Single Core Cable Bonding Methodology in Electrical (Petrochemical) Industries

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Abstract-High voltage cables have metallic sheaths or screens surrounding the conductors over main insulation, and/or armor and metallic wires over inner sheath surrounding the cables. During earth faults applied to directly earthed systems, these metallic paths are expected to carry a substantial proportion of the total fault current, which would otherwise flow through the general mass of earth& earthling grid, while returning to system neutrals. These alternative return paths must be considered when determining the extent of the grid potential rise at an electrical plant due to earth faults. For safety and reliable operation, the metallic sheath and screens of power cables must be grounded.

I.INTRODUCTION

Single conductor medium and high-voltage power cables employ a coaxial design essentially consisting of a metal conductor strands surrounded by insulation and an outer metallic sheath (outer conductor). Semiconducting layers are provided at the interface between the conductor and the insulation, and between the insulation and the metallic sheath in order to provide a smooth electrical interface for the insulation and thus establish a uniform electrical stress pattern within the insulation. Cable core conductors are normally comprised of aluminum or copper wires.

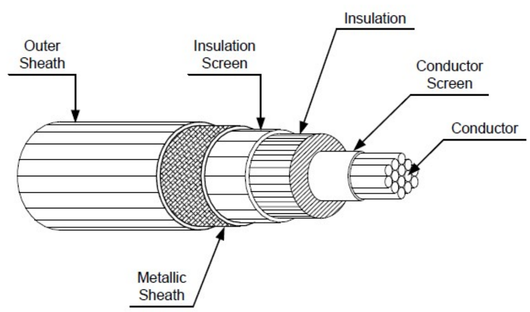


Fig 1. Cable cross section

II. LITRATURE SURVEY

Present day cable insulation materials generally consist of ethylene propylene rubber (EPR) or cross-linked polyethylene (XLPE) or polyvinyl chloride (PVC). The cables are constructed with an outer metallic sheath, which primarily comprises of one of the following:

- Concentrically applied copper wires, aluminum wires, or helically applied copper tapes
- Extruded lead or aluminum sheathes.
- Longitudinally applied corrugated copper tapes sealed at the overlap.
- Longitudinally applied thin copper or aluminum foil laminates sealed at the overlap.
- Combination of wires with any of the above copper tapes

The magnetic field resulting from current flow through the core conductor couples the metallic sheath and any other adjacent conductors. If the metallic sheath is also part of a continuous closed loop electric path, transformer action induces a current flow in the coupled metallic sheath and other adjacent conductors. Resistive losses due to the circulating currents in the metallic sheath then contribute to the temperature rise of the cable, limiting the amount of current that can be carried by the cable and reducing cable efficiency.

Conversely, if the electric path is interrupted through use of special bonding techniques, the metallic sheath circulating currents will be reduced or eliminated resulting in greater loading capability for the cable but at the disadvantage of developing a rise in metallic sheath voltage. Consequently, special bonding and grounding arrangements have been developed to limit the magnitude of metallic sheath voltages and to minimize the flow of circulating currents.

III. CABLE CONSTRUCTION

As part of the earlier cable designs, metallic sheath was exposed and in direct contact with the earth, water, mud, and conduit. This resulted in corrosion problems caused by ac electrolysis, leading to metallic sheath damage. Early efforts to limit such damage placed restriction on the maximum magnitude of sheath voltage, limiting these voltages to the range from about 12 V to 17 V. Present cable designs generally include an outer jacket that is insulating, and the likelihood of corrosion is thus effectively eliminated if the jacket remains intact. Since application of special bonding results in the build-up of significant voltage levels on the metallic sheath during faults and other abnormal operating conditions, designs take advantage of the state-of-the-art electrical insulating properties of the jacket to meet needed voltage withstand requirements.

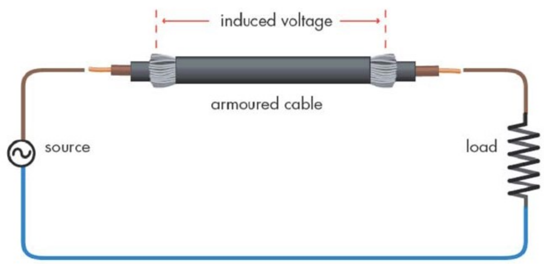


Fig 2. Induced voltage in a cable with a non-magnetic metallic sheath / armor

A graphite coating or an outer semi conductive layer is usually applied over the jacket at the factory to allow for testing of the jacket's electrical integrity.

With heavier loads on single conductor cable circuits, metallic sheath circulating current losses resulting from multipoint solidly bonded and grounded systems can be excessive for the intended application. To mitigate these losses, alternative metallic sheath grounding methods are available, and these are collectively referred to as special bonding techniques. Because long circuits and high currents tend to be more common on transmission class circuits, special bonding techniques tend to be more applicable on these types of circuits.

However, special bonding techniques can be applied on distribution circuits when operating conditions dictate a reduction in circuit losses.

Metallic sheath losses also increase with the spacing between cables, particularly when multiple points grounded; single-conductor cables are installed with wide spacing, such as when cables are placed in separate ducts or when they are direct buried in spaced configurations. When cables are spaced apart, significantly higher currents flow on the metallic sheath of solidly grounded systems, resulting in higher induced sheath circulating current losses. Increased spacing decreases the effects of mutual heating but increases the effect of magnetic coupling and therefore, increases metallic sheath circulating current losses resulting in lower cable current ratings.

Metallic sheath losses in single-conductor cables depend on several factors, one of which is the sheath bonding arrangement. Therefore, cable metallic sheath bonding and grounding are necessary to perform the following functions:

- Limit sheath voltages as required by sheath sectionalizing joints.
- Reduce sheath losses to a minimum.
- Maintain a continuous sheath circuit for fault current return and adequate lightning and switching surge protection

Some special bonding options include the following:

- Single-point bonding
- Multiple single-point bonding
- Solid bonding / both end bonding
- Cross bonding
  - Continuous cross bonding
  - Cross bonding with Transposition

IV. SINGLE CABLE BONDING

A system is single point bonded if the arrangements are such that the cable metallic sheaths provide no path for the flow of circulating currents or external fault currents. This is the simplest form of special bonding. The metallic sheaths of the three cable sections are connected and grounded at one point only along their length. At all other points there will be a voltage between metallic sheath and ground and between screens of adjacent phases of the cable circuit that will be at its maximum at the farthest point from the grounded bond. This induced voltage is proportional to the cable length and current. Single-point bonding can only be used for limited route lengths, but in general the accepted metallic sheath voltage potential limits the length. The maximum cable section length is governed by the permissible sheath standing voltage allowed at the isolated end. For typically permitted sheath voltage rise levels (i.e., no higher than about 200 V), this method is generally employed online lengths of up to about 2 km. Since there is no closed sheath circuit, except through the sheath voltage limiter, current does not normally flow longitudinally along the sheaths and no sheath circulation current loss occurs.

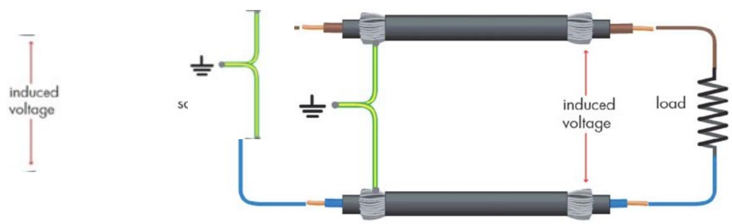


Fig 3. Single-point bonded system

Usually in single point bonded systems, the load side is earthed and is installed at the unearthed end to protect the cable insulation during fault conditions.

During a ground fault on the power system, the zero-sequence current carried by the cable conductors could return by whatever external paths are available.

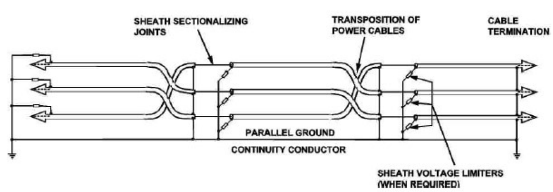


Fig 4. Single-point bonding diagram for a circuit comprised of three cable lengths

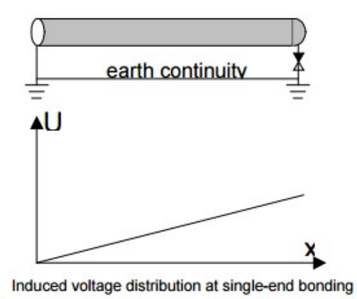


Fig 5. Induce voltage distribution for Single point bonding.

A ground fault in the immediate vicinity of the cable can cause a large difference in ground potential rise between the two ends of the cable system, posing hazards to personnel and equipment. For this reason, single-point bonded cable installations need a parallel ground conductor, grounded at both ends of the cable route and installed very close to the cable conductors, to carry the fault current during ground faults and to limit the voltage rise of the sheath during ground faults to an acceptable level. The parallel ground continuity conductor is usually insulated to avoid corrosion and transposed, if the cables are not transposed, to avoid circulating currents and losses during normal operating conditions.

For a single core armored cable, carrying an act. Load current, a voltage will be induced in the amour. Similarly, a voltage will be induced in a metallic screen and/or metallic sheath of a single-core cable. The magnitude of the induced voltage depends on factors which include the load current, the length of the cable, the arm our diameter and the cable spacing. The amour is effectively the secondary of a transformer and the conductor is the primary.

Single point bonding can only be used for limited route length but in general the accepted screen voltage potential limits the length.

Advantage

- No circulating current
- No heating in the cable sheath/screen
- Economical

Disadvantage

- Standing voltage at the unearthed end
- High voltage appears at unearthed end and can cause arching and damage to outer sheath.
- Requires SVL if standing voltage during fault is excessive.
- Requires additional earth continuity conductor for fault current if earth returned current is undesirable. Higher magnetic fields around the cable compared to solidly bonded system.

Annex C of IEEE 575 gives different values as followed in different Countries for the allowable limit of Standing end voltages.

V. SHEATH VOLTAGE LIMITER (SVL)

Cl.5.3.1 of Shell DEP 33.64.10.10-Electrical Engineering Design states “For single point bonded installations, the earth bond shall be at the field end of the circuit, i.e. the generator, motor or transformer terminations. Insulated cable glands shall be provided at the Switchboard termination”.

VI. MULTIPLE SINGLE POINT BONDED SYSYEM

It is also known as double length single point bonding System.

Cable metallic sheath continuity is interrupted at the midpoint and SVLs need to be fitted at each side of the isolation joint.

Other requirements are identical to single–point–bonding system like SVL, Earth continuity Conductor, Transposition of earth continuity conductor.

Effectively it consists two sections of single–point–bonding. There are no circulating currents, and Zero volt is observed at the earthed ends, standing voltage at the two cable ends.

Advantage

- No circulating current in the metallic sheath
- No heating effect in the cable metallic sheath
- Suitable for longer cable section compared to single–point–bonding system and solidly bonded single-core system

Disadvantage

- Suitable for 300~1000 m long cable sections, double the length of single–point–bonding system

VII. SOILD BONDING/ BOTH END BONDING

One way to eliminate the induced voltages is to bond the sheath at both ends of the cable circuit. This eliminates the need for the parallel continuity conductor used in single-point bonding systems. It also eliminates the need to provide SVL, such as that used at the free end of single-point bonding cable circuits. The disadvantage of this bonding method is that the considerable heat caused by the circulating currents in the cable sheaths reduces the current carrying capacity of the cable circuit.

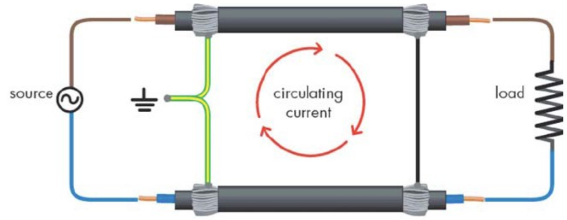


Fig 6. Solid bonded system

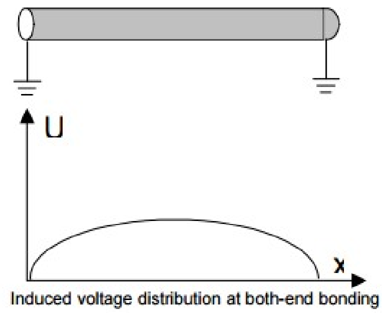


Fig 7. Induced voltage distribution for both end bonding

Advantages

- Minimum material required
- Most economical if heating is not a main issue
- Provides path for fault current, minimizing earth return current and EGVR (Earth Grid Voltage Rise)at cable destination
- Does not require screen voltage limiter (SVL)
- Less electromagnetic radiation

Disadvantages

- Provides path for circulating current
- Heating effects in cable screen, greater losses. Cable therefore might need to be de–rated or larger cable is required
- Transfers voltages between sites when there is an EGVR (Earth Grid Voltage Rise) at one site

Normally applies to short cable section of tens of meters long. Circulating current is proportional to the length of the cable and the magnitude of the load current.

VII. CROSS BONDING:

A system is cross-bonded if the arrangements are such that the circuit provides electrically continuous sheath runs from earthed termination to earthed termination but with the sheaths so sectionalized and cross-connected to reduce the sheath circulating currents. In this type, voltage will be induced between metallic sheath and earth, but no significant current will flow. The maximum induced voltage will appear at the link boxes for cross-bonding. This method permits a cable current-carrying capacity as high as with single-point bonding but longer route lengths than the latter. It requires screen separation and additional link boxes.

The most basic form of cross bonding consists of the cable length being divided into three approximately equal sections called minor sections. Three minor sections form one major section. Each of the three alternating magnetic fields induces a voltage with a phase shift of 120° in the cable sheaths. The cross bonding of sheaths takes place in the link boxes. Ideally, the Victoria addition of the induced voltages results in U (Rise) = 0. In practice, the cable length and the laying conditions will vary, resulting in a small residual voltage and a negligible current in one major section. Since there is no or negligible current flow, there are practically no losses in the screen. The total of the three voltages is zero, thus the ends of the three sections can be grounded. The sheaths are bonded and grounded at the beginning and end of each major section.

Longer cable circuits may consist of several major sections in series. When the number of minor sections is divisible by three, the cable circuit can be arranged to consist of more than one major section. In such a case, the cable circuit could consist of either sectionalized cross bonding or continuous cross bonding.

In the case of sectionalized cross bonding, the cables are transposed at each minor section, and the sheaths are bonded together and grounded at the junction of two major sections and at the beginning and end of the cable circuit.
In the case of continuous cross bonding, the cables are preferably transposed at each minor section and the sheaths are cross bonded at the end of each minor section throughout the whole cable route. The three cable sheaths are bonded and grounded at the two ends of the route only.
There are many variations of cross bonding for longer cable circuits.

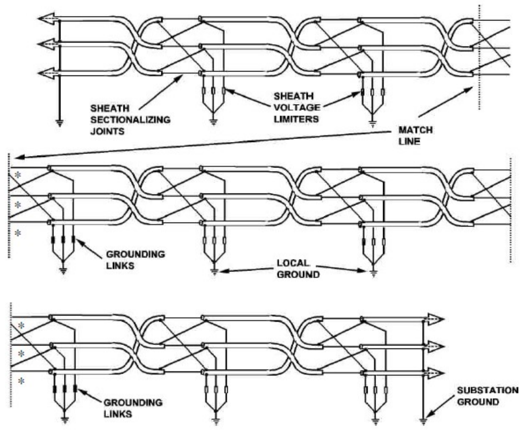
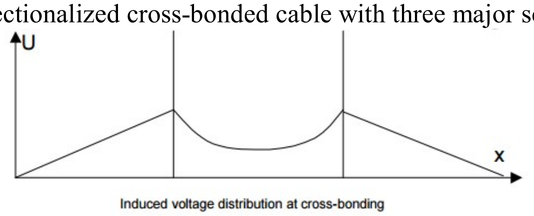


Fig 8. Sectionalized cross-bonded cable with three major sections



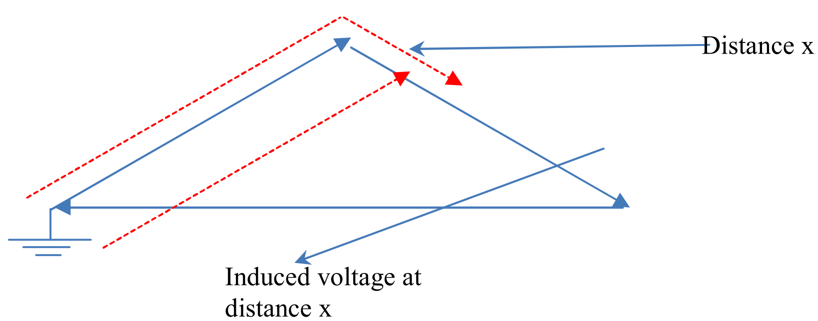


Fig 9. Induced voltage distribution for cross bonding

It breaks the electric continuity of each sheath. Three minor sections make up a major section, where the sheaths are interconnected between them and also are bonded to earth. The length of each minor section must be a third part of the total length of the distance between two earth-connections of the cable.
When dealing with triangular formation power cables, cross bonding eliminates the sheath currents. When dealing with flat formation power cables, the cross-bonding system doesn't eliminate totally the sheath currents due to the lack of symmetry of the three cables, but cross bonding substantially reduces the sheath currents.

Advantage

- Not required any earth continuity conductor
- Virtually zero circulating current in the screen
- Standing voltage in the screen is controlled.

- Technically superior to other methods
- Suitable for long distance cable network

Disadvantage

- Technically complicated
- More expensive

VII. CROSS BONDING WITH TRANSPOSITION

If the cross-bonding scheme does not allow to reduce totally the sheath currents, the cross bonding with transposition allows to reduce the sheath currents further. It consists of transposing cyclically the three main conductors in each minor section. This is the more suitable disposition to reduce the sheath currents.

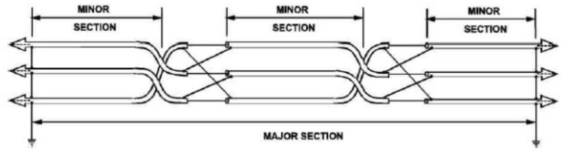


Fig 10. Cross-bonding with transposition


Fig 11. Cable Installation for cross-bonding

General Guideline for the application of the bonding method

Bonding Method	Length of Cable (mtr)
Double point bonding	If contractually acceptable. Also, generally applicable for MV cables 33kV and below. Cable derating & capacity to be ensured.
Single point bonding	$\leq$500
Midpoint bonding	Upto 1km
Cross bonding	Long distance

Above table is not a substitute for calculation.

Calculation of Power frequency sheath overvoltage

Following are the equations provided in IEEE-575 for the calculation of power frequency sheath voltage for single point bonding method.

(A) Three Phase Fault

$$E_a = j\omega I_a\left(2\times10^{-7}\right)\left[-\frac{1}{2}\log_e\left(\frac{2S_{ab}{}^2}{dS_{ac}}\right)+j\frac{\sqrt{3}}{2}\log_e\left(\frac{2S_{ac}}{d}\right)\right]\ \text{V/m}$$

$$E_b = j\omega I_b\left(2\times10^{-7}\right)\left[\frac{1}{2}\log_e\left(\frac{4S_{ab}S_{bc}}{d^2}\right)+j\frac{\sqrt{3}}{2}\log_e\left(\frac{S_{bc}}{S_{ab}}\right)\right]\ \text{V/m}$$

$$E_c = j\omega I_c\left(2\times10^{-7}\right)\left[-\frac{1}{2}\log_e\left(\frac{2S_{bc}{}^2}{dS_{ac}}\right)-j\frac{\sqrt{3}}{2}\log_e\left(\frac{2S_{ac}}{d}\right)\right]\ \text{V/m}$$

where

d is the geometric mean shield/sheath diameter (arithmetic mean may be assumed)
S_{ab} is the axial spacing of phases a and b
S_{bc} is the axial spacing of phases b and c
S_{ac} is the axial spacing of phases a and c

For Trefoil formation single circuit where $S_{ab} = S_{bc} = S_{ca}$ above equations reduce to following

$$E_a = j\omega I_a\left(2\times10^{-7}\right)\left(-\frac{1}{2}+j\frac{\sqrt{3}}{2}\right)\log_e\left(\frac{2S}{d}\right)\ \text{V/m}$$

$$E_b = j\omega I_b\left(2\times10^{-7}\right)\log_e\left(\frac{2S}{d}\right)\ \text{V/m}$$

$$E_c = j\omega I_c\left(2\times10^{-7}\right)\left(-\frac{1}{2}-j\frac{\sqrt{3}}{2}\right)\log_e\left(\frac{2S}{d}\right)\ \text{V/m}$$

For the other common formation of cables laid flat in which the axial spacing of adjacent cables = S, the sheath voltage gradients are given by Equation

$$E_a = j\omega I_a\left(2\times10^{-7}\right)\left(-\frac{1}{2}\log_e\frac{S}{d}+j\frac{\sqrt{3}}{2}\log_e\frac{4S}{d}\right)\ \text{V/m}$$

$$E_b = j\omega I_b\left(2\times10^{-7}\right)\log_e\frac{2S}{d}\ \text{V/m}$$

$$E_c = j\omega I_c\left(2\times10^{-7}\right)\left(-\frac{1}{2}\log_e\frac{S}{d}-j\frac{\sqrt{3}}{2}\log_e\frac{4S}{d}\right)\ \text{V/m}$$

(B) Phase-to-phase Fault

$$E_a = j\omega I_{ab}\left(2\times10^{-7}\right)\log_e\left(\frac{2S_{ab}}{d}\right) \text{ V/m}$$

$$E_b = -j\omega I_{ab}\left(2\times10^{-7}\right)\log_e\left(\frac{2S_{ab}}{d}\right) \text{ V/m}$$

$$E_c = -j\omega I_{ab}\left(2\times10^{-7}\right)\log_e\left(\frac{S_{bc}}{S_{ac}}\right) \text{ V/m}$$

(C) Single Phase-to-Ground Fault

$$E_a = I_{ag}\left[R_g + j\omega\left(2\times10^{-7}\right)\log_e\left(\frac{2S_{ag}^{\ 2}}{dr_g}\right)\right] \text{ V/m}$$

$$E_b = I_{bg}\left[R_g + j\omega\left(2\times10^{-7}\right)\log_e\left(\frac{S_{ag}S_{bg}}{r_g S_{ab}}\right)\right] \text{ V/m}$$

$$E_c = I_{cg}\left[R_g + j\omega\left(2\times10^{-7}\right)\log_e\left(\frac{S_{ag}S_{cg}}{r_g S_{ac}}\right)\right] \text{ V/m}$$

where

S_{ag}, S_{bg}, S_{cg} are geometric mean spacings between cables a, b, and c, respectively, and the ground conductor

R_g is the resistance of ground conductor in Ω/m

r_g is the geometric mean radius of the ground conductor (for stranded conductors take 0.75 of the overall radius)

Accessories for High Voltage Cable Sheath Bonding:

High voltage cable systems must always be earthed. The earthling, sometimes referred to as grounding, very much depends on cable parameters and on the application of cable systems.

(1) Link Box

Link box are used to realize the earthling at terminations or joints. Link boxes can be realized for three phase or for single phase earthling. Link box can also be equipped with SVL.

Fig 12. Link Box

Link Box is electrically and mechanically one of the integral accessories of HV underground above ground cable bonding system, associated with HV XLPE power cable systems.

Link boxes are used with cable joints and terminations to provide easy access to sheath breaks for test purposes and to limit voltage build-up on the sheath.

In HV Cable, the bonding system is so designed that the cable sheaths are bonded and earthed or bonded with earth via SVL in such way as to eliminate or reduce the circulating sheath currents.

(2) Sheath Voltage Limiters (SVL) (Surge Arrestors)

SVL is protective device to limit induced voltages appearing on the bonded cable system due to short circuit. It is necessary to fit SVL's between the metallic sheath and ground inside the link box. The metallic sheath separation of power cable joint (insulated joint) will be protected against possible damages as a result of induced voltages caused by short circuit by break down of SVL.

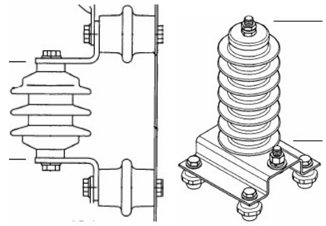


Fig 13. Surge Voltage Limiter

For single point bonding, the voltage is induced linearly along the whole cable length and at the 'open end' a standing voltage occurs. The open end should be protected with a Sheath Voltage Limiter (SVL) This diminishes the chance of over voltages occurring inside the cable screen, protects the cable system and ensures that relevant safety requirements are upheld.

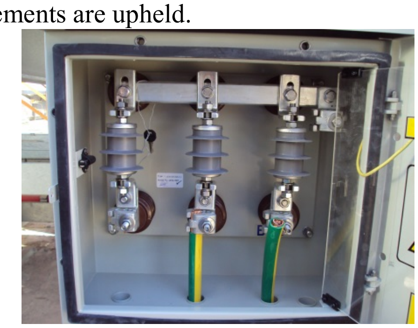


Fig 14. Link box with SVL

(3) Insulated Cable Glands

Insulated cable glands are used to allow the cables to be earthed at one end only (Single point bonding/Mid-point bonding) and insulated at the field end. This gland ensures that no contact is made between the earth circuit carried through the amour and the electrical equipment enclosure through which the cable enters via insulated cable gland.

VIII. CONCLUSION

If grounded at only one end, any possible fault current must traverse the length from the fault to the grounded end, imposing high current on the usually metallic sheath of conductor. Such a current could readily damage or destroy the sheath and require replacement of the entire cable rather than only the faulted section.

With both ends grounded, the fault current would divide and flow to both ends, reducing the duty on the sheath, with consequently less chance of damage.

Multiple grounding, rather than just grounding at both ends, is simply the grounding of the cable sheath at all access points, such as manholes or pull boxes. This also limits possible sheath damage to only the faulted section.

Hence depending on various factors like the laying pattern, sheath voltage calculations and length the type of bonding is to be chosen.

ATTACHMENTS

Att-1–IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5kVthrough 500 kV (IEEE SD 575™-2014)

Att-2-Power installation standard sheath voltage limiter for single core HV cables typical installation-P16A/B/C

Att-3-“ELECTRA NO 28” issued by CIGRE study committee No 21, May 1973

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