General Technical Information

SF_6 Gas-insulated Switchgear Earthing of GIS Type ELK

Content

1. Introduction

In high-voltage switchgear earthing serves as a safety measure. By earthing hazardous potentials on conductive parts are normally eliminated. But during switching operations or faults potentials might attain dangerous for people, animals or equipment.

In gas-insulated Switchgear (GIS) type ELK so-called “multipoint earthing” is employed, providing a number of advantages. Due to multiple earthing connections the magnetic field intensity outside of the enclosure as well as HF transient overvoltages on the GIS enclosure are significantly reduced.

By multiple earthing connections, loops are formed which carry induced currents during normal operation (via enclosure - earthing conductor - earthing net - enclosure - earthing conductor). To avoid too high currents flowing through the earthing net, the enclosures of all three phases are connected directly by numerous crossing conductors. Within these loops (via enclosure — crossing conductors — enclosure — cross-

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ing conductors) considerable currents are induced due to strong electromagnetic coupling and low impedances. In some sections of the GIS they may attain the amplitude of the operating current.

The distribution of both, induced currents during normal service condition and short-circuit currents in case of an earth fault in the GIS have been calculated for GIS type ELK, and have also been measured. Based on this knowledge earthing and crossing conductors (return current) are designed.

Travelling wave (TW) phenomena, as a result of switching operations inside the GIS, are characterised by very fast transients (VFT). These travelling waves can leave the GIS enclosure only by electromagnetic apertures (like SF_6-air bushings).

The TWs passing through a bushing will propagate on the overhead line and on the outer surface of the enclosure. As they run along the enclosure they generate HF transient voltages on this enclosure (TEV, TGPR). Although these TEV do not represent a hazard for humans (very short duration, very high frequency), they may cause sparking in the substation (e. g. across insulating flanges) and electromagnetic interference with secondary circuits.

By use of multiple earthing connections, short earthing strips and an earthing net with narrow mesh width (as well as appropriate earthing of secondary cable shielding) these voltages are kept below critical levels.

The earthing of the GIS type ELK meets the requirements of internal rules, taking in account internal regulations and relevant earthing standards (IEC, ANSI, VDE, SEV).

This paper will inform about earthing principles and dimensions as used on GIS type ELK. It also gives some recommendations for the interface with the earthing net provided by the customer.

2. Protective earthing in high-voltage switchgear

During a short circuit (earth fault) the fault current flows through the earthing conductors into the earthing net, causing voltage drops which result in potential differences. These potential differences may be bridged by humans or animal (touch voltage, step voltage), who thus might become endangered.

To eliminate a serious risk for humans (staff), the current flow through the body must be prevented or limited to harmless values. Although the danger of electricity is determined by the current value and by its path through the body, safety regulations define maximum permissible voltage levels (Fig. 1) since these can be checked easily. These voltage limits are derived from the current values and body resistances.

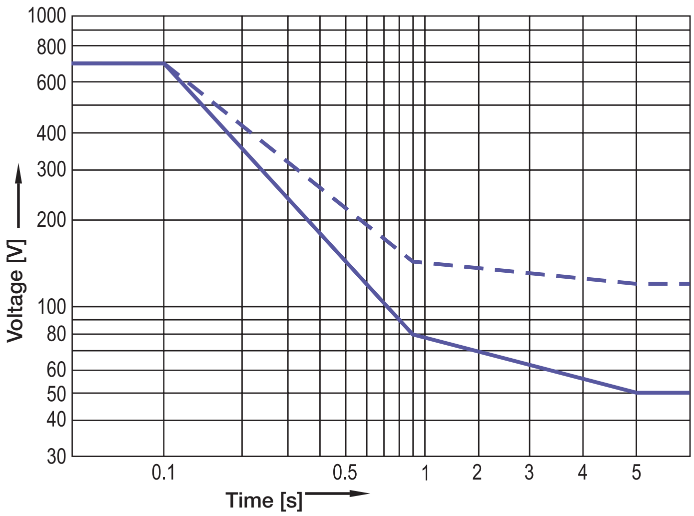


Fig. 1: Permissible touch voltage and duration according to SEV [12]

Fig. 2 shows earthing situations and typical hazards for persons during an earth fault.

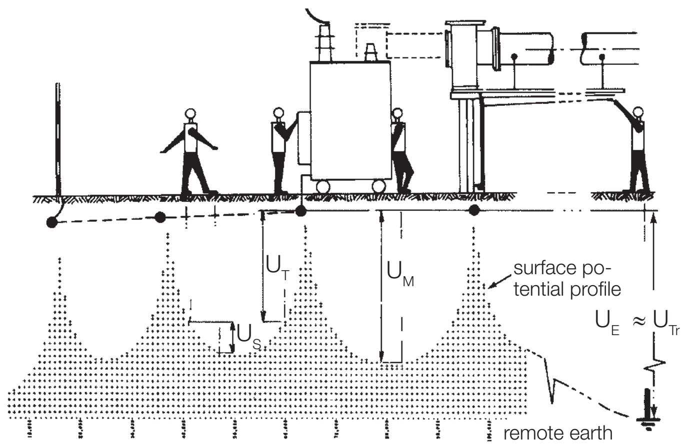


Fig. 2: Basic shock situations and typical hazards for persons during an earth fault [2]

U_T	Touch voltage
U_S	Step voltage
U_M	Mesch voltage
U_E	Earthing voltage
U_{Tr}	Transferred voltage

3. General aspects of the earthing of GIS substations

3a Fault situation (short-circuit)

In GIS the main topic in case of a fault is the touch voltage. The step voltage is of minor importance, as the floor beneath the GIS is covered with a finely meshed earthing net, which is galvanically connected to the iron concrete reinforcement[1].

The part of the short-circuit current which runs through the enclosure and the earthing conductors in case of a fault, results in potential differences in the enclosure, which might be bridged by personnel (Fig. 3)

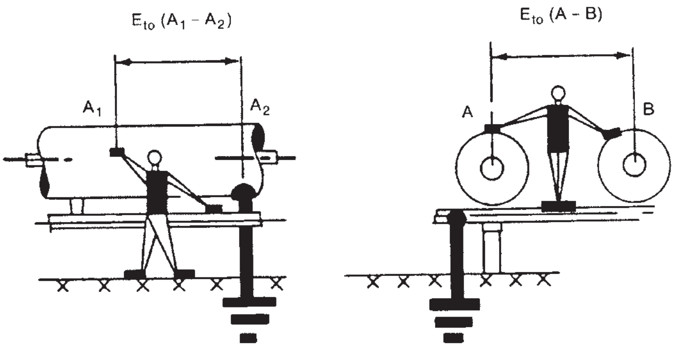


Fig. 3: Typical metal-to-metal touch situation in GIS [2]

Potential differences on the enclosure may be caused by internal faults (e.g. flashover between conductor and enclosure) and by faults external from the GIS (with a fault current running through the GIS) (Fig. 4, cases A, B, and C).

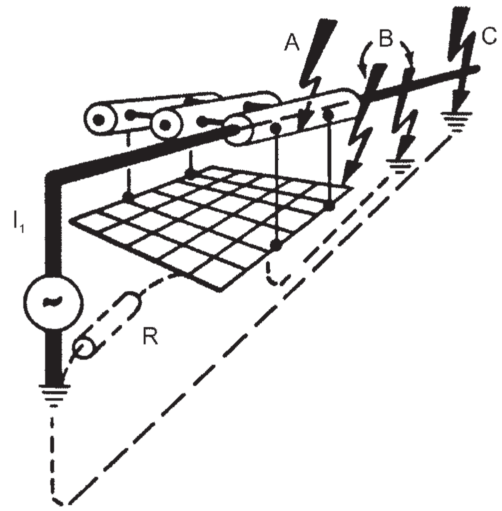


Fig. 4: Typical faults in GIS [1]

The permissible touch voltages for metal-to-metal contacts are (according to IEEE Std. 80, [2]):

– $U_{T50} = 116 / \sqrt{t_F}$ (for a weight of 50 kg) and
– $U_{T70} = 157 / \sqrt{t_F}$ (for a weight of 70 kg),

which is shown in Fig. 5 (t_F: time period of fault).

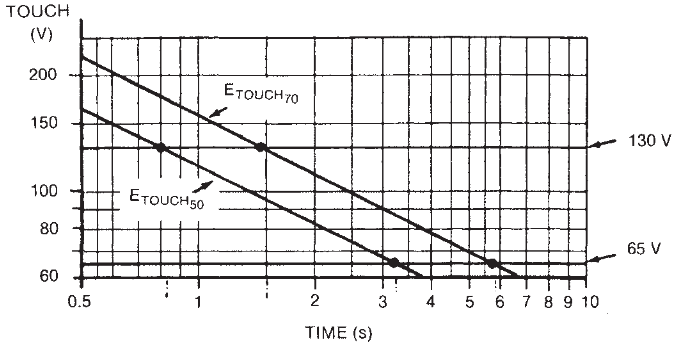


Fig. 5: Maximum permissible touch voltage for metal-to-metal contacts (acc. to IEEE Std. 80, [2])

The permissible touch voltages for 50 kg weight according to IEEE are about equal to those of SEV [12] (Fig. 1).

The touch voltage on a GIS depends, apart from the location, on the impedances of the enclosure and the earthing conductors. Since the impedance of the enclosure is given, the touch voltage can be influenced only by the impedances of the earthing conductors (material, cross section and laying of the conductors).

3b Transient high-frequency overvoltages

By switching operations (circuit-breakers, disconnectors and earthing switches) and insulation breakdowns in GIS steep transient overvoltages are generated. These voltages propagate as TW (travelling waves) into both directions with nearly speed of light.

The TW can leave the GIS only at apertures on the enclosure like SF_6-air bushings or isolating flanges (transformer and cable terminals). The TW, escaped through a SF_6-air bushing, will propagate on the overhead line and on the enclosure. The latter part, running on the outer surface of the enclosure generates HF transient voltages (TEV). Due to their high frequency and short duration (i.e. low energy) they represent no harm for staff. However they can cause electromagnetic interference and sparking in some locations of the GIS (optical and acoustical phenomena). Therefore they have to be kept low.

This is achieved by the following earthing measures:

– Narrowly meshed earthing net
– Appropriate earthing of the GIS enclosure at SF_6-air bushings. If the building of an indoor GIS substations is provided with walls of sheet metal or reinforced concrete, the enclosure shall be galvanically connected with the wall metal where it leaves the building (see Fig. 19)

[1] Reinforcement bars and earthing net shall be interconnected to reduce HF overvoltages

- Short interconnections between the enclosure and the earthing net, in intervals of about 10...20 m
- Meshed interconnections (not radial arranged) between earthing conductors and earthing net
- Earthing conductors and earthing connections with lowest possible inductance. They shall be short and have large surface (a flat profile is prefered to an equivalent but circular cross section, or two conductors in considerable distance instead of one with equivalent cross section respectively)
- The reinforcement steel in floor and walls shall be integrated into the earthing layout. It shall be interconnected in short intervals to the earthing system designed for earth fault currents
- Across to the insulation of the insulated cable, transformer or busduct connections LV-surge arresters shall be installed

4. Earthing of GIS type ELK

The multipoint earthing method employed at GIS type ELK has a number of advantages compared to the one-point earthing method:

- better reliability concerning earthing safety (earthing of the enclosure at numerous points)
- smaller magnetic field intensity outside the enclosure (compensation by return current in the enclosure)
- lower touch voltage in case of fault
- smaller HF transient voltage on the GIS enclosure during switching operations
- lower induced currents in secondary cables
- no insulation between GIS enclosure and the structure requested

4.1 Earthing and return current conductors

4.1a Earthing conductors

Earthing conductors interconnect the GIS enclosure at numerous points with the earthing net (multipoint earthing). Being a component of the earthing system they effectively help to avoid dangerous touch voltages during a short circuit, and to keep HF transient overvoltages on a sufficiently low level during normal service. To meet these requirements they shall have low impedances at 50/60 Hz as well as in the HF range.

4.1b Return current conductors

The enclosures of all three phases of GIS type ELK are many times interconnected to each other and to the earthing net. In the so formed loops, the induced currents are circulating due to electromagnetic coupling with the phase conductors.

The return current in the enclosure of each phase is shifted against the operating current by approx. 180°. This is the reason why these induced currents are called „return“ currents.

During normal service the return current conductors (crossing conductors) carry permanently the return currents, which can achieve up to 90% of the operating current, and balance return currents respectively. Accordingly, in case of external three-phase short circuit the return currents can achieve up to 90% of the short-circuit current. The return current conductors are dimensioned accordingly to these currents.

4.2 Distribution of the induced currents during normal operation and distribution of the fault current and enclosure voltage in case of earth fault

The distribution of the induced currents during normal operation and distribution of the fault current and enclosure voltage in case of earth fault are demonstrated in an example (GIS substation acc. to Fig. 6).

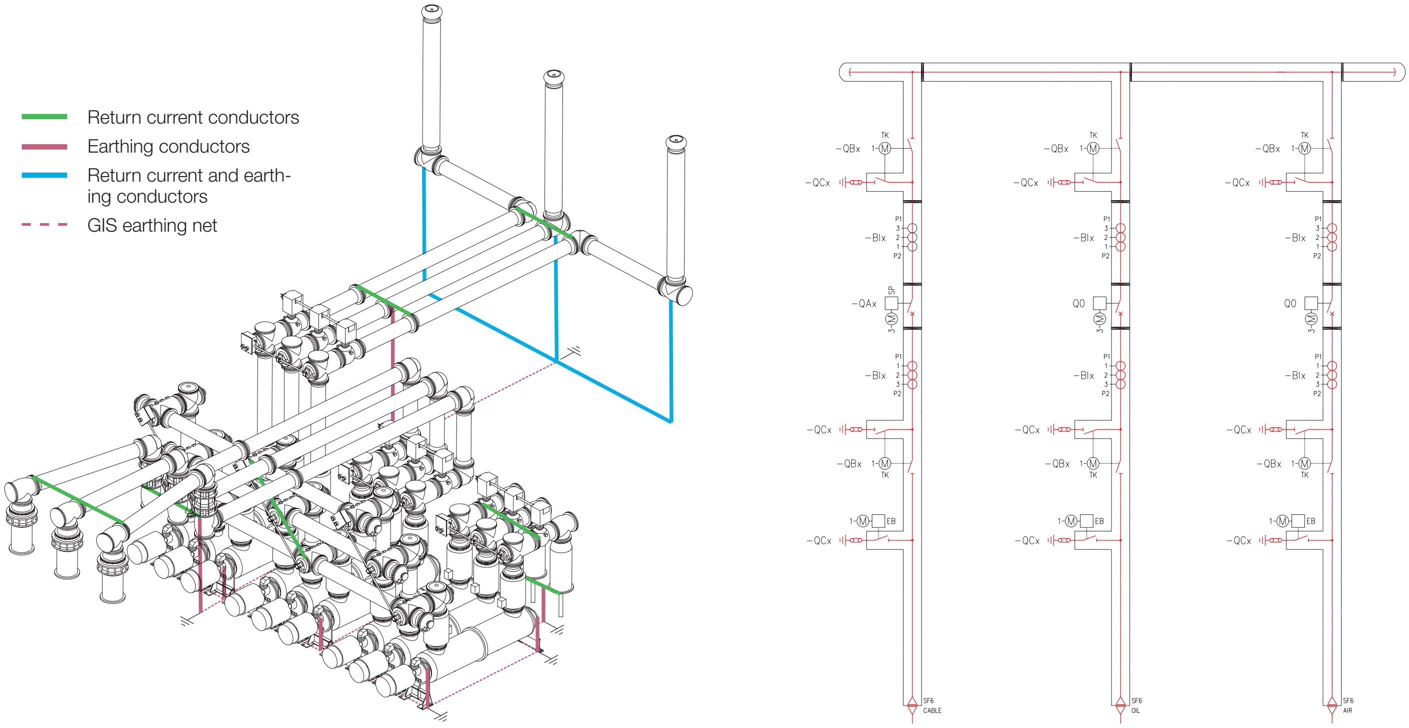


Fig. 6: An example of the arrangement of the earthing and crossing conductors at the GIS type ELK with OHL, transformer and cable feeder

The calculation of the induced currents in the normal operation and calculation of the fault current distribution and enclosure voltage in case of an earth fault were done with the EMTP-Rv programme (electro-magnetic transient programme). The calculation results are shown in diagrams 1to 9.

Calculation procedure

According to our internal earthing directives the points on the GIS enclosures for connection of the earthing and crossing conductors, material and dimensions of conductors are determined.

For the earthing conductors the following are chosen:
- Cu 40x5 (for the earthing grid conductors and for the earthing conductors between enclosures and the earthing grid in the bay area)
- Cu 60x5 (for the earthing conductors between the enclosures and the earthing grid at the end of GIS overhead line connection, cable connection and transformer connection)
- Steel structure

For the crossing conductors the following are chosen:
- Cu 40x5 (for the crossing conductors between the circuit-breaker enclosures)
- Al 60x10 (for the other crossing conductors in the bay area and at the transformer connections)
- Al 100x10 (for the crossing conductors at the overhead line and at the cable connection)
- Steel structure (others)

The whole GIS has been divided into several collateral parts (2D arrangement), which have been simulated in the program EMTP-Rv as high-voltage cables. The input data consists of the geometrical dimensions of conductor's arrangement, conductor's dimensions and physical property of conductor's material. Since only circular conductors can be considered in the program, the rectangular earthing conductors, which are collateral with GIS have been modelled as circular conductors with approximately the same internal impedance as the rectangular conductors.

The earthing conductors, which couldn't be considered in the impedance matrixes calculations, and crossing conductors were simulated by internal impedance (R, L) only.

This calculation method was approved by very good conformity of the measured and calculated currents of the real GIS substation under normal operation.

4.2a Normal operartion

The calculation of the induced currents in normal service was made assuming a situation as per Fig. 7. Energy was delivered from the cable terminal (2000 A) and the transformer terminal (1150 A) to a consumer (3150 A) at the side of the overhead line.

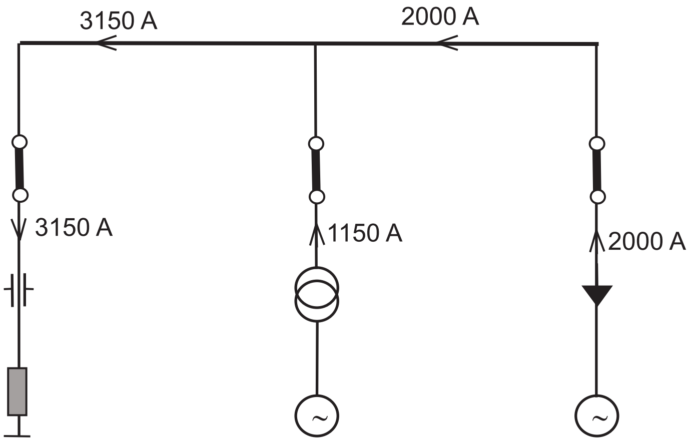


Fig. 7: Equivalent circuit diagram for the calculation of induced currents during normal operation

The calculation results (induced currents in the enclosures, earthing and crossing conductors) are shown in diagrams 1, 4 and 7.

From the calculation results it can be concluded:

- During normal operation small parts of the return currents flow through the earthing conductors (as the loops formed by the earthing conductors and the earthing net have much higher impedances, than the loops established by the return current conductors)
- The currents induced in the enclosure can reach up to 100% of the operating current (busbar range)
- Whereas the return current conductors carry only small currents (balance return currents) in the fields area, they are loaded with the full enclosure current at the GIS terminals, which may reach up to 90% of the operating current (depending on the phase distances of the terminals). The larger the phase distance is (taking into consideration the rated voltage), the smaller is the return current in the enclosure and the return current conductors respectively at this place.

4.2b Earth fault situation

The calculation of the fault current in case of an earth fault has been made for an arrangement as per Fig. 8. A earth fault current of 63 kA had been assumed. It was supplied with 25 kA from the cable terminal, 7 kA from the transformer terminal and 31 kA from the overhead line feeder. The earth fault was located in phase R, in the transformer terminal.

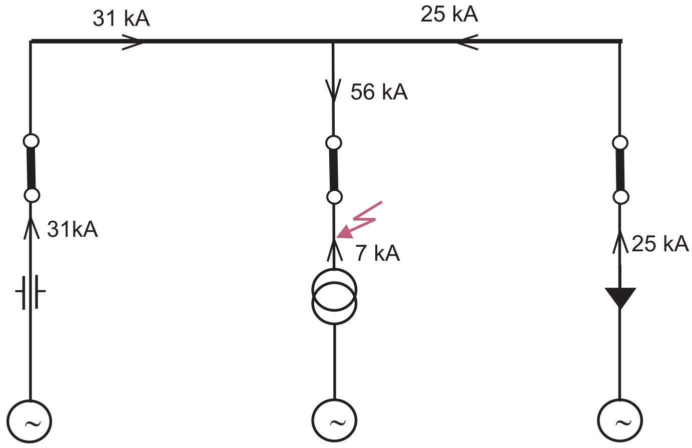


Fig. 8: Equivalent circuit diagram for the calculation of the fault current distribution in case of an earth fault

The calculated distribution of the fault current is shown in diagrams 2, 5 and 8 and the enclosure voltage in diagrams 3, 6 and 9.

It should be noted, that in case of an earth fault only small portions of the short-circuit current run through the return current and earthing conductors in the bay area, whereas near the terminals the current is much higher.

In case of a three-phase fault (short circuit external from the GIS) the current distribution in the enclosures and the return current conductors shows a pattern similar to normal operation, taking into account the value of the short-circuit current. From diagrams 3, 6 and 9 it can be seen, that the enclosure voltage to ground is smaller than the maximal allowed touch voltage. In the field area, where the operating staff could normally be situated, its value doesn't reach 30 V.

4.2.1 Overhead line feeder

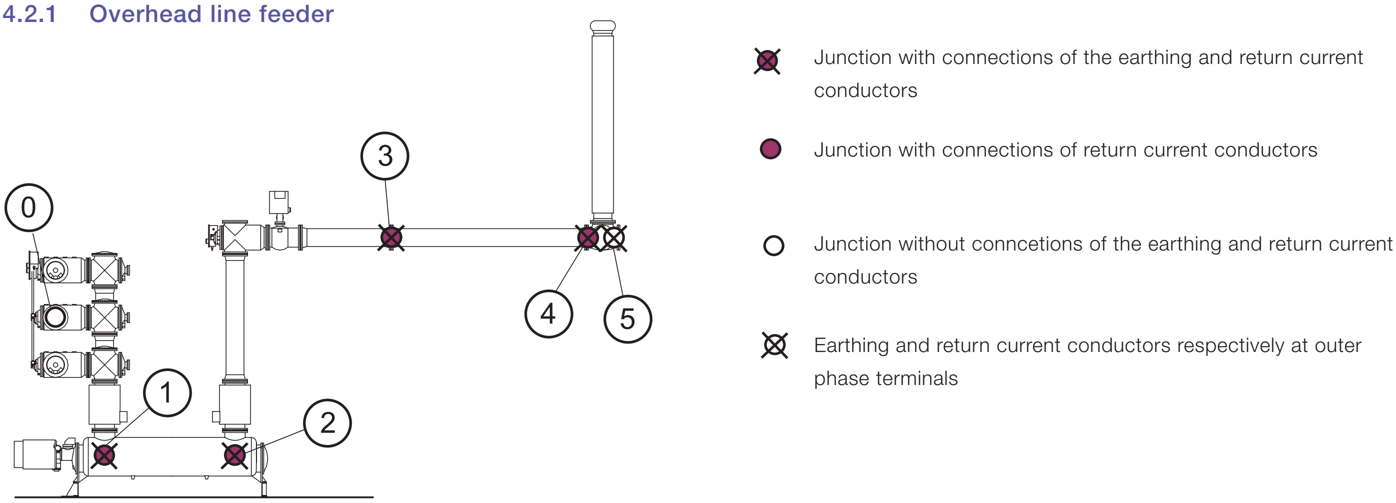
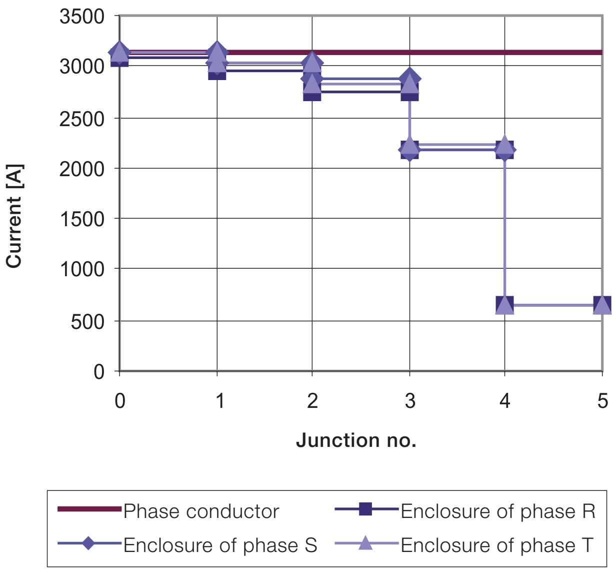
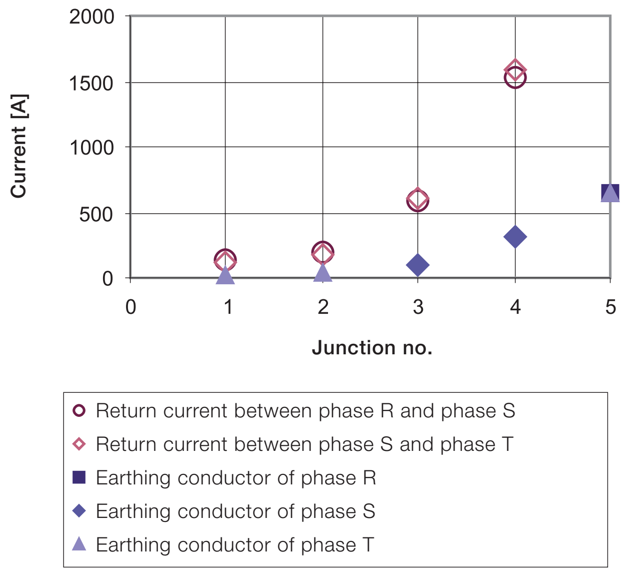


Fig. 9: Bay with OHL feeder (junction no. 0 to 5)

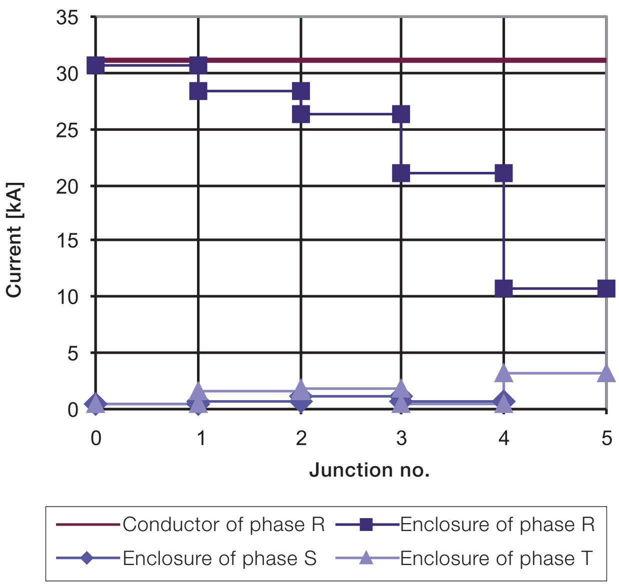


a) Phase currents and enclosure currents

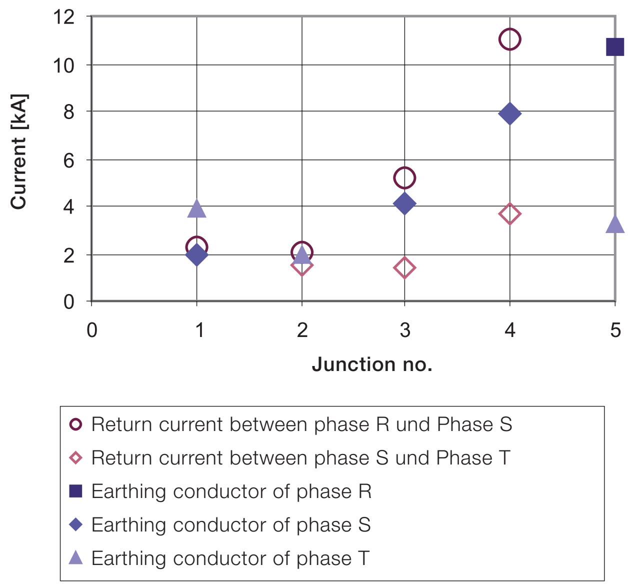


b) Currents in earthing and return current conductors

Diagram 1: Current distribution in the bay with OHL feeder during normal operation



a) Phase currents and enclosure currents



b) Currents in earthing and return current conductors

Diagram 2: Current distribution in the bay with OHL feeder during earth fault

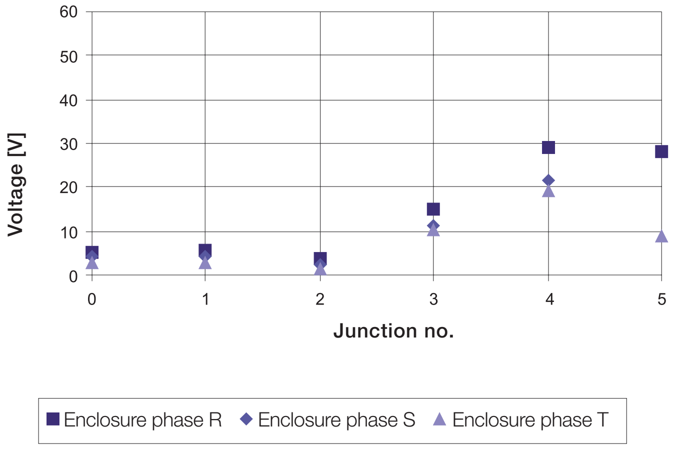


Diagram 3: Enclosure voltage to ground in the bay with OHL feeder during earth fault

4.2.2 Transformer terminal

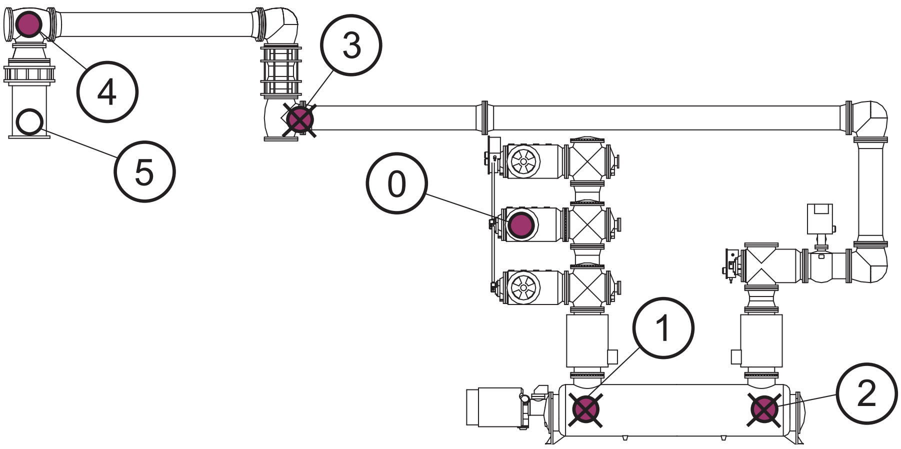
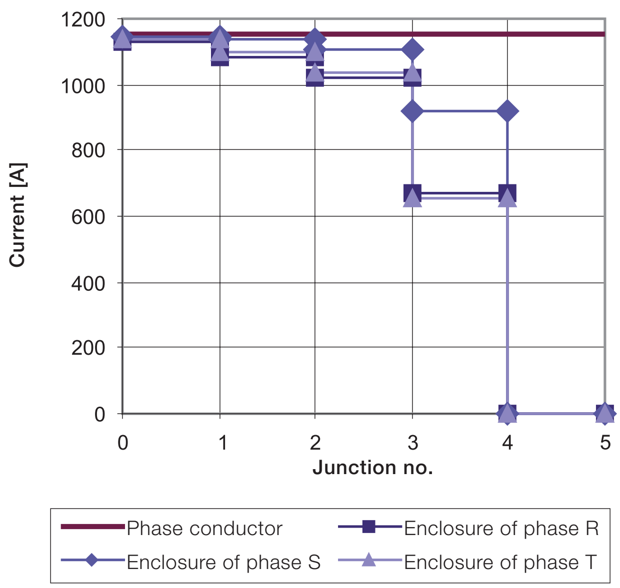
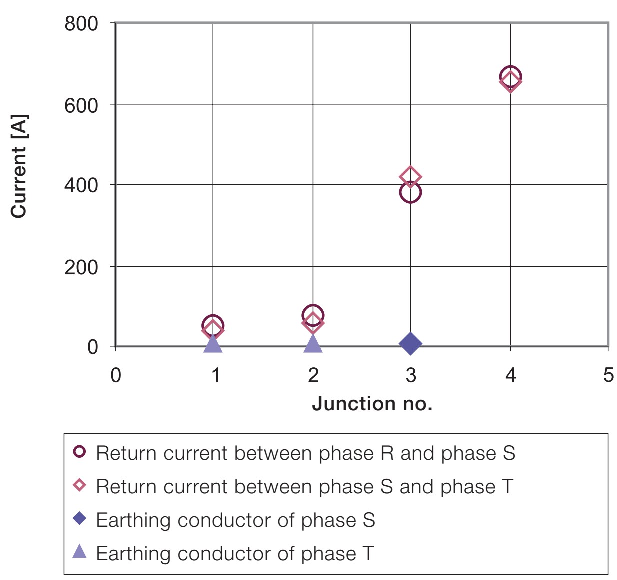


Fig. 10: Bay with transformer terminal (junction no. 0 to 5)

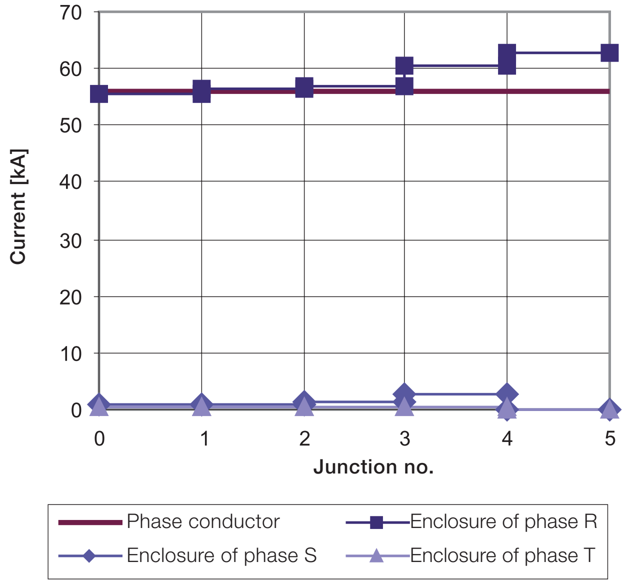


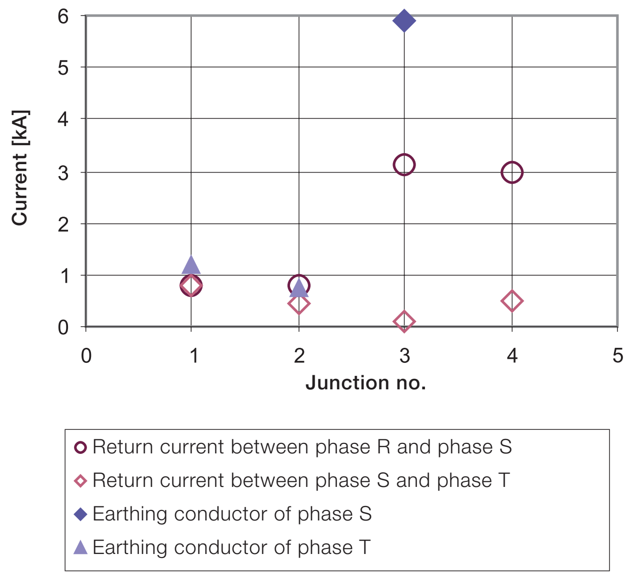
a) Phase currents and enclosure currents



b) Currents in earthing and return current conductors

Diagram 4: Current distribution in the bay with transformer terminal during normal operation





a) Phase currents and enclosure currents

b) Currents in earthing and return current conductors

Diagram 5: Current distribution in the bay with transformer terminal during earth fault

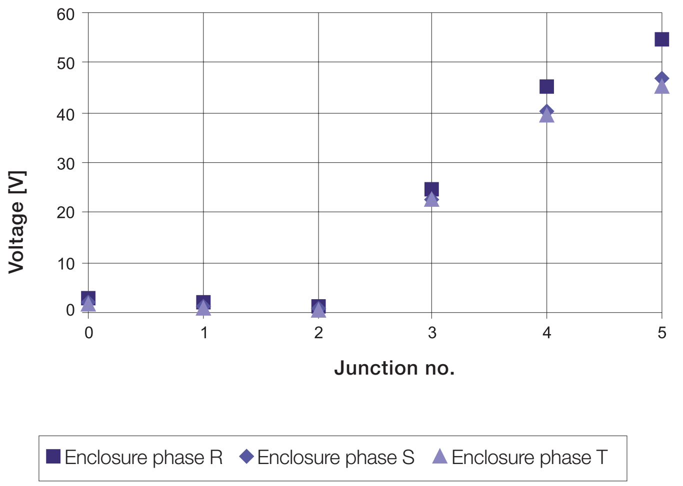


Diagram 6: Enclosure voltage to ground in the bay with transformer terminal during earth fault

4.2.3 Cable terminal

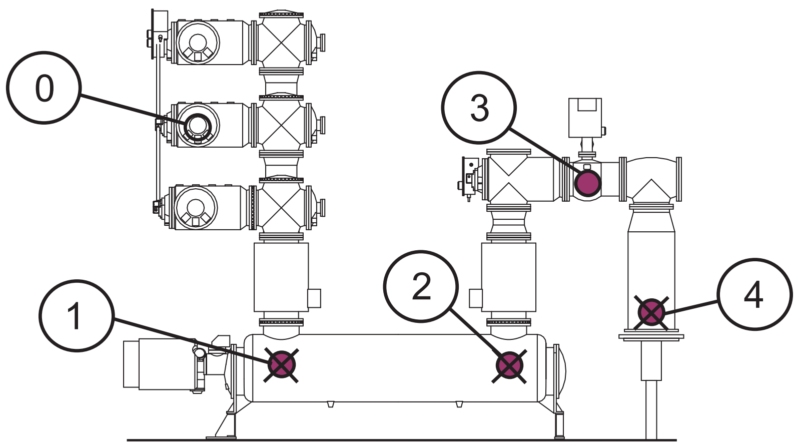
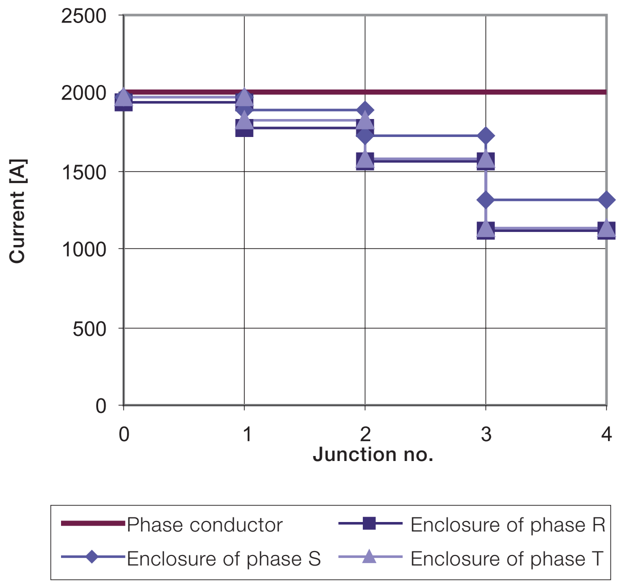
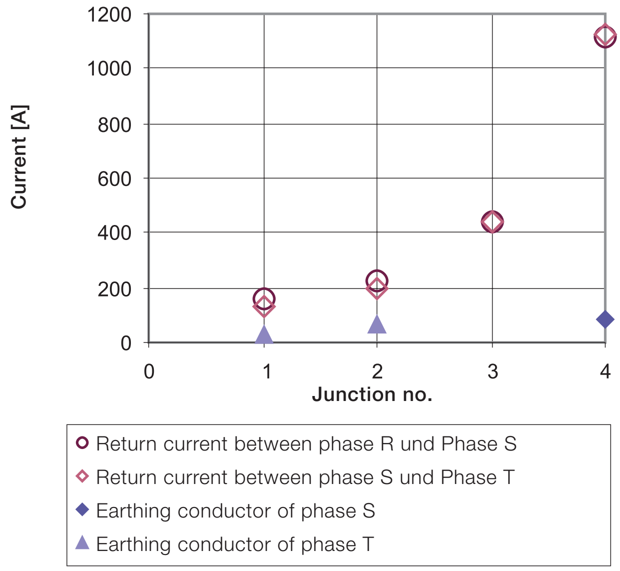


Fig. 11: Bay with cable terminal (junction no. 0 to 4)

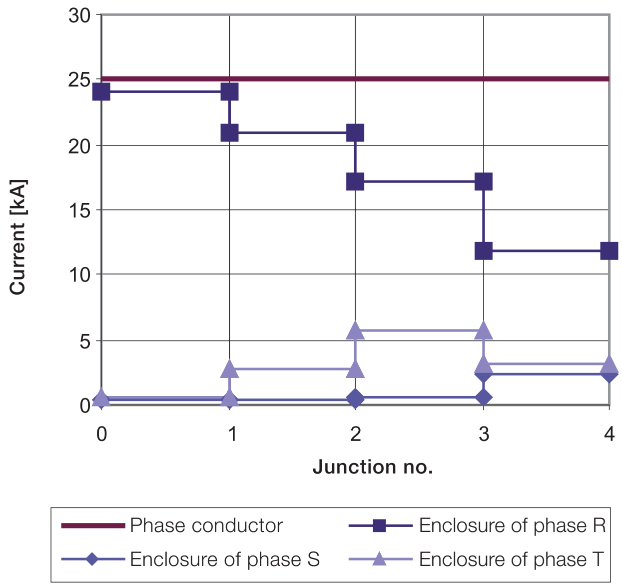


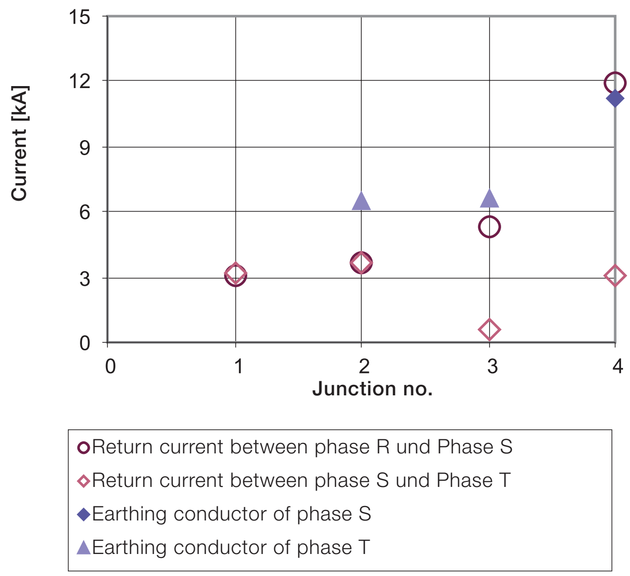


a) Phase currents and enclosure currents

b) Currents in earthing and return current conductors

Diagram 7: Current distribution in the bay with cable terminal during normal operation





a) Phase currents and enclosure currents

b) Currents in earthing and return current conductors

Diagram 8: Current distribution in the bay with cable terminal during earth fault

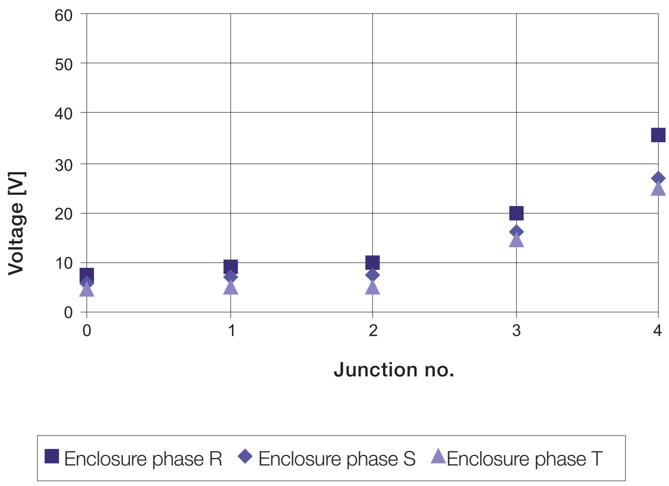


Diagram 9: Enclosure voltage to ground in the bay with cable terminal during earth fault

4.3 Design of the earthing and return current conductors

4.3.1 GIS End

At the GIS terminals the return current conductors (during normal and fault condition) as well as the earthing conductors (under fault condition) are stressed with high currents. The earthing conductors in this area have a strong influence on the touch voltages in case of an earth fault, and also on the HF overvoltages caused by switching operations during normal service.

4.3.1.1 Overhead line connection

Depending on rated voltage and substation layout of the ELK switchgear there are four typical connecting possibilities for OHL connections. They are shown with corresponding layout of the earthing and return current conductors in Fig. 12.

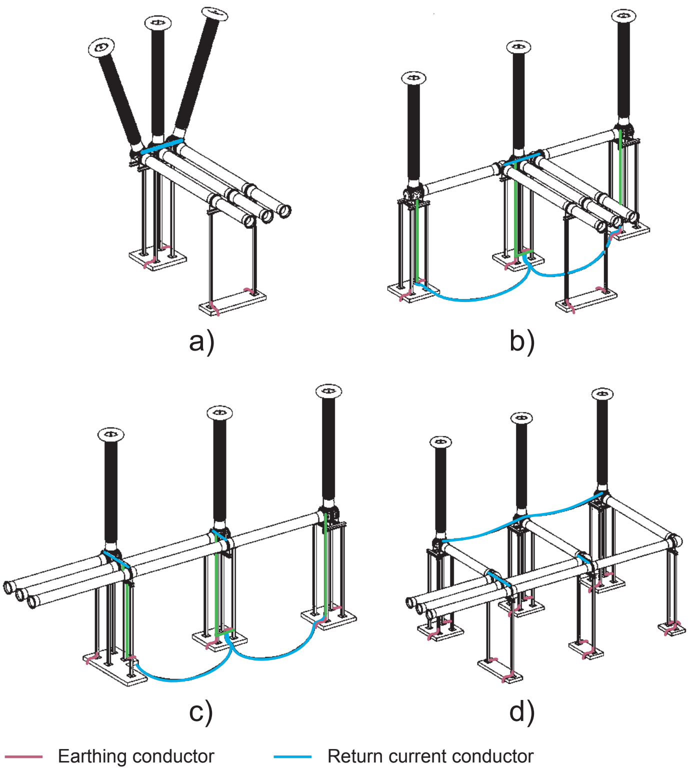


Fig. 12: Typical arrangement of the OHL terminals with corresponding layout of the earthing and return current conductors

At the arrangement according to the fig 12a the return current connections are very short and return currents may be as high as 90% of the operating current. Thereby a good magnetic shielding is achieved and the magnetic field intensity in the GIS surroundings is small.

For the arrangements according to the fig 12b and 12c it is not recommended to put the return current conductors straight between the phases, but over or in the floor (because with straight connections a significant part of the return current would run anyway through the earthing conductors and the earthing net). The return current conductors serve in these cases as earthing conductors at the same time.

At the arrangement according to the fig 12d, aluminium wires are used for the crossing conductors.

4.3.1.2 Cable terminal

The arrangement of the return current and earthing conductors for cable terminals is shown in Fig. 13.

On cable terminals, cable sheaths can be either connected directly to the GIS enclosure or isolated from the GIS enclosure (Fig. 14). The latter case is more common.

However, a direct connection between jacket and enclosure is recommended - if possible - because of improved service conditions (smaller transient overvoltages on secondary equipment). This solution is feasible as well with cables, which are earthed on one end, as also those earthed on both ends.

The connection is performed with four or more flat straps (avoiding any loops), distributed symmetrically around the flange. The cross section area of these straps is chosen according to the return current in the cable sheath.

If cable current transformers are used on cables, which are earthed on both ends, the connections (straps) must return through the current transformer to eliminate the effect of the sheath return current. To keep the connecting loops as small as possible the current transformer should be positioned as near as possible to the cable terminal.

If a direct connection is not permissible (cable earthed at the far end, or other reasons) an isolating flange is provided between the end of the cable sheath and the GIS enclosure (Fig. 14). To avoid flashover across the insulation by HF overvoltages, the insulation must be by-passed by low voltage metal-oxide surge arresters (e.g. for 400 V).

The arresters must be dimensioned in such a way that they will safely clear at the power-frequency voltage on the cable sheath during a short circuit. It is recommended to install at least four arresters symmetrically around the flange with connections as short as possible.

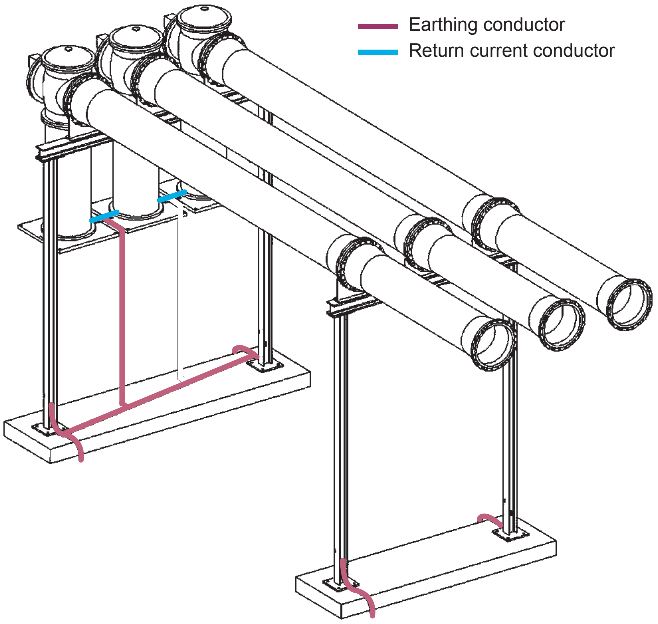


Fig. 13: Earthing and return current conductors at cable terminals

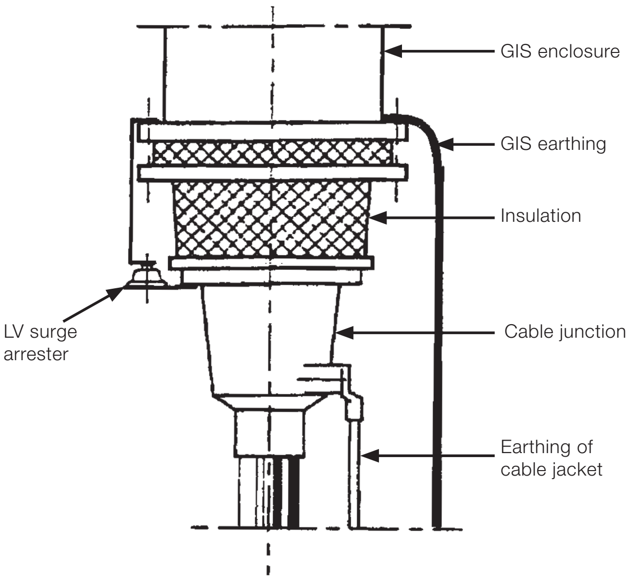


Fig. 14: Isolated junction between GIS enclosure and cable jacket

4.3.1.3 Transformer terminal

Transformers can be connected to the GIS either directly or insulated. The insulated alternative is preferred, as in this case a separation between GIS and transformer is achieved. Thus return currents will not stress the transformer tank.

With a direct connection, on the other hand, it cannot be avoided that a part of the return current is running through the transformer tank and additionally warm it up. At three-phase transformer units the return current is closed through the tank and at single-phase units it will run through the tank and the earthing net. This has to be taken into account when dimensioning the earthing net.

At an insulated connection, an insulating flange has to be inserted at the transformer connection (Fig. 15).

To avoid a flashover across the insulation at HF overvoltages, the insulation must be by-passed by low voltage metal-oxide surge arresters (ABB supply). It is recommended to install at least four arresters symmetrically arranged on the flange with connections as short as possible.

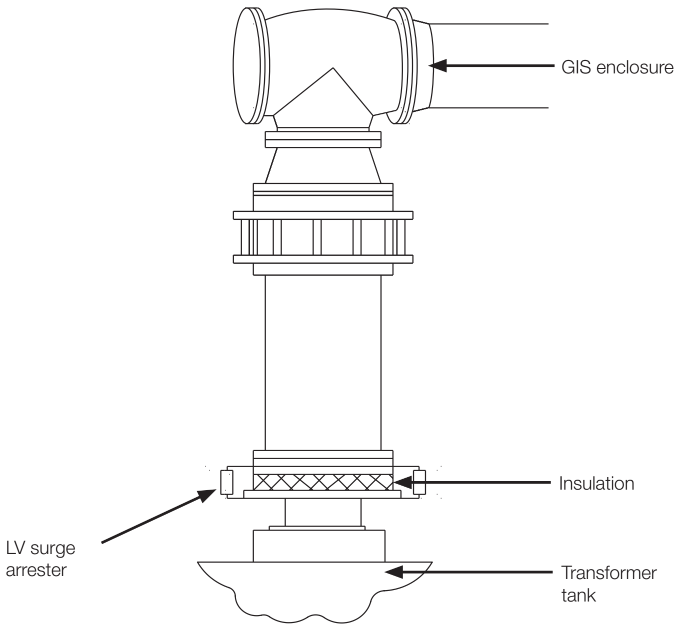
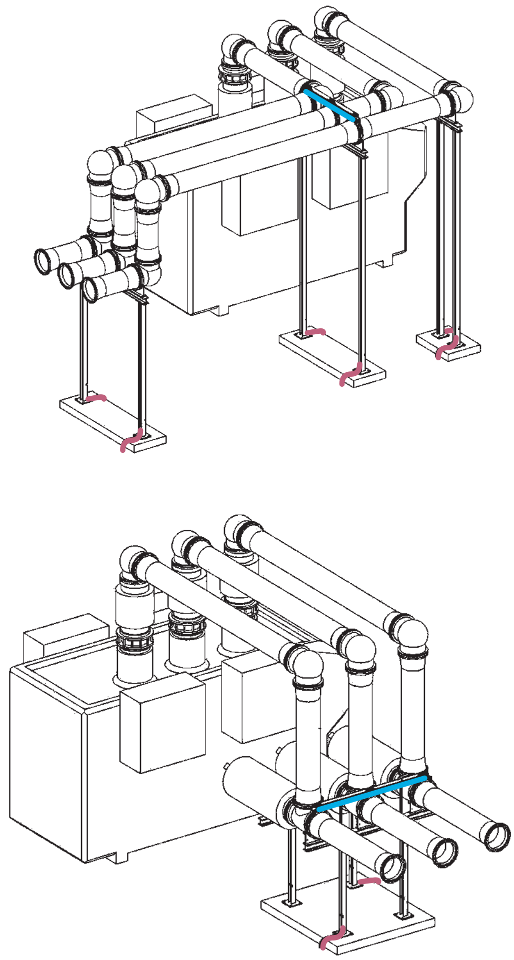


Fig. 15: Isolated junction between GIS enclosure and transformer tank

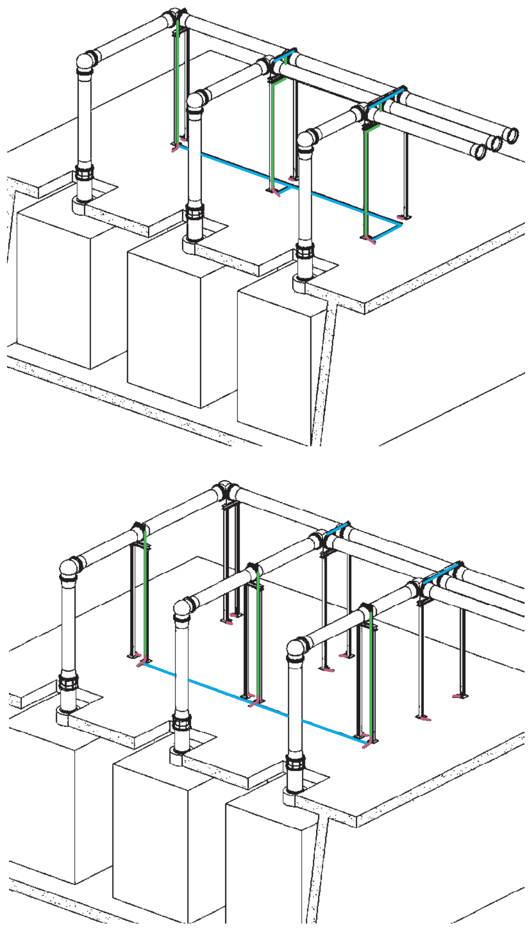
The installation of the crossing and earthing conductors in case of the three-phase transformer unit show Fig. 16a and Fig. 16b and in case of the single-phase transformer units the Fig. 17a and 17b.



a)

b)

Fig. 16: Earthing and return current conductors at three-phase transformer unit



a)

b)

Abb. 17: Earthing and return current conductors at one phase transformer units

4.3.1.4 Connection of gas-insulated line (GIL)

Normally, gas-insulated ducts are directly connected to the GIS. In this case they are considered as GIS extensions, and therefore the duct end is the GIS end.

Return current conductors shall be provided on many places along the busducts (every 20 to 30 m). At these points the busduct enclosure shall be earthed.

If busducts for some reasons have to be connected isolated, return current connections will be installed at the insulated connection. This place is GIS end for which the same rule is applied, with respect to return and fault current, as for cable terminals. The isolating flange here shall also be by-passed with low-voltage surge arresters.

4.3.2 GIS part close to GIS end

If the GIS building is made of metal or concrete reinforcement it is possible to reduce the transient enclosure voltage due to improved earthing possibility on the places where ducts enter in the building (Fig 18). For this purpose ABB has developed the special wall sealing for GIS type ELK (Fig 19).

The wall sealing should be connected to the reinforcement on many points and earthed through minimum two earthing conductors.

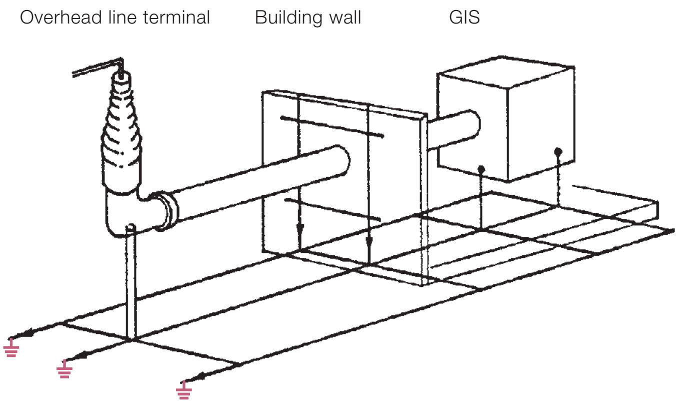


Fig. 18: Overhead line terminal with wall passage (schematic)

Fig. 19: Wall sealing

4.3.3 GIS bay range

In the bay area of a GIS the return current conductors carry balance return currents during normal operation, which will remain rather below 15% of the operating current, and even smaller parts of the short-circuit current in case of an earth fault.

Only small parts of the earth fault current will also flow through the earthing conductors into the earthing net (up to 20%). Due to the impedance ratio the earth fault current tends to flow through the enclosure return towards the supply.

4.3.4 Surge arresters

Earthing of surge arresters shall be of low impedance (short earthing connections, finer earthing mesh width).

4.3.4.1 Outdoor surge arresters

Surge arresters shall be situated as close as possible to the GIS (besides SF_6-air bushings). The field distribution of the arrester and the bushing must not be disturbed.

A direct interconnection (if possible) shall be established between the earthing connection of the surge arrester and the enclosure part of the bushing. This increases the effectiveness of the surge arrester in case of lightning overvoltages (Fig. 20).

In the range of the arrester the mesh width of the earthing net shall be as in the GIS bay range.

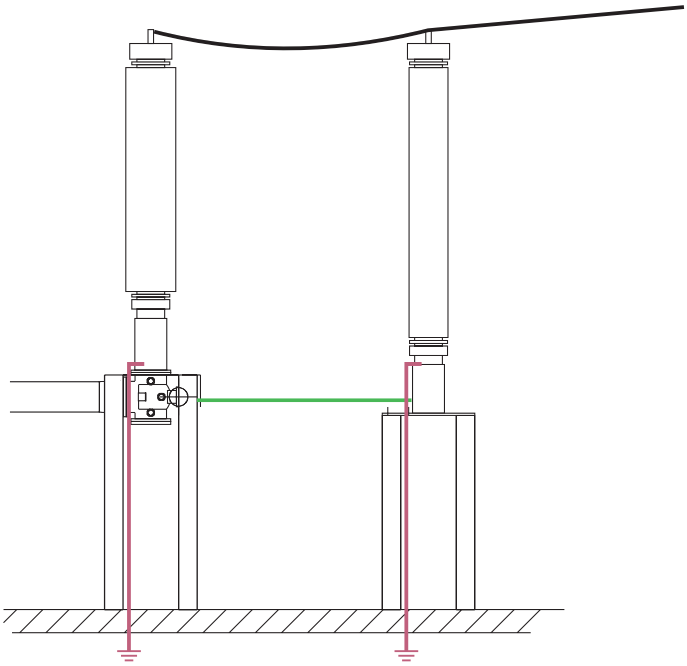
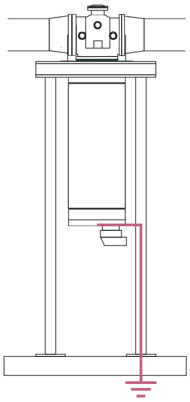


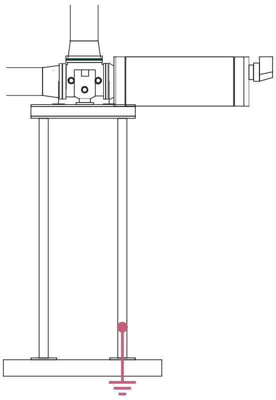
Fig. 20: Connection of outdoor surge arrester at the GIS entrance

4.3.4.2 Metal-clad surge arresters

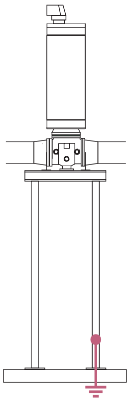
Normally there are 3 alternatives to install a GIS surge arrester:
- suspended (Fig. 21a)
- horizontal (Fig. 21b)
- standing (Fig. 21c)



a) suspended installation



b) horizontal installation



c) standing installation

Fig. 21: Installation of GIS surge arrester

4.4 Dimensioning of earthing and returm current conductors

4.4.1 Material for earthing and return current conductors

4.4.1a Earthing conductors

The GIS enclosures are normally grounded through the steel structure (Fig 23). Therefore a well electrical contact between the flanges and the steel support, as well as between the steel support and earthing grid should be established (paint on the contact areas on the flanges should be removed and all contact surfaces of the screw connections on the steel support cleaned and greased). The steel structure is connected to the earthing net with corresponding cooper conductors.

At outdoor GIS the additional two or four (depending on the connection variant) copper conductor are installed along the steel structure to reduce the transient enclosure voltage

4.4.1b Return current conductors

In the GIS area where the balance return currents flow, (currents up to max. 15% of operating current), the steel structure is used as a return current conductor (Fig. 22).

On the GIS ends (interface to OHL, HV cables or power transformers), where the high return currents flow (currents up to about 90% of operating power), return current conductors from aluminium should be used (bar or wire). Where the return current conductors are installed on the floor, cooper conductors are used (bar or wire).

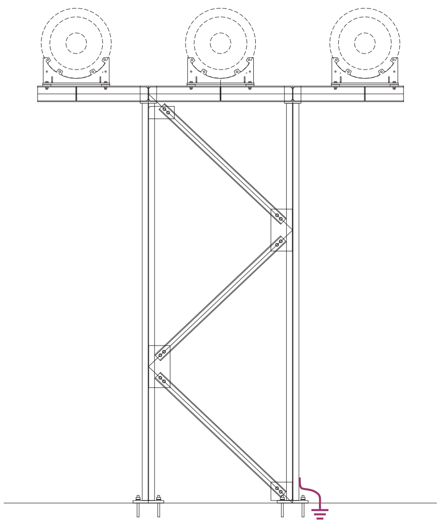


Fig. 22: Steel structures as return current and earthing conductors

4.4.2 Dimensioning of earthing and return current conductors

4.4.2a Earthing conductors

Earthing conductors are dimensioned with respect to the short-circuit currents they have to carry in case of an earth fault.

The conductor cross-sectional areas for the short-circuit current load are calculated according to IEC 60364-5-54 [3] and DIN VDE 0141 [9] respectively (equation (1)). The so calculated cross-sections are larger than those following other standard (IEEE Std. 80-1986).

$$q = \frac{I_K \cdot \sqrt{t}}{\sqrt{\frac{Q_C(B+20)}{\rho_{20}} \cdot \ln\left(1+\frac{\vartheta_e - \vartheta_a}{B+\vartheta_a}\right)}} [mm^2]; \quad (1)$$

For loaded structures: q' = 2 q

I_K: Short-circuit current [A]

t: Duration of short circuit [s]

Q_C: Thermal capacity of conductor material [J/(°C mm³)]

B: Reciprocal value of the temperature coefficient of conductor materials at 0°C [°C]

ρ_{20}: Specific resistance of conductor material at 20 °C [Ωmm]

ϑ_a: Initial conductor temperature [°C]

ϑ_e: Permissible final temperature of conductor [°C]

4.4.2b Return current conductors

Return current conductors are dimensioned with respect to the return currents flowing during normal operation and to the short-circuit currents in case of a fault respectively.

Due to the operating current load the conductor cross-sectional areas for the load are calculated according to DIN 43670 [10] for aluminium conductors and according to DIN 43671 [11] for cooper conductors.

4.4.3 Laying and connecting of earthing and return current conductors

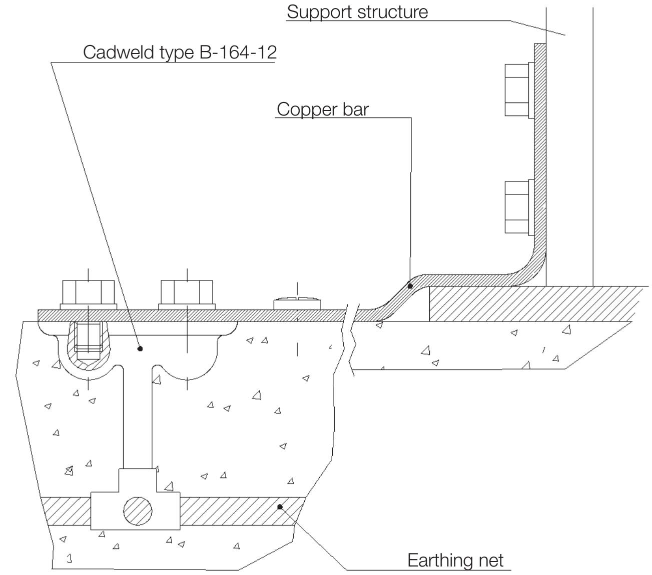
Earthing and return current conductors shall be installed straight (not in loops). Installing with sharp angles should be avoided.

The connections of earthing and return current conductors are executed in accordance with internal guidelines “GIS Earthing Details”.

The connection surface on the enclosure flanges have to be thoroughly cleaned from the paint and oxide and lubricate with contact grease.

To connect earthing conductors to the steel structure (to connect the steel structure with the ground network), all steel structure are performed with 2 holes of 14 mm diameter.

To connect earthing conductors to the earthing net it is recommended that the customer provides suitable connection points according to the indications given by ABB. The type of connection is left to the customer. Two favourable examples are shown on Fig. 23.



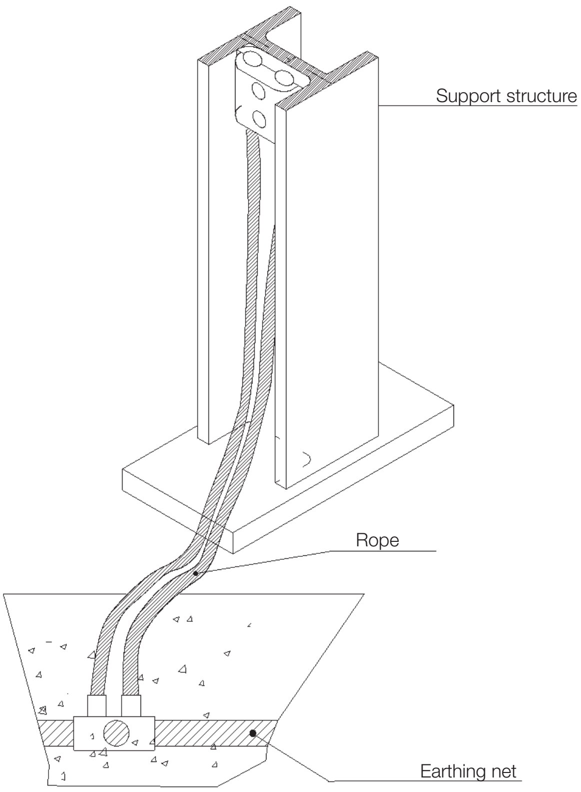


Fig. 23: Two examples how to connect earthing conductors to the earthing net

4.5 Secondary cables and control cubicles

To limit the amplitude of noise signals interfering with secondary equipment and to achieve its reliable operation (measuring, control and communication) following measures shall be taken:

4.5.1 Arrangement

- The control equipment shall be outside of the busbar and feeder areas, and shall have largest possible distance from bushings. It shall not be situated beneath or surrounded by power conductors
- Primary and secondary conductors shall, as far as possible, be laid perpendicularly to each other. If parallel laying is inevitable, the distance should be as large as possible
- The structure of the secondary cable system shall be radial (tree-like distribution, no meshes) with the centre in the control building (whereas the structure of the earthing system is meshed, the secondary cables (secondary circuits) themselves are not meshed)
- Secondary cables on different potentials or different functional purposes shall be separated, and not led in the same cable
- Placement of capacitor batteries on the border of the substation

4.5.2 Laying, connection and earthing of cable shields (control cable jackets)

- Secondary cables shall be shielded
- Cable shields shall be earthed coaxially at both cable ends (Fig. 24)
- In the cubicle the shields shall be connected without interruption to the cubicle‘s shielding walls by suitable coaxial plugs
- Shields shall be capable of carrying currents. Minimum shield cross section is 4 mm^2. (2.5 mm^2 may be used, if more than one cable is mounted on a raceway. If a single cable has only 2.5 mm^2, an additional earthing wire has to be provided)
- Parallel to the cable shields earthing conductors shall be provided to reduce both, the thermal loading of the shields and the inductance of the shield-earthing loops
- Free wires of a shielded cable shall (if at all) be earthed on one end only and not on both ends
- Metallic, galvanic interconnected ducts or raceways shall be used for laying the secondary cables
- Secondary cables shall be mounted on the enclosure by the shortest way

– If possible, secondary cables shall run close and in parallel to the earthing conductors
– The concept of a radial network comprises particularly also the following requirements:
  - Supply and return conductor of a control or a measure circuit shall be placed in the same cable
  - Secondary conductors, which go from the control room to a device or a device assembly, shall be installed directly in parallel to each other
  - Wires, which belong to the same control or measure circuit, should not be part of different, separately shielded cables. Should it be necessary, the cable shields should be in close contact
– Every current circuit of a secondary network may be earthed only on one side, or it must be potential free (Fig. 25). By this measure a galvanic coupling of currents from earthing network into signal circuits will be avoided

Dimensions and transient overvoltages increase with the voltage rating of the substation. By both effects the possibility of disturbance on the secondary equipment rises. Therefore, the above-mentioned measures have to be performed more carefully, if the rated voltage is higher.

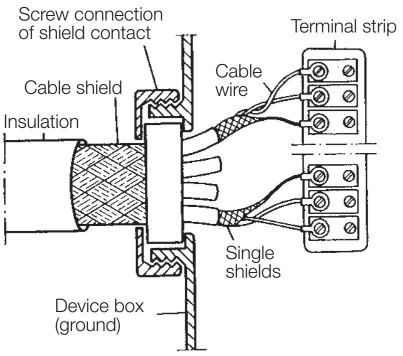


Fig. 24: Connection of a shielded cable

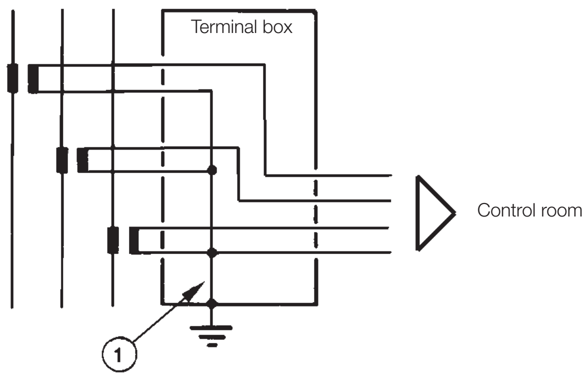


Fig. 25: Neutral earthing of secondary circuit of a current transformer (no more earthing points in control room)

5. GIS earthing net

In the area of the GIS substation the earthing net shall have fine meshes (width 3 to 5 m, lower values with higher voltage rating). At each crossing node the earthing conductors must be interconnected (with suitable clamps or by welding, for copper with Thermit or Caldwell method).

The GIS enclosure and the structures are connected to the earthing net at several points.

All metal construction elements of the building like beams, supports, crane rails, door frames, cable trenches, metal walls etc. have to be well connected to the earthing net.

The floor reinforcement has to be earthed to equalize the ground potential. (Throughout the structural steel matting in the floor interconnections shall be provided by clamping, welding or wire binding).

5.1 Indoor GIS

The GIS earthing net for indoor application is schematically shown in Fig. 26. The net has to be mounted either on the structural steel before casting the concrete, or onto the crude concrete surface, before the final flooring is applied.

In rooms with double floor it is recommended to install the earthing net on the building floor after this has been finished.

If the GIS is installed in an upper floor of the building, the GIS earthing net shall be connected downwards on all walls to be interconnected with the main earthing system.

The earthing net in a building is to be connected at several points with a potential control ring around the building. The potential control ring shall be connected with the earthing net of the outdoor substation (if available) in approximately 10 m intervals and in the shortest ways (Fig. 27).

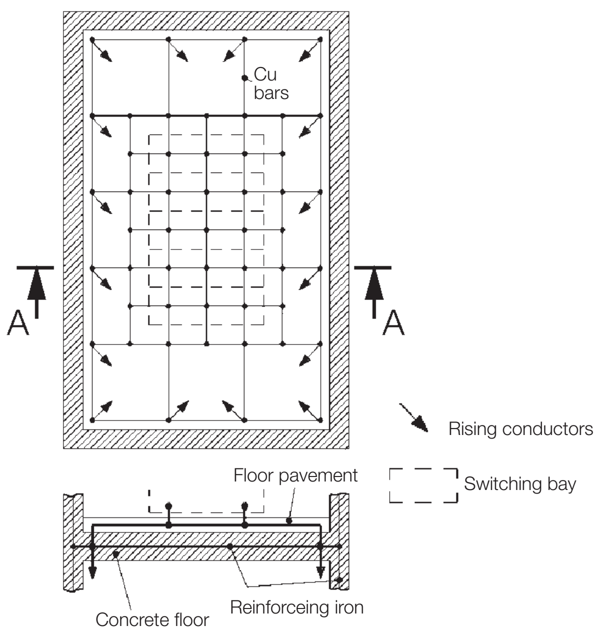
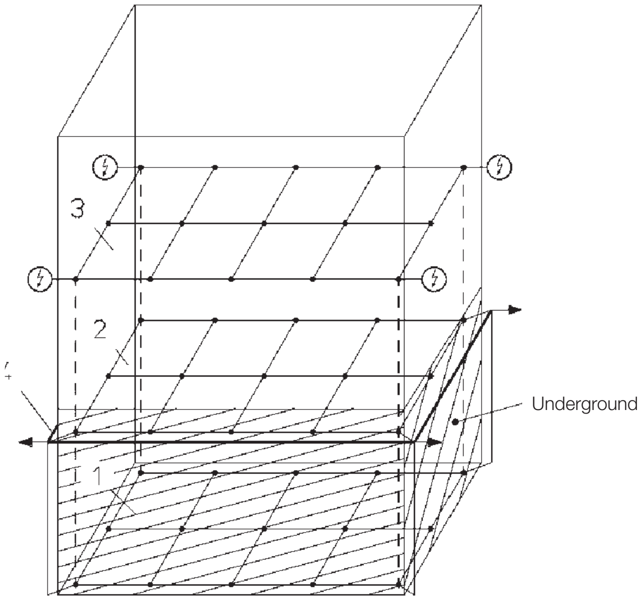


Fig. 26: Earthing net of indoor GIS



1 - Mesh network - foundation earthing

2 - Mesh network - ground floor

3 - Mesh network - upper floor

4 - Potential control ring

---- Rising conductors

→ Earthing connection to outdoor section

Earthing connection on lightning protection equipment

Fig. 27: Earthing system of a substation building

5.2 Outdoor GIS

At outdoor GIS, connections for earthing and return current conductors are designed weatherproof (corrosion protection).

Because there are no wall outlets, the TEV is higher than for indoor GIS. Therefore bushings shall be mounted at levels as low as possible, regarding the necessary safety distances.

The GIS earthing given by the steel frames carrying the bushing, should be improved by 2 to 4 copper conductors, running from the base of the bushings to the earthing net.

If the GIS is integrated in conventional substation, the GIS earthing net shall be connected with the earthing system of the substation in intervals of 5 to 10 m (Fig. 28).

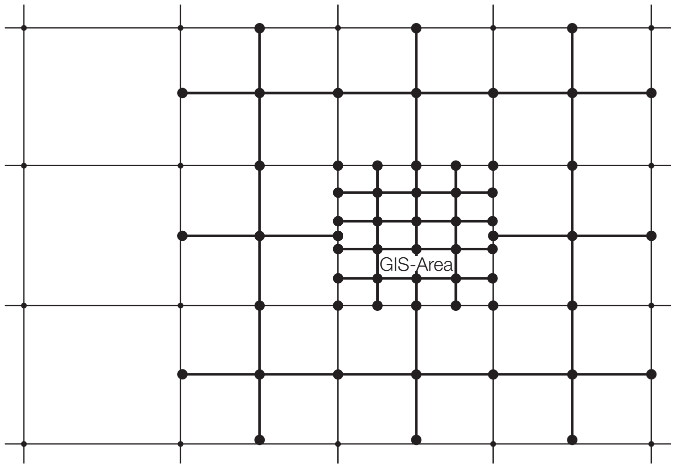


Fig. 28: Earthing net of outdoor GIS as part of an outdoor switchgear

6. Earthing drawings

The earthing and return current conductors are drawn schematically in a drawing named ,,Earthing Layout“. The drawing also includes the design details for construction. The accompanying list of parts specifies the required material (conductors, clamps, screws, nuts, etc.).

7. Delivery and installation

Usually, the scope of supply includes the GIS itself with its support structures, local control cubicles and the secondary cables between equipment and control cubicles, and the earthing and return current conductors until the earthing terminals on the support structure.

The connection conductors between the earthing terminals on the support structure and the earthing net, as well as their assembly is part of the main contractor’s scope of supply.

Deviations from standard scope of supply are defined in the documents “Scope of supply” and “share of supply”.

8. Conclusion

The above-mentioned measures for the earthing of the GIS substations type ELK are taken into account by ABB for the design and installation. Together with the earthing net and the earthing conductors between the earthing terminals and the earthing net (both provided by contractor), a high degree of safety for personal and equipment is achieved, both in normal operation, as well as in the case of short circuit.

9. References

[1] CIGRE Working Group 23-10, Electra No 151, Dec. 1993, p. 31-51; Earthing of GIS — An Application Guide

[2] IEEE Std 80-2000, Guide for Safety in AC Substation Grounding

[3] IEC 60364-5-54, Low-voltage electrical installation — Selection and erection of electrical equipment — Earthing arrangements and protective conductors

[4] IEC 62271-203, High-voltage switchgear and controlgear — Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

[5] IEC 62271-209, High-voltage switchgear and controlgear — Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

[6] IEC 61639, Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages of 72.5 kV and above

[7] IEC 61000-5-2, Electromagnetic compatibility (EMC) — Installation and mitigation guidelines — Earthing and cabling

[8] IEC 61000-6-5, Electromagnetic compatibility (EMC) — Generic standards — Immunity for power station and substation environments

[9] DIN VDE 0141, VDE-Bestimmungen für Erdung in Wechselstromanlagen für Nennspannungen über 1 kV

[10] DIN 43670, Aluminium bus bars; design for centinuous current

[11] DIN 43671, Copper bus bars; design for centinuous current

[12] SEV 3569, Erden als Schutzmassnahme in elektrischen Starkstromanlagen

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