8TH SOUTHERN AFRICA REGIONAL CONFERENCE

14 - 17 NOVEMBER 2017

Technology solutions and innovations for developing economies

Evaluating Step and Touch Potential Risks on Earthing Systems of High Voltage Cable Systems

TP, THINUS DU PLESSIS

ESKOM

SOUTH AFRICA

HJ, HARTMUT JAGAU

AURECON

SOUTH AFRICA

DV, DEON-LOUIS VISAGIE,

ESKOM

SOUTH AFRICA

SUMMARY

When designing the earthing systems of a High Voltage (HV) cable system comprising of single core cables; an important consideration is the determination of step and touch potentials risks on the HV cable system earthing. Step potential risks may arise along the cable route in public areas where an uninsulated earthing system is buried directly in native soil. Touch potential risks may arise in public areas and substations where link disconnecting kiosks' conductive housings are bonded to the HV cable system earthing, and not designed and installed with a separate equipotential earth that is insulated from the HV cable system main fault current conducting earthing system. Case studies will be used along with Finite Element Analysis (FEA) to demonstrate the risks and to discuss and propose possible mitigating solutions.

KEYWORDS

High Voltage (HV) cable systems, Step potential, Touch potential, Finite Element Analysis (FEA), earthing, Safety.

1. INTRODUCTION

In South Africa, High Voltage (HV) cable systems are primarily used in urban environments due to limited space for HV overhead lines. These HV cable systems that connect distribution substations are mostly installed in directly buried trenches below sidewalks and roadways that are accessible by the general public on a daily basis. The HV cable system main earthing along these cable routes consist off; sheath interrupting joints installed to manage sheath standing voltages and circulating currents in the cable, bonding leads to connect the cable sheaths electrically to the above ground level or buried link disconnecting kiosks, and earth continuity conductors (ECCs) applicable to some earthing philosophies. The most common found HV cable system main earthing designs used in South Africa make use of link disconnecting kiosks with conductive outer housings and uninsulated ECCs.

During the initial planning and design of new HV cable systems, step potential and touch potential risks must therefore always be assessed through Finite Element (FE) simulations and analyses or prevented by inherently safe designed earthing systems. This will ensure the safest earthing philosophy for the public and the cable system, while also optimising for performance factors such as the cable system's current rating capacity under various loading conditions (i.e. ensuring circulating current losses and de-rating effects is kept to a minimum). It was however confirmed by retrospective FE simulations and analyses performed in this paper and visual inspections on existing installed and operated HV cable systems that the safety considerations may not have been considered historically at the time of installation, posing a safety risk to members of public and utility operators in close proximity to the installed HV cable systems.

Various HV cable system earthing design and configurations are discussed and explained in Cigre 283, and earth potential rise calculation methods and design considerations in Cigre 347. The scope of this paper will however be to only review the unsafe Step and Touch potentials risks on uninsulated earth continuity conductors and conductive housings of link disconnecting kiosks used as part of these HV cable system earthing philosophies implemented on single end-point, double end-point, multiple end-point bonded and cross bonded cable systems. These Step and Touch potential risks considered will be emanating from internal or external power system fault currents, flowing in the HV cable system earthing that are accessible to the public and utility operators.

The following assumptions were made for the FEA Step and Touch potentials simulations in this paper: A source substation, load substation and link disconnecting kiosks forming part of the various earthing philosophies of a HV cable system, are connected together as indicated in Cigre 283, for all the case studies. The single phase to ground fault level is 40kA, the soils resistivity is 100Ωm and the source and load substation earth resistance is 1Ω. The maximum allowable step and touch voltages for a 50kg person and a fault clearance time of 0.5s is 262V and 189V as per IEEE80.

2. CASE STUDY: STEP POTENTIAL RISK

Step potential risks should be evaluated along HV cable systems comprising of single core cables, an uninsulated / bare ECC and bare earthing electrodes at the joint bays (buried bare conductors), using FEA for HV cable system earthing.

Uninsulated ECCs is typically used between source and load substations where a multiple end-point bonding earthing philosophy is used. However, this can also be used with cross-bonded systems to improve safety. Another application of ECCs are to simply conduct fault current from the load substation back to the source substation for substation earthing reasons, where it may not form part of any HV cable system earthing.

The authors' of this paper is not aware of any recorded step potential safety incident that occurred in South Africa as yet on HV cable systems. However, should an unsafe Step potential be identified along the route of a bare ECC from FE simulations and analysis, an insulated ECC or different save earthing philosophy shall be considered.

Unsafe Step potentials are however suspected to be more common at joint bay electrodes, which are connected to the cable's sheath or ECC and forms part of the HV cable system earthing that conduct fault currents to earth. This paper therefore provides step potential FEA results for joint bay earth electrodes only.

Figure 2.1a shows unsafe step potentials at the single-end point bonded joint bay for a hybrid bonded system using the case study assumptions described in section 1 and the earthing connection arrangement of Figure 3.1a. Safe design FEA results are then obtained in Figure 2.1b for the Figure 3.1b simulated design.

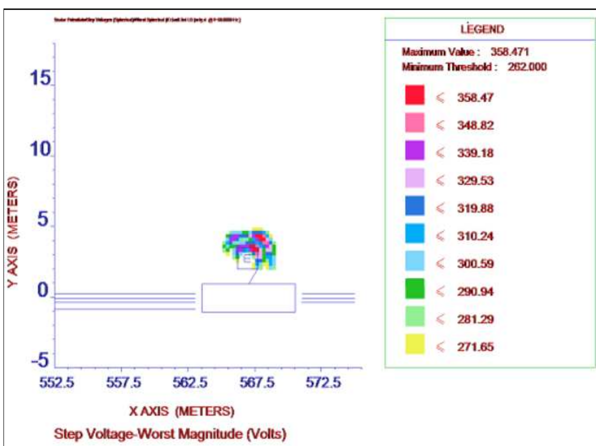

Figure 2.1a Unsafe Step potential using configuration as per Figure 3.1a

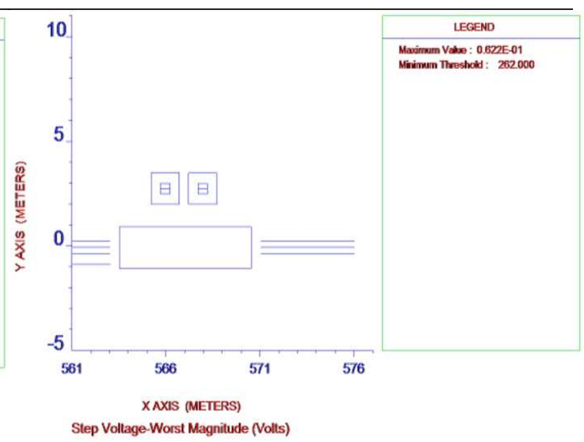

Figure 2.1b: Safe Step potential using configuration as per figure 3.1b

The bare earthing electrodes in Figure 3.1a at the joint bays demonstrated that an unsafe step potential may exist. The mitigating strategy consider then to decouple the joint bay earthing from the HV cable's earth (sheath) and ECC as shown in Figure 3.2b. This will then eliminate any fault current that may be conducted in the sheath / ECC, from entering the joint bay earthing electrode to return to the source, and in doing so, creating a potential Step potential risk. All earthing philosophies making use of a cable sheath or ECC connected to a joint bay earth, whereby a fault current can be conducted through the joint bay earth electrode must therefore be simulated to confirm the Step potential risks.

In the next case study, it will be shown how the joint bay earthing and conductive kiosk housing should be connected and earthed to mitigate against both Step and Touch potential risks.

3. CASE STUDY: TOUCH POTENTIAL RISK

Touch potential risks will be evaluated along the cable route using FEA for cable systems that make use of above ground level conductive link disconnecting kiosk housings which are bonded to the earthing system of the HV cable system. (I.e. The uninsulated link disconnecting kiosk housing is bonded to the HV cable system joint bay earth electrode and the cable metal sheath.)

Many different earthing arrangements and link disconnecting kiosk design configurations exist. In the following section, the most popular arrangements will be discussed.

Case studies 3.1 to 3.4 illustrate unsafe touch potential risks for link disconnecting kiosks that may be installed in the vicinity of public areas. For the case studies in section 2 and section 3 of this paper, the equipotential earthing connected to the housing of the kiosk comprises of 16mm2 stranded copper. This 16mm2 stranded copper is installed 0.5m from the kiosk at a depth of 0.5m. The joint bay earth comprises of 1.5m long, 16mm diameter earth rods installed at the four corners of the sheath interrupting joint bay in a rectangular formation of approximately 7m by 2m. The top of the rods are installed approximately 1.65m from natural ground level and is connected together through 16mm2 stranded copper. More details about the exact connection and electrode positions will be given in the individual case studies provided in this paper. Case studies in 3.5 illustrate unsafe installations for kiosks installed at substations.

Case studies:

3.1. Six (6) Way link disconnecting kiosk comprising of 3 SVLs and 3 earth connections

In Figure 3.1a, a typical 6 Way link disconnecting kiosk comprising of 3 SVLs (Surge/Sheath Voltage Limiter) and 3 earth connections used in multiple-end point bonded earthing systems are shown with the internal earth bar connected to the ECC (which can be a single connection or loop-in and loop-out connection) together with a connection from the earth bar to the joint bay earth. The conductive housing is connected to the earth bar as well as the equipotential earth.

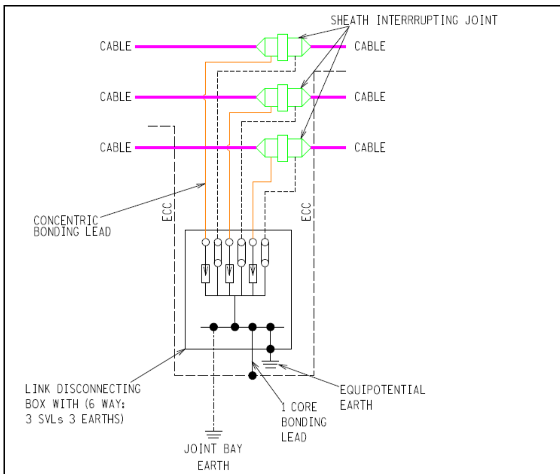

Figure 3.1a: Unsafe connection for a 6 Way link disconnecting kiosk comprising of 3SVLs and 3 earth connections

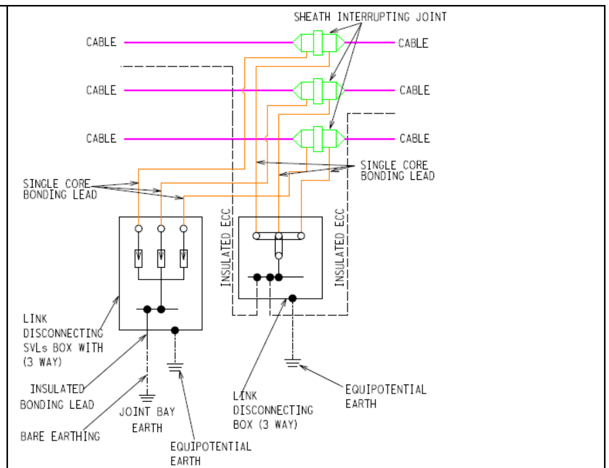

Figure 3.1b: Safe connection for a 6 Way link disconnecting kiosk comprising of 3SVLs and 3 earth Connections

Figure 3.1c and 3.1d below provides the Touch potential results of the FEA for the Figure 3.1a and 3.1b configurations.

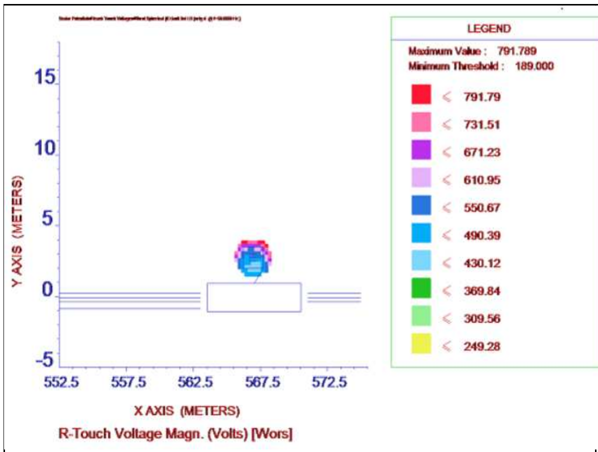

Figure 3.1c: Unsafe Touch potential using configuration as per Figure 3.1a

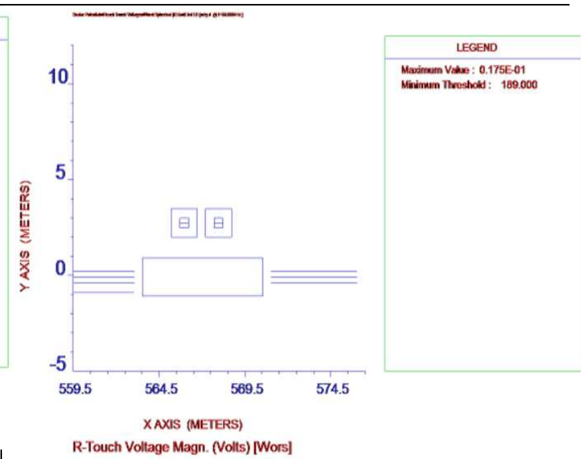

Figure 3.1d: Safe Touch potential using configuration as per Figure 3.1b

As can be seen from the results FEA results in Figure 3.1c, an unsafe Touch potential is possible and exists if the kiosk's housing is connected to the HV cable system earthing. In order to mitigate against this Touch potential risk, as well as the Step potential risk mentioned in section 2, consider the earthing connection diagram shown in Figure 3.1b.

In Figure 3.1b, the multiple-end point bonded system's earthing kiosk is divided into two kiosks, to demonstrate the earth bars are connected to different sides of the sheath-interrupting joint, and must remain disconnected and not form a common earth connection. The left side 3 way link disconnecting kiosk with SVLs' earth bar is connected to the joint bay earth but not to the link disconnecting kiosk's housing. The link disconnecting kiosk housing is connected to the equipotential earth installed around the link disconnecting kiosk.

The Figure 3.1b right side 3 way link disconnecting kiosk earth bar is connected to the insulated ECC but not to the link disconnecting kiosk housing. The ECC connection will allow fault currents to flow through as well as to conduct faults currents that may emanate from the cable metal sheath. The link disconnecting kiosk housing is then connected to the equipotential earth installed around the link disconnecting kiosk.

As can be seen from the FEA results in Figure 3.1d, the simulations show that the Figure 3.1b is a safe solution. This is because, for the left side 3 way link disconnecting kiosk with SVLs, the SVL ratings are selected such that it will not conduct under fault conditions. Therefore, no fault current will flow to the joint bay earth electrode or the housing or its equipotential earth, and thus mitigating a Touch (and Step potential) risk.

The equipotential earth electrode connected to only the disconnecting kiosks' housings in all case studies are simply added to ensure the conductive housing are then bonded to earth for any electro-magnetic stray voltage coupling effect.

3.2. Six (6) Way link disconnecting kiosk comprising of 6 SVL connections

In Figure 3.2a, a typical 6 Way link disconnecting kiosk comprising of 6 SVLs connections used in a double-end point bonded systems are shown with the internal earth bar connected to the ECC (which can be a single connection or loop-in and loop-out connection) together with a connection from the earth bar to the joint bay earth. The conductive housing is connected to the earth bar as well as the equipotential earth.

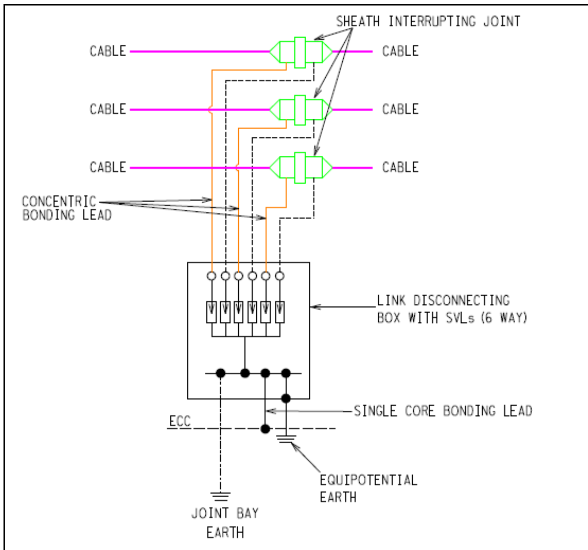

Figure 3.2a: Potentially unsafe connection for a 6 Way link disconnecting kiosk comprising of 6 SVL earth connections

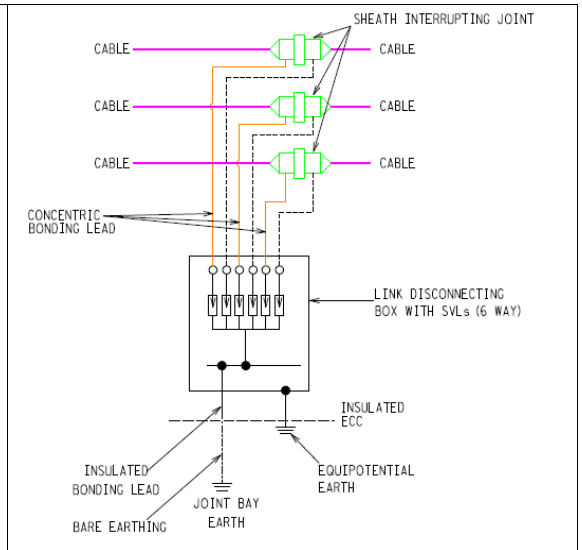

Figure 3.2b: Safe connection for a 6 Way link disconnecting kiosk comprising of 6 SVL connections

In order to mitigate against this Touch potential risk, as well as the Step potential risk mentioned in section 2, the connection must then be changed as seen in Figure 3.2b. The bare / insulated ECC should not be connected to the joint bay earth, link disconnecting kiosk's conductive housing or equipotential earth. The joint bay earth must be connected to the earth bar of the SVLs and the equipotential earth must be connected to the housing. This then eliminates any unsafe touch or step potential risk.

Figure 3.2c and 3.2d provide the Touch potential results of the FEA. The results show that no unsafe touch potential exists for either of the bonding methods, but clearly shows a reduction in the Touch potential for Figure 3.2b and illustrates that a Touch potential risk may exist for Figure 3.2a.

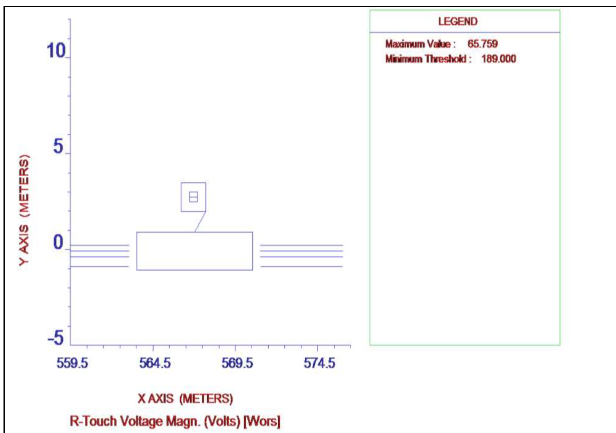

Figure 3.2c: Potentially unsafe Touch potential using configuration as per Figure 3.2a

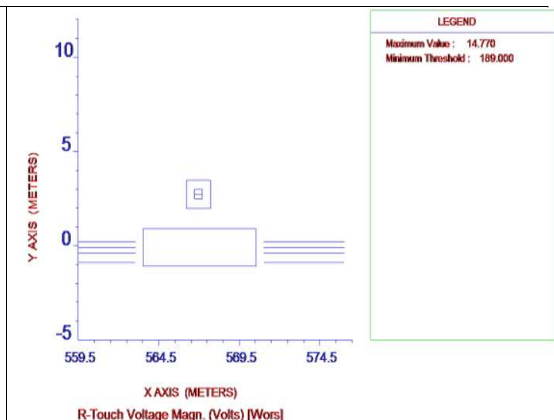

Figure 3.2d: Safe Touch potential using configuration as per Figure 3.2b

3.3. Six (6) Way link disconnecting kiosk comprising 6 earth connections

In Figure 3.3a and 3.3b, a typical 6 Way link disconnecting kiosk comprising of 6 earth connections is shown and is used in some cross-bonded systems or multiple end-point bonded systems. All connections coming from the sheath interrupting joints is connected to the earth bar which in turn is connected to the joint bay earth, link disconnecting kiosk conductive housing and equipotential earth.

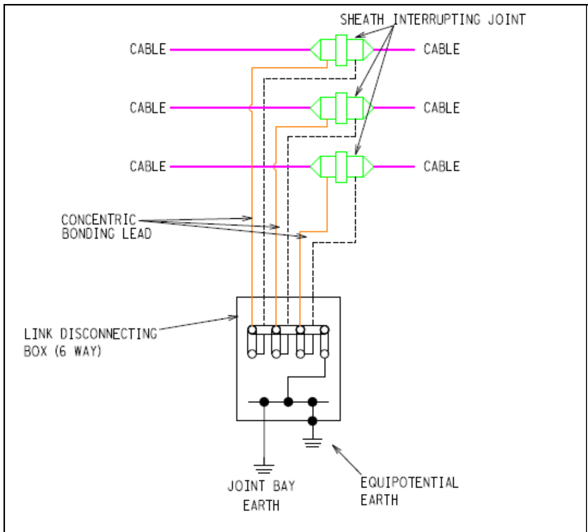

Figure 3.3a: Unsafe connection for a 6 Way link disconnecting kiosk comprising of 6 earth connections

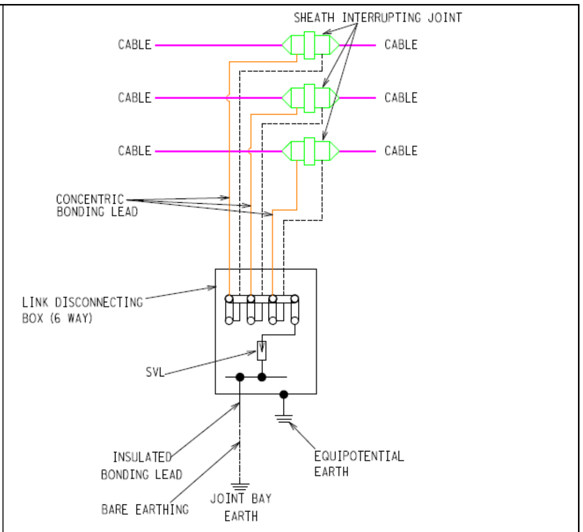

Figure 3.3b: Safe connection for a 6 Way link disconnecting kiosk comprising of 6 earth connections, that is connected through an SVL to earth

As with the previous case study, an unsafe Touch potential may exist because the housing and joint bay electrode is bonded to the HV cables system earthing.

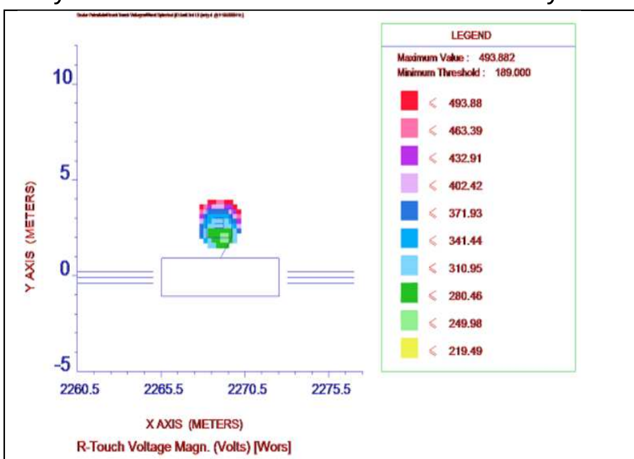

Figure 3.3c: Unsafe Touch potential using configuration as per Figure 3.3a

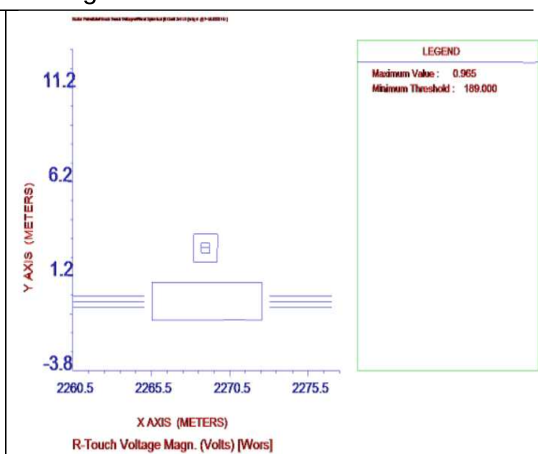

Figure 3.3d: Safe Touch potential using configuration as per Figure 3.3b

Figure 3.3c and 3.3d provide the Touch potential results of the FEA. The link disconnecting kiosk equipotential earth is disconnected from the conductive housing, which then eliminates any Touch potential risk as it is insulated from the HV cable system's earth (see Figure 3.3d). The 6 Way link disconnecting kiosk connects all the sheaths together before connecting to an SVL and then to earth. This is done to ensure the SVL can still conduct during lightning dischargers to earth. The authors are unsure if such a link disconnecting kiosk design exists, and a cross-bonded configuration as shown in the case study 3.4., may then be used as an alternative.

3.4. Cross-bonding link disconnection kiosk with SVLs to earth and in a delta configuration

In Figure 3.4a and 3.4b, typical 6 Way link disconnecting kiosks comprising of 6 SVLs to earth and in a delta configuration connection is shown, and are used in cross-bonded and continuous cross-bonded earthing systems. In Figure 3.4a all connections coming from the sheath interrupting joints is connected through SVLs to the earth bar which in turn is connected to the joint bay earth. In Figure 3.4b, all connections coming from the sheath interrupting joints is connected through SVLs in a delta formation with no earth bar connection and a joint bay earth is not required.

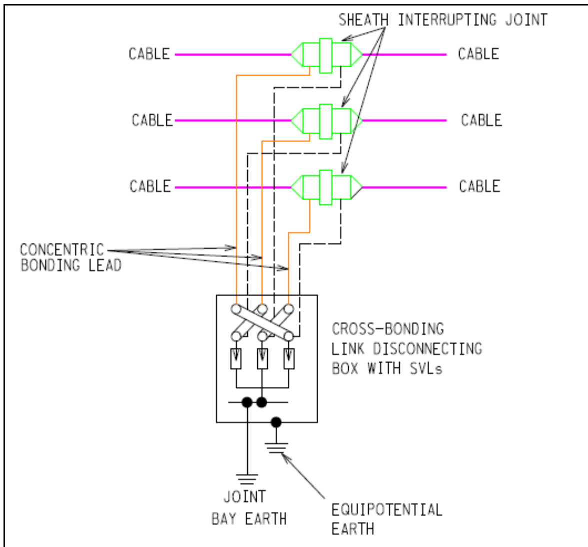

Figure 3.4a: Safe connection for a cross-bonding link disconnection kiosk with SVLs

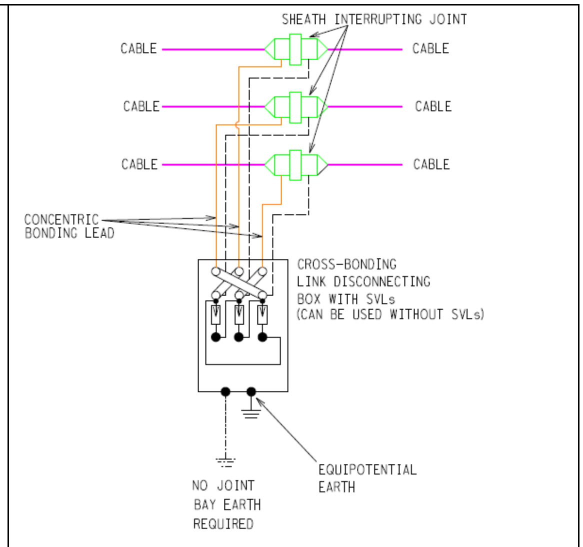

Figure 3.4b: Safe connection for a cross-bonding link disconnection kiosk with SVLs connected in a delta formation

The connections shown in Figure 3.4a are inherently safe, as the HV cable systems earth is separated from the joint bay earth, kiosk housing and equipotential earth through the use of correctly specified SVLs.

The connections shown in Figure 3.4b are also inherently safe, as the HV cable systems earth is separated from the kiosk housing and equipotential earth through its delta configuration design, and no joint bay earth is required. The FEA results are shown in Figure 3.4c and no Touch potential risk exists with this bonding method.

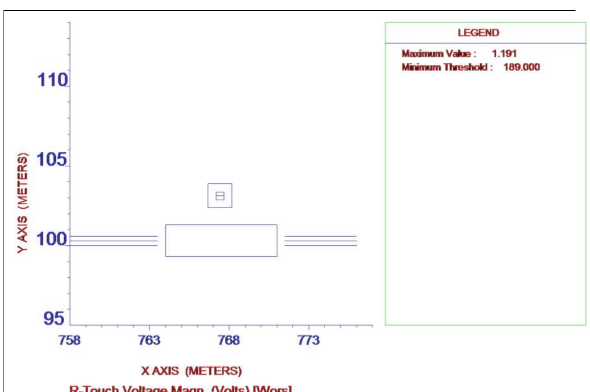

Figure 3.4c: Safe Touch potential using configuration as per Figure 3.4a and 3.4b

3.5. Three (3) Way link disconnecting kiosk comprising 3 earth connections and Three (3) Way link disconnecting kiosk comprising 3 SVL connections

In Figure 3.5a and Figure 3.5c, 3 Way link disconnecting kiosk comprising of 3 earth connections and 3 Way link disconnecting kiosk comprising of 3 SVLs are shown and are typically installed at the remote end substations. All connections coming from the termination are connected to the links/SVLs before being connected to the link disconnecting kiosk earth bar which in turn is connected to the substation earth mat.

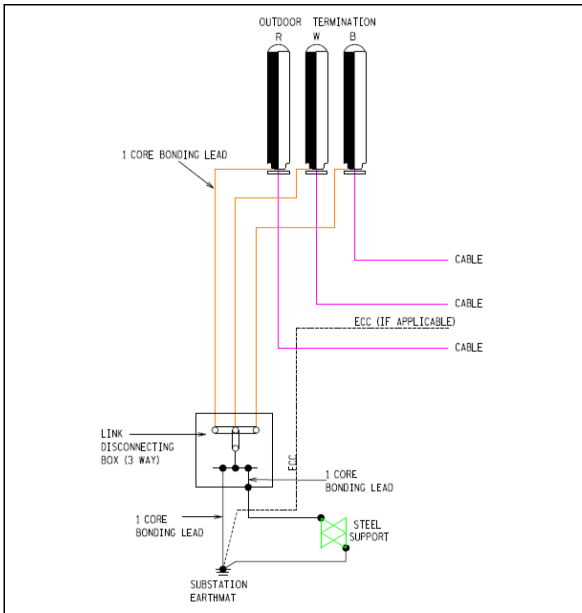

Figure 3.5a: Possible Unsafe connection for a 3 Way link disconnecting kiosk comprising of 3 earth connections

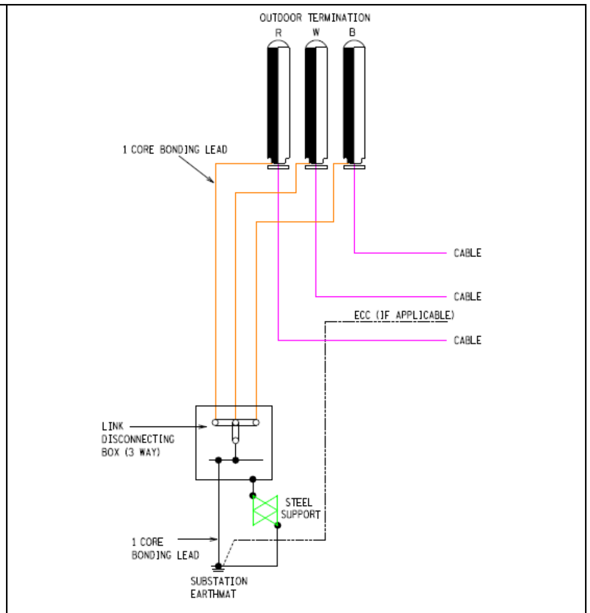

Figure 3.5b: Safe connection for a 3 Way link disconnecting kiosk comprising of 3 earth connections

The mitigation of Step and Touch potentials within a substation is beyond the scope of this paper. Assuming therefore that safe Step and Touch potentials exist within a substation, all conductive equipment should be safe to touch during a fault conditions.

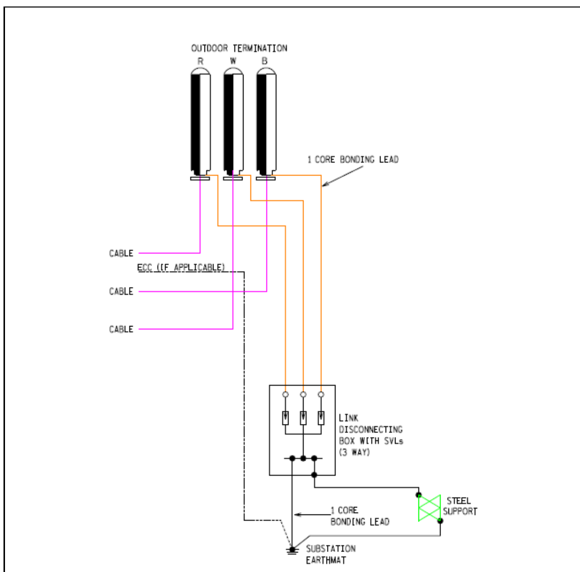

Figure 3.5c: Possible Unsafe connection for a 3 Way link disconnecting kiosk comprising of 3 earth connections

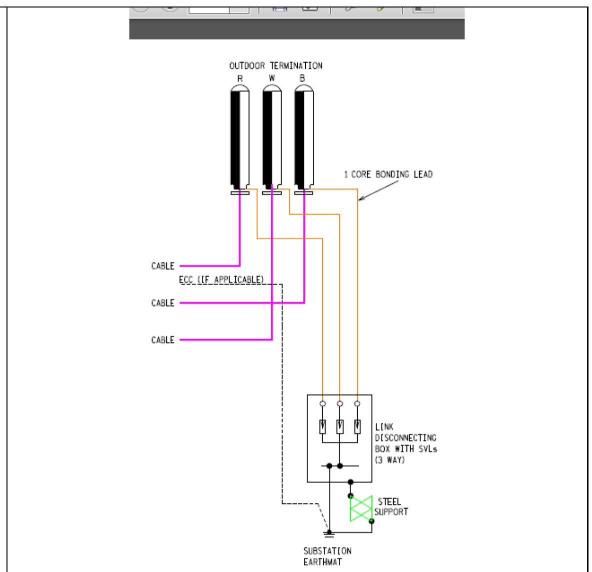

Figure 3.5d: Safe connection for a 3 Way link disconnecting kiosk comprising of 3 SVL connections

However, the connection methodology shown in Figure 3.5a and Figure 3.5c might be unsafe. This can be in the case where an external fault is conducted through the steel support and onto the steel support mounted HV cable system's earthing link disconnecting kiosk. The fault current will then conduct through the steel support connected to the substation earth mat and the HV cable earthing kiosk housing that is connected to the kiosk's earth bar which in turn is connected to the substation earth mat. The safety concern is that the housing might not be designed or tested to sustain fault currents in this method and may damage the link disconnecting kiosk earthing connections. Possible solution are shown in Figures 3.5b and Figures 3.5d as it separates the cable's earth from the substation earth inside the kiosks, which then prevents fault current from passing through the outer conductive housing, which then makes the installation safer.

4. CONCLUSION

To mitigate Step potential risks on HV cable earthing systems, consideration should be given to make use of an insulated ECC or another earthing philosophy that does not require ECCs at all.

To mitigate against Step and Touch potential risks at the HV cable joint bays, consideration should be given for joint bay earth electrodes, conductive link disconnecting kiosk housings and enclosure equipotential earths being insulated from the fault current conduction earth path of the HV cable system.

Many different case studies were given to explain the different unsafe and safe configurations and FEA was used to support the results from the case studies.

When planning and designing a new HV cable system, step potential and touch potential risks must always be assessed through safe designs and FE simulations and analyses to determine the safest earthing philosophy for the public and the cable system.

A retrospective review and analyses of existing installed HV cable system earthing are also recommended to ensure all existing unsafe installations are identified and rectified where applicable.

5. BIBLIOGRAPHY

[1] *Cigre 283*, Special bonding of high voltage power cables.

[2] *Cigre 347*, Earth potential rises in specially bonded screen systems.

[3] *IEEE Guide for Safety in AC Substation Grounding*, IEEE Standard 80, 2013.

[4] *SESTECH HIFREQ*, http://www.sestech.com/products/softmodule/hifreq.htm.