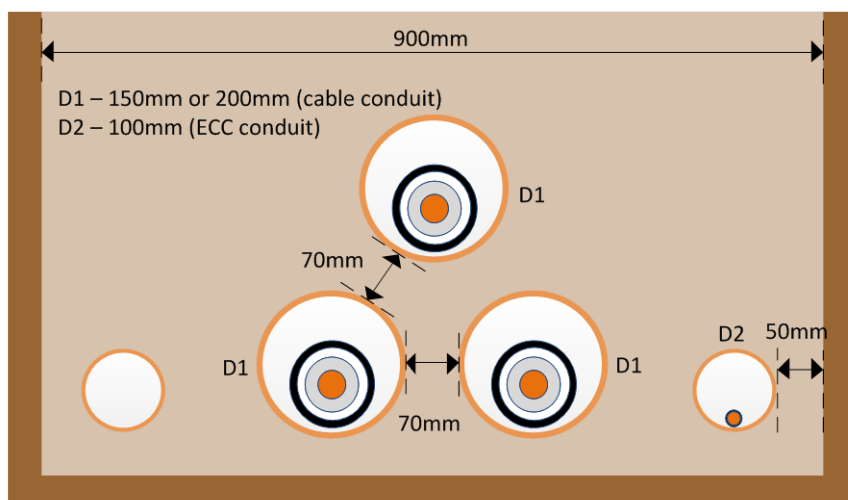


Figure 11 – Standard cable laying configuration.

5.9.2 Alternative trench profile

If the maximum cable lengths for end-point or mid-point bonded systems are insufficient using the standard trench profile, the alternative trench profile may be used, as depicted in Figure 12. If cross bonding is used, the ECC is not required.

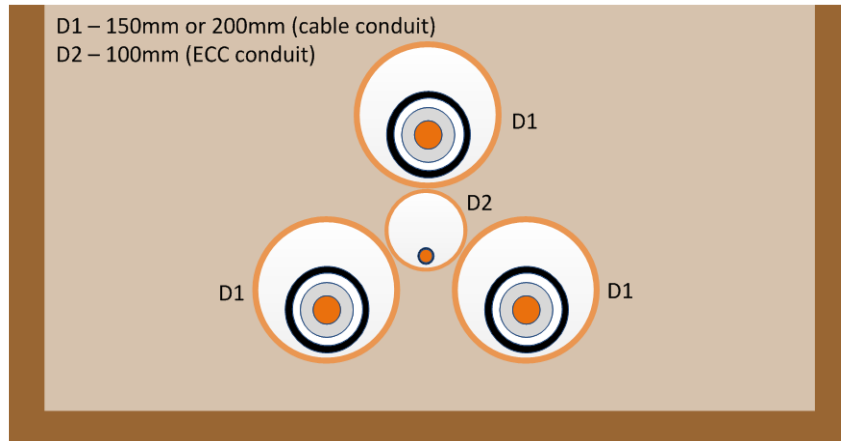


Figure 12 – Alternative cable laying configuration.

5.9.3 Cables installed in underbores

Underbored cables must use the lengths associated with the standard trench profile in Section 5.9.1.

Joint bays and transitions to UGOHs where the cable arrangement changes to flat for short lengths do not need to be considered and the values for the standard arrangement will suffice.

5.10 Single core cables within substations

5.10.1 General metallic sheath earthing requirements

Single core cables connected between the switchgear and transformer (inside a substation) of lengths less than 200 m must be:

- end-point bonded without SVLs;
- the source end of the cable unearthed (floating); and,
- the load end of the cable earthed.

As the metallic sheath is to be treated as live low voltage, a non-tracking heat shrink insulation cover (suitable for a minimum of 4 kV) must be installed around the exposed metallic sheath wires at the unearthed end, as shown in Figure 13. If the cable termination is installed both outside and horizontally, suitably rated self-amalgamated tape must be applied 20 mm either side under the heat shrink insulation to prevent moisture ingress.

Lengths greater than 200 m will require SVLs to be installed or a bonding design completed to verify SVLs are not required.

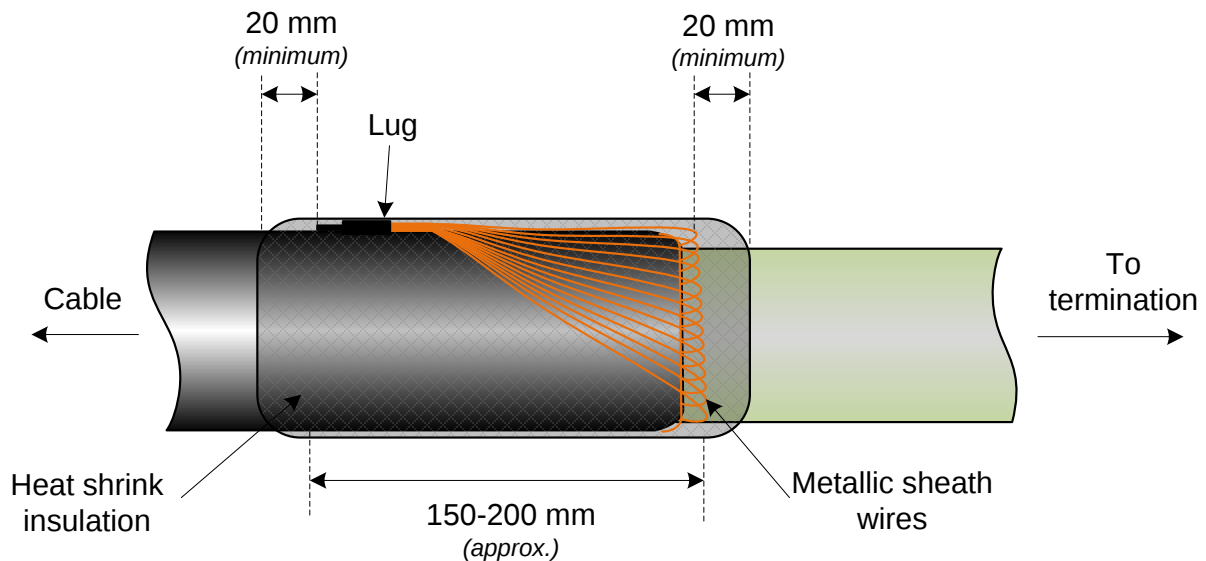


Figure 13 – Cable metallic sheath termination at the floating end.

5.10.2 Cable metallic sheath earthing for plugin GIS installations

If the cable metallic sheath is required to be earthed at the GIS, as defined by the selected bonding method or Section 5.10.1, the metallic sheath must be bonded to the plugin termination flange on the GIS enclosure. Electrical connections must also exist between the plugin termination flange and the GIS enclosure. The number, size and nature of these connections must be in accordance with the GIS manufacturer's specifications.

To prevent fault current travelling through the GIS enclosure frame, electrical connections must be made between the plugin termination flange and the earth bar (which is connected to the substation earth grid), as shown in Figure 14.

If the metallic sheath is required to be connected to a link box with SVLs (as stipulated in end-point or mid-point bonding), the metallic sheath is to be connected directly to the link box and must not be connected to the GIS flange.

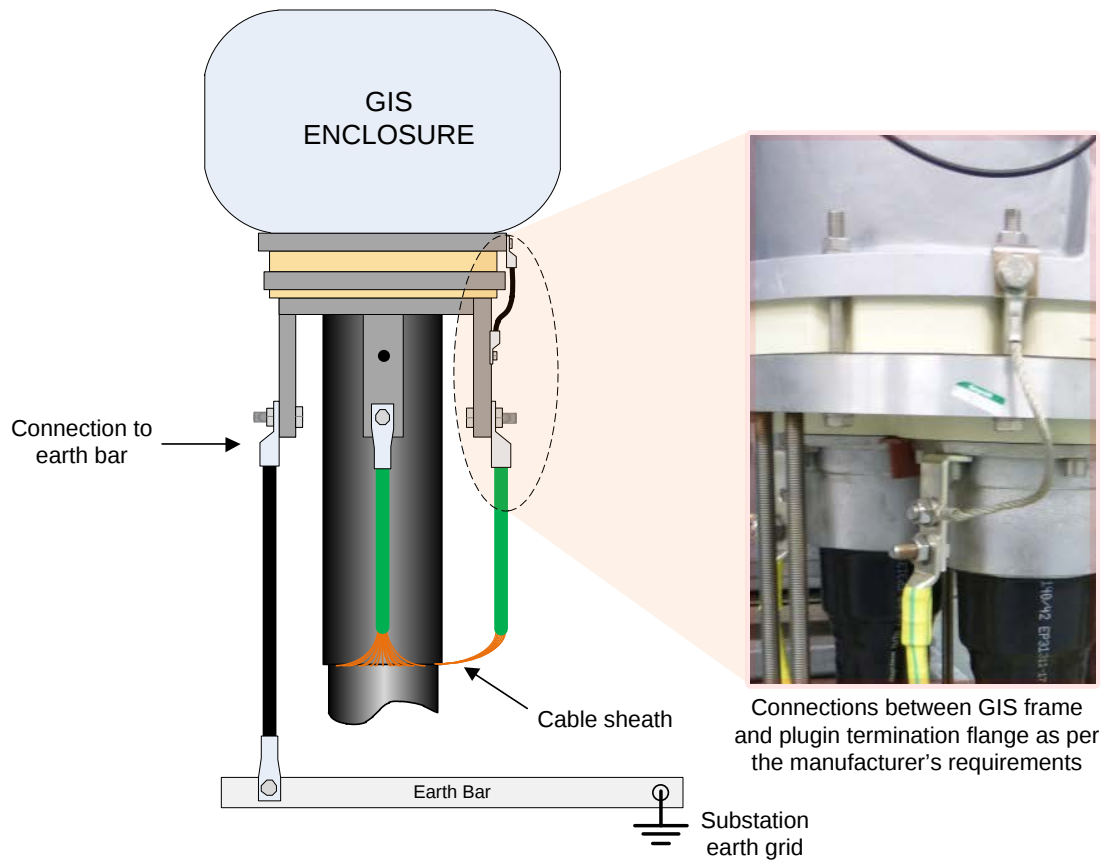


Figure 14 - Metallic sheath earthing arrangement at GIS.

5.11 ECC and bonding lead requirements

The ECC and bonding leads must be 240 mm² stranded copper single core cables.

6.0 AUTHORITIES AND RESPONSIBILITIES

General Manager Asset Management has the authority and responsibility for approving this instruction and approving variations from the requirements of this instruction.

Manager Asset Standards & Design has the authority and responsibility for:

- revising and updating this instruction in accordance with Company Policy and Procedures; and,
- endorsing and recommending changes and revisions to this instruction.

Mains Assets Manager has the authority and responsibility for:

- overseeing that all designs carried out under their responsibility conform to the requirements of this instruction;
- endorsing and recommending changes and revisions to this instruction; and,
- endorsing variations from the requirements of this instruction.

Mains & Civil Design Manager has the authority and responsibility for:

- overseeing that all designs carried out under their responsibility conform to the requirements of this instruction;

Substation Assets Manager has the responsibility to maintain equipment specifications and provide connection diagrams to allow for the safe connection to GIS and transformers within the Company's substations.

Substation Primary Design Manager has the responsibility for:

- providing substation earth grid impedances; and,
- providing guidance to designers completing earthing risk assessment for voltage rise at UGOHs and link boxes.

Power Quality & Reliability Planning Manager has the authority and responsibility for supplying fault level and source impedance information.

Manager Network Connections has the authority and responsibility for verifying all designs submitted by Level 3 Accredited Service Providers (ASP) conform to the requirements of this instruction.

It will be the **ASP's** responsibility to obtain the latest issue of any instruction or drawing relevant to or listed in this instruction for use during the design of any project.

7.0 DOCUMENT CONTROL

Documentation content coordinator: Mains Assets Manager

Documentation process coordinator: Standards Process Coordinator

Annexure A – Bonding concepts

End-point and mid-point bonding requires the metallic sheath to be earthed at one location. The load in the cable induces a voltage on the metallic sheath. If the metallic sheath was bonded to earth at the ends of the cable, the voltage on the metallic sheath causes a circulating current that may de-rate the cable.

As a consequence of only bonding the metallic sheath to earth at one point, the metallic sheath is unable to carry the fault current back to the source for a phase to earth fault. Hence, an ECC is installed with the cable to provide a fault current return path.

In contrast to end-point and mid-point bonding, cross bonding enables the metallic sheath to be bonded to earth at the ends of a major section (after three minor sections). This is due to the metallic sheath being transposed, producing a voltage 120° out of phase from the metallic sheath voltage in each minor section. The summation of these voltages after three equal minor sections is approximately zero, resulting in very little circulating current. This is depicted in Figure A 1.

With the metallic sheath earthed at the ends of each major section, the metallic sheath forms the path for fault current to flow back to the source and does not require an ECC.

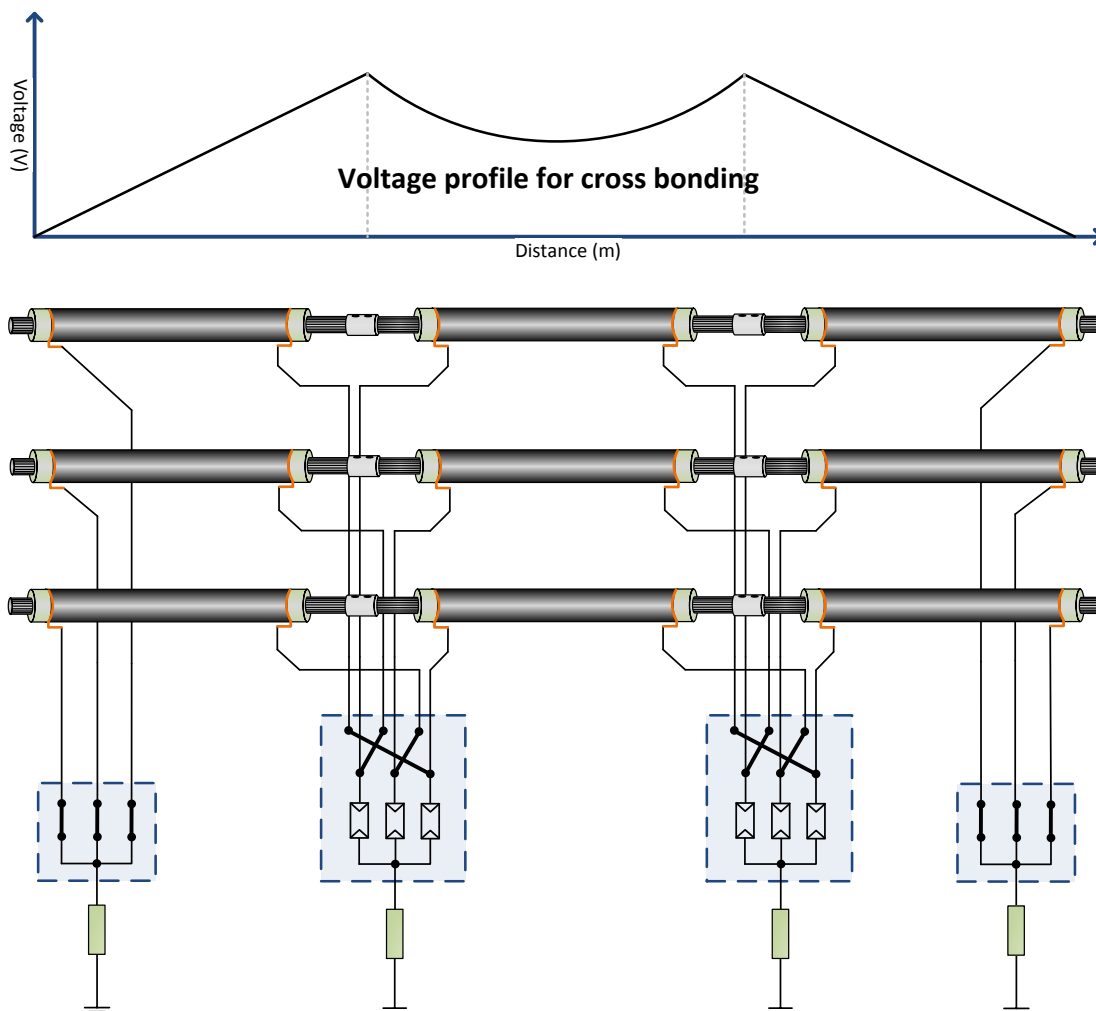


Figure A 1 – The generalised voltage profile over the metallic sheath for one phase. The metallic sheath transposition allows the voltage vectors to summate to approximately zero after three minor sections.