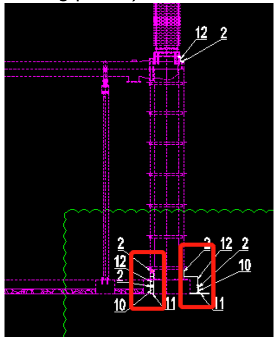
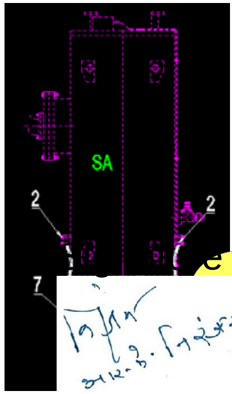
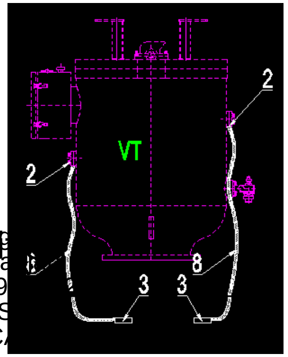
COMMENT RESOLUTION SHEET	
DRG / DOC TITLE	**Guaranteed Technical particulars of GIS**
NTPC DRG / DOC NO.	**9585-001-572-PVE-F-0039**
Revision	**0**
Reviewed By	**NTPC**
Review Date / Location	**08-05-2019 / NTPCEOC**

400kV GIS Switchyard

SR. No.	Page No. / Clause No. / Sheet No.	NTPC Observations / Comments	Vendor Reply
1	Sheet 20	Minimum two numbers of grounding connections for equipment should be ensured.	1.Earthing connections for Bays and Bushing (2 earthing points) are as follow:  Earthing points for BAYs  Earthing points for Bushings 2. Voltage Transformer and Surge Arrester(2 earthing points):  Earthing points for SA  Earthing points for VT 3. Earthing connections for outdoor bus duct The distance between 2 earthing conections is not more than 30m, we will provide an earthing point every 15m.
2	Sheet 20	Under the floor	We have revised the drawings and documents accordingly.
3	Sheet 20	Please furnish the document number of earthing design of outdoor switchyard(If any) or not, include in this documents.	Kindly be noted, Earthing design of outdoor switchyard (bus duct & steel support) is included in this document

Equipment earthing philosophy for pothead yard equipment is to be submitted in separate document (9585-001-572-PVE-F-0038-Equ

BHARAT HEAVY ELECTRICALS LIMITED

TRANSMISSION BUSINESS HVDC ENGINEERING & SYSTEMS

NTPC Doc No.	9585-001-572-PVE-F-0039	Rev. No.	01	Prepared	Checked	Approved
BHEL Doc No.	TB-397-316-GIS-010					
TYPE OF DOC.	Design		SIGN	[signature]	[signature]	[signature]
TITLE	GIS – Earthing Philosophy		NAME	HG FAN	YQ DONG	YZ CAO
			DATE	24-06-19	24-06-19	24-06-19
			GROUP	HVDC	W.O. No	87009

CUSTOMER	Patratu Vidyut Utpadan Nigam Ltd. (PVUNL) (A Subsidiary of NTPC in Joint Venture with JBVNL)
PROJECT	400kV GIS at Patratu Super Thermal Power Project Expansion Phase-I (3 X 800 MW)
NOA NO.	01/PVUNL-CS-9585-001-2/NOA-FC Dated 08-Mar-2018 01/PVUNL-CS-9585-001-2/NOA-SC Dated 08-Mar-2018 01/PVUNL-CS-9585-001-2/NOA-TC Dated 08-Mar-2018
Station	Patratu, Jharkhand

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01					Revised as per NTPC's comments.
Rev No.	Date	Altered	Checked	Approved	REVISION DETAILS

Distribution	To	HVDC	TBMM	TBQM	Customer
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CUSTOMER:	Patratu Vidyut Utpadan Nigam Ltd. (PVUNL)
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PROJECT:	400kV GIS at Patratu Super Thermal Power Project Expansion Phase-I(3×800 MW）
NTPC DOC. NO.	9585-001-572-PVE-F-0039
BHEL NOC. NO.	TB-397-316-GIS-010
REV. NO.	01

GIS - Earthing Philosophy

June. 22th, 2019

Sieyuan Electric Co., Ltd.

CONTENT

1 Introduction

The intent of this document is to provide the requirements of earthing system design for Sieyuan SF6 Gas-insulated Metal-enclosed Switchgear(GIS) against fault current resulting from breakdown inside the GIS enclosure and the additional factors arising from the high frequency phenomena generated during operation of GIS.

2 General requirements of earthing in GIS substation

2.1 Shock hazard on GIS during fault condition

For GIS, the conductor is positioned inside a grounded metallic enclosure. Whenever a fault current flows through the conductor, a voltage is induced in the enclosure. Certain parts of the enclosure might be at different potentials with respect to the substation ground.

In Gas-insulated Metal-enclosed Switchgear the main consideration in case of a short-circuit fault is the shock-hazard voltage or touch voltage. The step voltage is of minor importance as the floor beneath the GIS is covered with a finely meshed earthing mat.

The part of the short-circuit current which runs through the enclosure and the earting conductors in case of a fault results in potential differences in the enclosure, which might be bridged by personnel shown as Figure 1 and experience a shock.

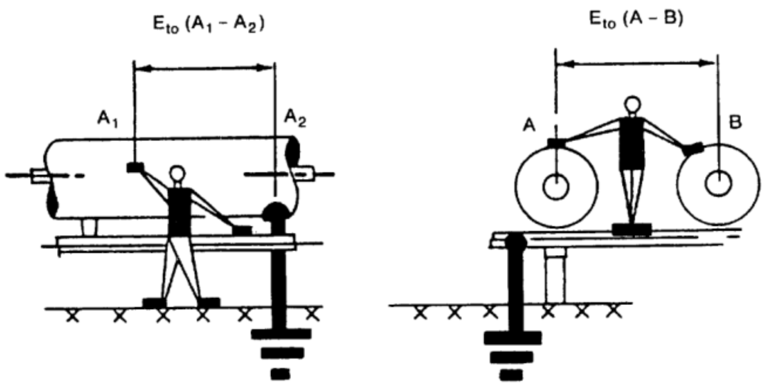


Figure 1 - Typical metal-to-metal touch situation in GIS

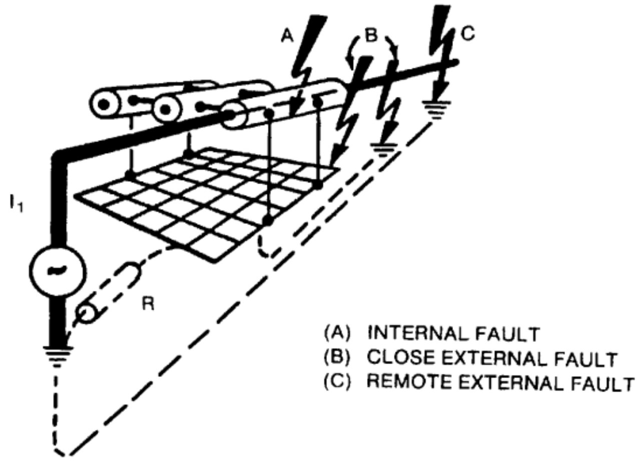


Figure 2 - Typical faults in GIS

Potential differences on the GIS enclosure may be caused by internal faults(e.g. flashover between conductor and enclosure) and by faults external to GIS with a fault current running through the GIS shown as Figure 2(case A, B and C).

The maximum rise of shock-hazard voltage on a GIS enclosure depends on the inductance of the enclosure to ground, inductance of inner conductor and mutual inductance of individual busbars for a given configuration. Since the inductance of the GIS enclosure is known design value, the other factor which can influence is the inductance of the earthing conductors(material, cross section and laying method of the conductors).

Sieyuan has taken every care that its GIS enclosure is properly designed and provision for adequate grounding is made so that potential difference between enclosures and the potential difference between enclosure and grounded structure doesn't exceed 65-130 Volts during fault conditions.

The metal to metal touch voltage equation 34 & 35 of IEEE-80(given below) indicates that the voltage range 65-130 V corresponds to fault times ranging from 0.8 sec. to 3.2 sec. for a body weight of 50 kg and 1.46 sec. to 5.8 sec. for a body weight of 70 kg. The graphical presentation below at Figure 3 gives a better understanding of safety margins.

$E_{mm\text{-}touch50}$=116/ √ t_s (for a body weight of 50kg)——Ref. IEEE-80 Equation 34

$E_{mm\text{-}touch70}$=157/ √ t_s (for a body weight of 70kg)——Ref. IEEE-80 Equation 35

Where t_s is the duration of shock current in seconds.

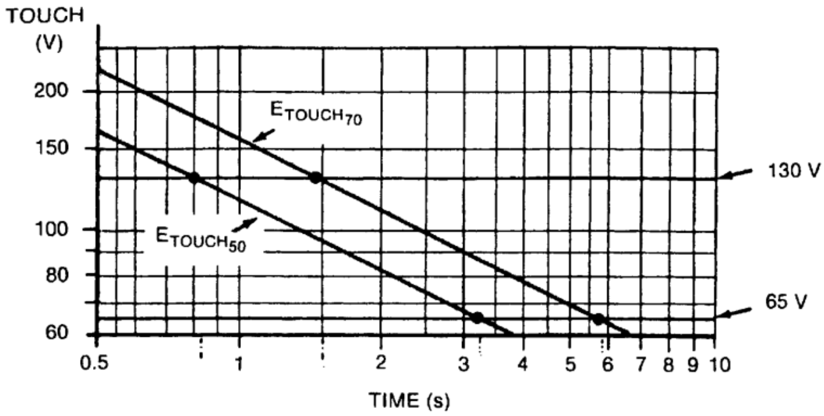


Figure 3 - Typical voltage limits for metal-to-metal contact and a typical range of enclosure voltages to ground

The above graph shows that a person with body weight of 50 kg can withstand 65 V for 3.2 sec. whereas 130 V for 0.8 sec. only. Similarly, a person with body weight of 70 kg can withstand 65 V for 5.8 sec. and 130 V for 1.46 sec. The touch voltage withstand time duration for specified voltage range is quite safe as it is much above the fault duration and it's clearing time. A person is safe if the value of current passing through human body is less than 100 mA which is the ventricular fibrillation threshold limit.

2.2 High frequency Phenomena

In GIS, the switching operations of circuit-breakers, disconnectors and earthing switches cause SF6 insulation breakdowns due to discharges between contacts and thus steep transient overvoltage are generated. These voltages propagate as travelling waves(TW) into both directions with nearly speed of light.

The TW can leave the GIS only at apertures in the enclosure like SF6/air bushings or isolating flanges(transformer and cable terminals).

The TW , escaped through an SF6/air bushing will propagate on the overhead line and on the GIS enclosure. The latter part, running on the outer surface of the enclosure generates high frequency Transient Ground Potential Rise(TGPR). Due to their short duration and low energy phenomena they cause no harm to operating personnel of GIS. However, they can cause electromagnetic interference and sparking in some locations of the plant(optical and acoustical phenomena). Therefore they have to be kept low.

This is achieved by following earthing measures:

- Narrowly meshed earthing net of GIS.
- Short interconnections between the enclosure and the earthing net.
- Meshed interconnections between the enclosure and the earthing net.
- Earthing conductors and earthing connections with lowest possible inductance.

They shall be short and have large surface(a flat profile is preferable to an equivalent cross section, or two conductors in considerable distance instead of one with equivalent cross section respectively).

3 Earthing system of Sieyuan GIS substation

3.1 Earthing principle of Sieyuan in 400kV GIS substation

They shall be short and have large surface(a flat profile is preferable to an equivalent cross section, or two conductors in considerable distance instead of one with equivalent cross section respectively).

3.1.1 Multi-Points Earthing System

Sieyuan has applied the multi-points earthing system for GIS substation in India market as well as other countries. The multi-points earthed with proper metal conductor in other words, there is no isolating point in GIS substation.

The multi-points earthing method has a number of advantages, compared with the one-point earthing method:

- Better reliability concerning earthing safety.
- Smaller magnetic field intensity outside the enclosure.
- Lower shock-hazard voltage in case of fault.
- Smaller high frequency transient voltage during switching operations.
- Lower interference by induced currents in secondary cables.
- No insulation of the structure requested.

3.1.2 Typical earthing connection of the GIS to the earth riser

a) Earth riser directly connected to main earthing grid.

b) Earth riser as 75mm×12mm steel earthing mesh.

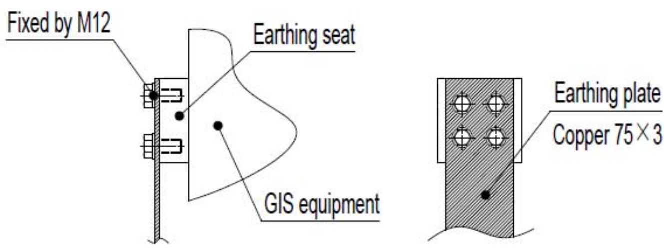


Figure 4 - Earthing connection at GIS side

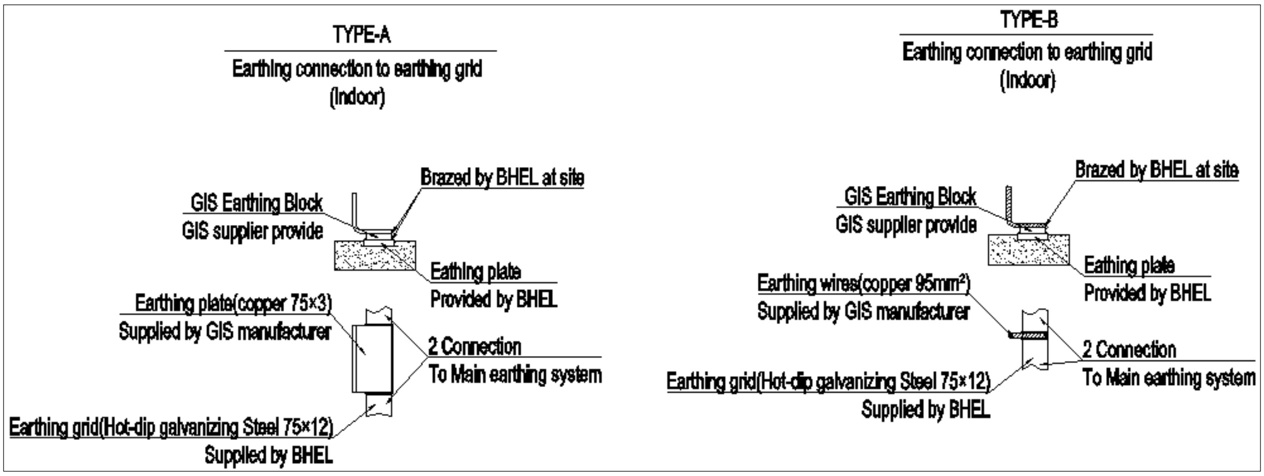


Figure 5 - Earthing connection to earthing grid(indoor)

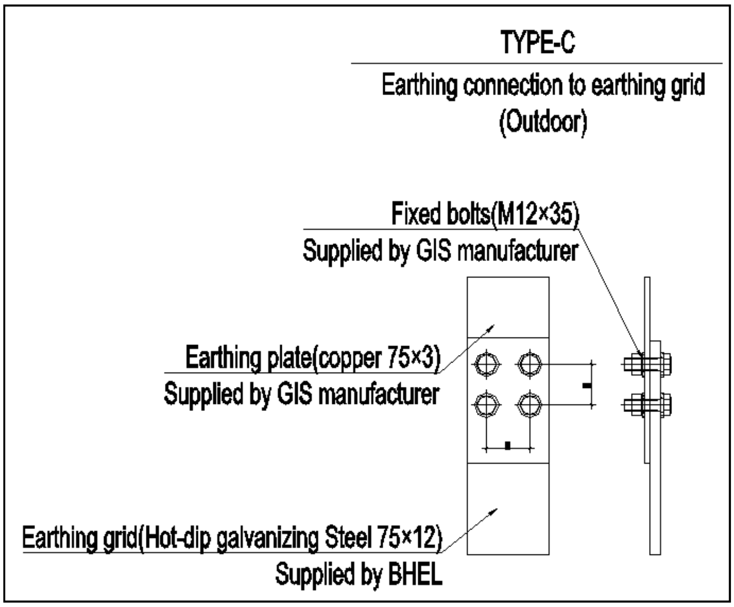


Figure 6 - Earthing connection to earthing grid(outdoor)

c) Design of earthing material and size

$$A_{mm^2} = I \frac{1}{\sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \cdot \alpha_r \cdot \rho_r}\right) \ln\left(\frac{K_0 + T_m}{K_0 + T_a}\right)}}$$ --------------Ref. IEEE 80 Equation (40)

For earthing riser and earthing grid(75mm×12mm steel),

$$A_{mm^2} = 63 \times \frac{1}{\sqrt{\left(\frac{3.28 \times 10^{-4}}{0.5 \times 0.0016 \times 15.9}\right) \ln\left(\frac{242+1084}{242+45}\right)}} = 317[mm^2]$$

For earthing plate of GIS(75mm×3mm copper),

$$A_{mm^2} = 63 \times \frac{1}{\sqrt{\left(\frac{3.42\times10^{-4}}{0.5\times0.00381\times1.72}\right)\ln\left(\frac{242+1084}{242+45}\right)}} = 157.6[mm^2]$$

Where

I	is the rms current in kA
A_{mm^2}	is the conductor cross section in mm^2
T_m	is the maximum allowable temperature in ℃
T_α	is the ambient temperature in ℃
T_r	is the reference temperature for material constants in ℃
α_r	is the thermal coefficient of resistivity at reference temperature T_r in 1/℃
ρ_r	is the resistivity of the ground conductor at reference temperature T_r in μΩ-cm
K_0	$1/\alpha_0 1$ or $(1/\alpha_r)-T_r$ in ℃
t_c	is the duration of current in s
TCAP	is the thermal capacity per unit volume in J/(cm^3·℃)

d) Earthing connections for Sieyuan GIS(Figure 7-10) and details shown on Appendix-1.

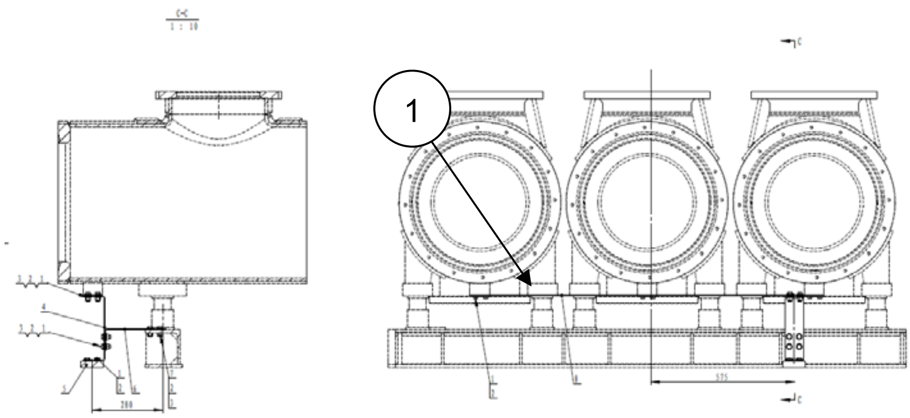


Figure 7 - Earthing connection for BAY

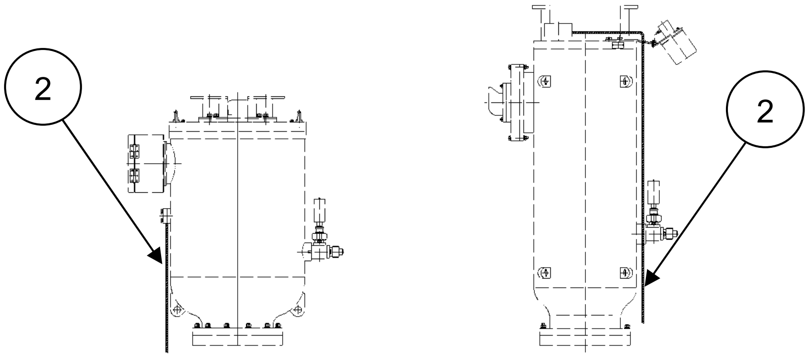


Figure 8 - Earthing connection for PT/SA

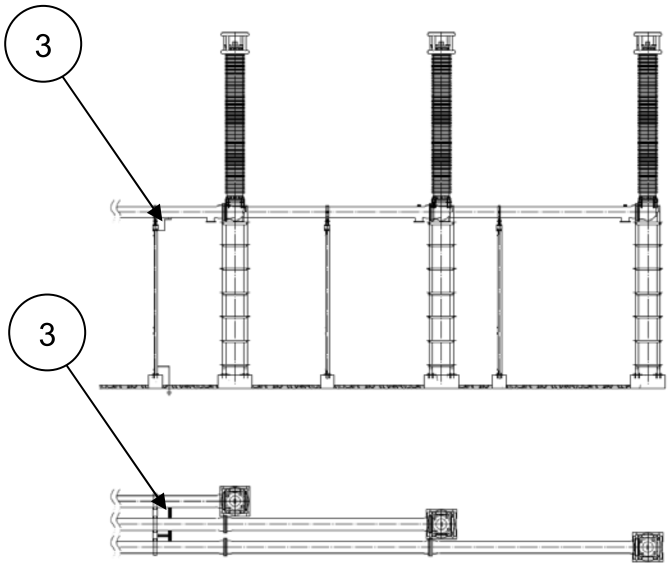


Figure 9 - Earthing connection for bus bar

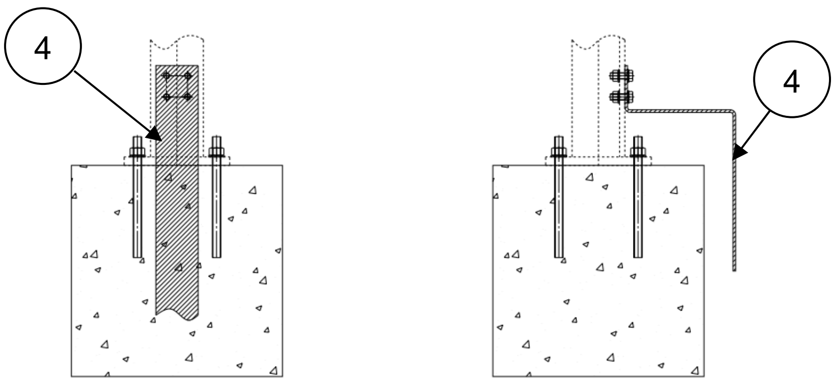


Figure 10 - Earthing connection for steel support

3.2 Enclosure Voltage Rise analysis against fault current

Fault location、current direction、earthing location are relevant to the enclosure voltage. The below picture indicates the worst situation.

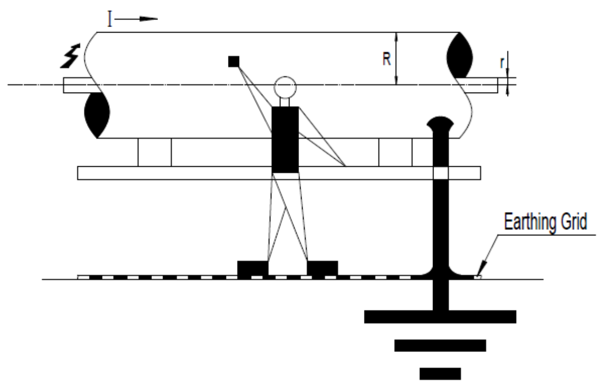


Figure 11 - Enclosure Voltage Rise on Busbar

For one enclosure, it shall be like conductor,

$$L_0 = \frac{\mu_0 L}{2\pi}\left(\frac{1}{4} + \ln\frac{R}{r}\right)$$

For the power system frequency is 50Hz, the resistance of enclosure is far less than inductance. The touch voltage(U) on the enclosure of busbar,

$$U = X_L \cdot I = 2\pi f \cdot \frac{\mu_0 L}{2\pi}\left(\frac{1}{4} + \ln\frac{R}{r}\right) \cdot I$$

where, $X_L = 2\pi f \cdot L$

μ_0	Magnetic permeability in vacuum (=$4\pi \times 10^{-7}$ H/m)
L	Half of distance between two continuous earthing point in meter
I	Short current in A
R	Half of diameter of enclosure(=0.166m)
r	Half of diameter of conductor(=0.055m)

In this project, the length of the longest parts between two earthing point is 30m.

L=1/2×30=15m

$$U = 2 \times \pi \times 50 \times 2 \times 10^{-7} \times 15 \times \left(\frac{1}{4} + \ln\frac{0.166}{0.055}\right) \times 63 \times 10^{3}$$

$$U = 80.3V$$

The maximum enclosure voltage rise is 80.3V for 400kV GIS. Besides, the maximum touch voltage occurs when a person touch the part of enclosure which is the furthest away from the earthing point during short circuit fault. Meanwhile, the enclosure voltage rise of this part of enclosure is maximum value. Based on calculation above, the maximum touch voltage shall be 80.3V for this project.

$E_{mm\text{-}touch50}$=116/ √ t_s (for a body weight of 50kg)——Ref. IEEE-80 Equation 34

where, t_s =1s,

So, $E_{mm\text{-}touch50}$=116V.

The maximum touch voltage for this project is 80.3V<116V.

Hence, the value of maximum enclosure voltage rise and maximum touch voltage for this project is satisfied as requirement of technical specification and IEEE 80.

4 Design of grid

The purpose of the earth gird is to provide a low impedance path for the earth fault current and, also the high frequency current arising from TEV. Before designing the grid, it is necessary to know the maximum earth fault current that the system will have to carry and maximum allowable earth potential rise.

In order to figure out design factor for earthing grid, we assume severe fault condition that the system fault current flow single conductor of earthing grid along the longest path.

4.1 Inductance of earthing plate

Formula for calculating inductance of single conductor,

$$L = \frac{\mu_0 l}{2\pi}\left(\frac{1}{4} + \ln\frac{2h}{r}\right)$$

$L = \frac{4\pi\times10^{-7}\times1}{2\pi}\left(\frac{1}{4} + \ln\frac{2\times0.6}{0.0375}\right) = 7.43\times10^{-7}$ [H/m]

Where,

μ_0 - Magnetic permeability in vacuum (=$4\pi\times10^{-7}$ H/m)

r - Half width of earthing plate (=0.0375m)

h - Depth from ground to earthing rod (=0.6m)

Thus, Earthing plate inductance (X_L)

$X_L = 2\pi f\cdot L = 2\pi\times50\times7.43\times10^{-7} = 2.33\times10^{-4}$ [Ω/m]

4.2 Resistance of earthing plate

R=(ρ×1)/A

Where,

ρ - Resistivity

Earthing plate(Steel 75mm×12mm)：9.7×10^{-8}[Ω/m]

A - Cross section

Earthing plate cross section

$=75\times12\times10^{-6}=9\times10^{-4}$[$m^2$]

Thus, earthing plate resistance(R)

$R=9.7\times10^{-8}\times1/(9\times10^{-4})=1.1\times10^{-4}$[Ω/m]

4.3 Impedance of earthing plate

$Z = \sqrt{X_L^2 + R^2} = 2.58\times10^{-4}$ [Ω/m]

4.4 Earthing mat induced voltage

$V_E=2.58\times10^{-4}\times63kA=16.2V/m$

4.5 Results

The allowed touch voltage as per IEEE 80,

$V_{step}=116/\sqrt{1}=116V$

Thus, the longest path of fault current through earthing grid,

$L_g= V_{step} / V_E =7.2m$

Thus, the space of earthing grid conductor chosen

$L_s=L_g\times2=14.4m$

5 Calculation of step voltage and touch voltage

5.1 Step voltage

The step voltage have been shown in the picture as bellow. The voltage distribution of earth surface will be reset by grounding grid. The step voltage will be reduced by it.

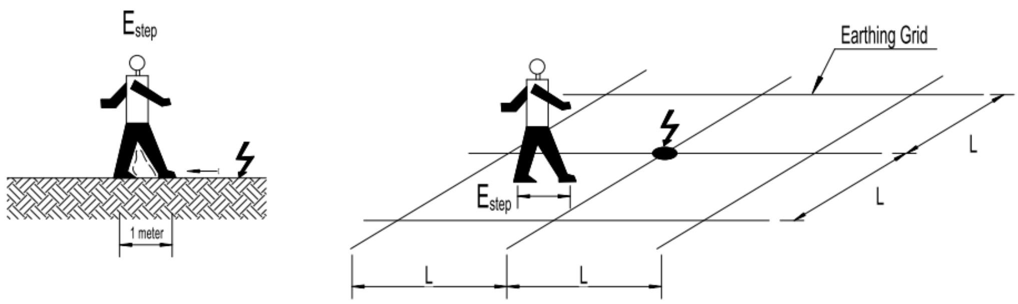


Figure 12 - Touch voltage

According to the ohm's law,

$$Eg = I * R$$

where,

Eg - the grid voltage

I - Fault current(63kA)

R- Resistance of grid rod

R=ρ×L/S

Where,

ρ - Resistivity

Earthing plate (Steel 75mm×12mm)： 9.7×10^{-8}[Ω/m]

S - Cross section

Earthing plate cross section

$=75\times12\times10^{-6}=9\times10^{-4}$[m2]

Thus, earthing plate resistance(R)

$R=9.7\times10^{-8}\times16/(9\times10^{-4})=1.7\times10^{-3}\Omega$

So,

$$E_{step} = Eg$$

where,

Estep - Step voltage

Lstep - distance of step(1 meter)

L - length of grid(9 meter)

$E_{step} = Eg = 63 \times 10^3 \times 1.7 \times 10^{-3}$ =108.6V

According to IEEE 80, Clause 8.3, For step voltage the limit is

$$E_{step50} = (1000 + 6C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}}$$

where,

E_{step50} For body weight of 50kg

C_s Correction factor

ρ_s Surface material resistivity in Ω·m

If no protective surface layer is used, then $C_s = 1$ and $\rho_s = \rho$.

Regarding to the most demanding conditions, the ρ could be 100Ω·m according to the IEEE 80, Table-7.

So,

$$E_{step50} = (1000 + 6 \times 1 \times 100)\frac{0.116}{\sqrt{0.5}} = 262.5V$$

So, the step voltage for this project is 108.6V<262.5V.

It's safe for personal body in case of "Shock hazard on GIS during fault condition" about the step voltage.

5.2 Touch voltage

The below picture indicates the worst situation. And the value of touch voltage for people will be the maximum.

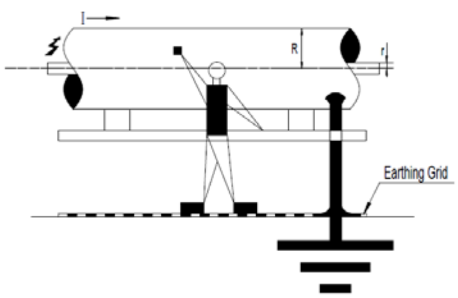


Figure 13 - Touch voltage

For one enclosure, it shall be like conductor,

$$L_0 = \frac{\mu_0 L}{2\pi}\left(\frac{1}{4} + \ln\frac{R}{r}\right)$$

For the power system frequency is 50Hz, the resistance of enclosure is far less than inductance. The touch voltage(U) on the enclosure of busbar,

$$U = X_L \cdot I = 2\pi f \cdot \frac{\mu_0 L}{2\pi}\left(\frac{1}{4} + \ln\frac{R}{r}\right) \cdot I$$

where, $X_L = 2\pi f \cdot L$

μ_0	Magnetic permeability in vacuum (=$4\pi \times 10^{-7}$ H/m)
L	Half of distance between two continuous earthing point in meter
I	Short current in A
R	Half of diameter of enclosure(=0.166m)
r	Half of diameter of conductor(=0.055m)

In this project, the length of the longest parts between two earthing point is 30m.

L=1/2×30=15m

$$U = 2 \times \pi \times 50 \times 2 \times 10^{-7} \times 15 \times \left(\frac{1}{4} + \ln\frac{0.166}{0.055}\right) \times 63 \times 10^3$$

$$U = 80.3V$$

According to the IEEE-80, clause-8.3,

$E_{mm\text{-}touch50}$=116/ √ t_s (for a body weight of 50kg)——Ref. IEEE-80 Equation 34

where, t_s =0.5s,

$E_{mm\text{-}touch50}$=164V.

So, the touch voltage for this project is 80.3V<164V.

It's safe for personal body in case of "Shock hazard on GIS during fault condition" about the touch voltage.

6 Conclusion

Sieyuan GIS apply the multi-points earthing system that are linked among the entire GIS enclosure and its support structures. The multi-points are earthed with proper metal conductor.

in other words, there is no isolating point in GIS substation and each earthing points can pass the fault current complementarily.

Applied earthing bar and cable of GIS have sufficiently big size than calculated earthing bar size at 63kA, thus the fault current of GIS can be passed sufficiently.

6.1 Enclosure Voltage Rise analysis against fault current

The value of maximum enclosure voltage rise and maximum touch voltage for this project is 80.3V, and it is satisfied as requirement of technical specification and IEEE 80.

6.2 Calculated safe design value of earthing grid

$L_s = L_g \times 2 = 14.4m$ (Space of earthing grid conductor)

Hence, the space of earthing grid(steel) is not more than 14.4m for recommendation. The earthing grid could be designed indoor for reference as Figure 14.

Typically, the GIS installation necessitates around 25% of the land area required for conventional equipment of the same rating. Because of this small area special consideration has to be given in earth mat design of GIS based on the recommendation of IEEE 80.

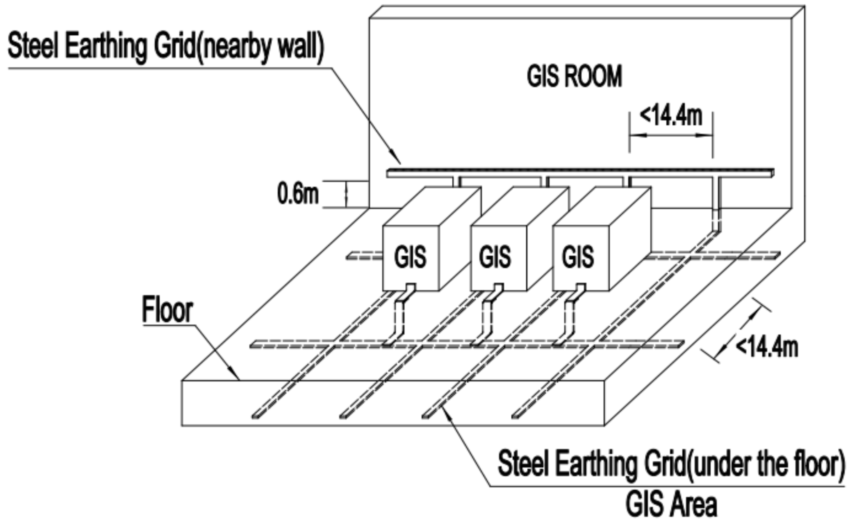


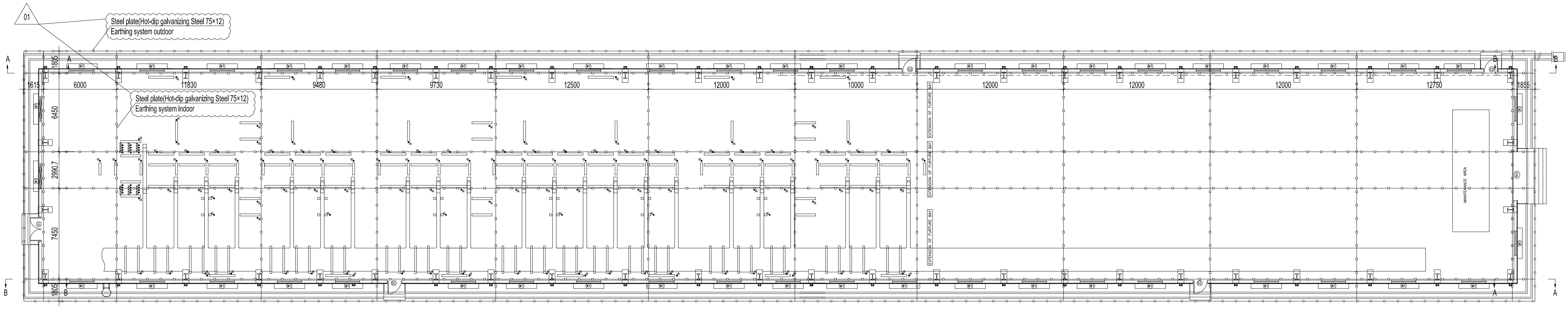
Figure 14 - Earthing Grid for GIS indoor

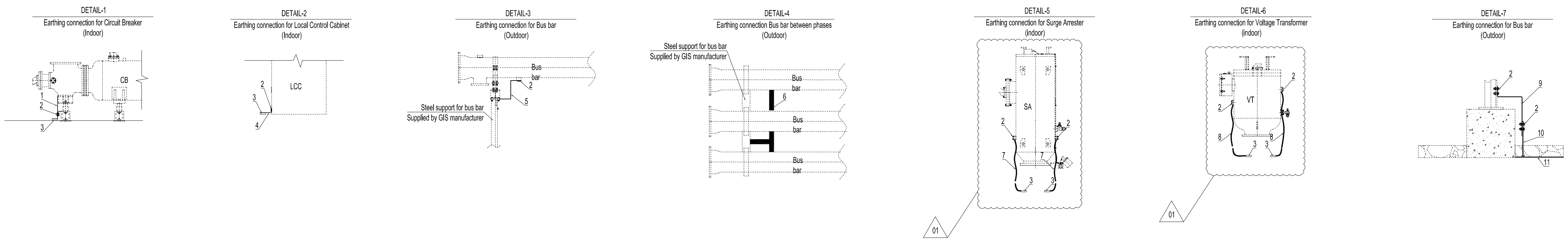
7 Reference

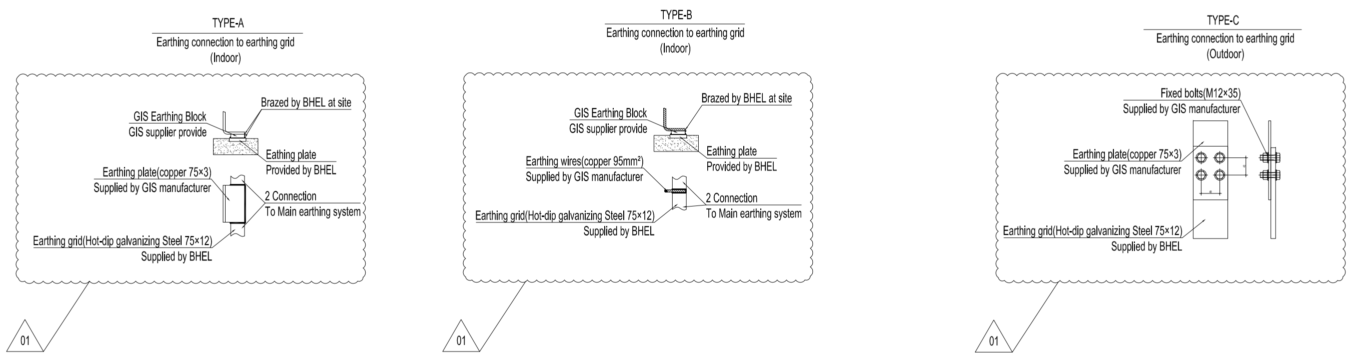
IEEE 80 - Guide for Safety in AC Substation Grounding

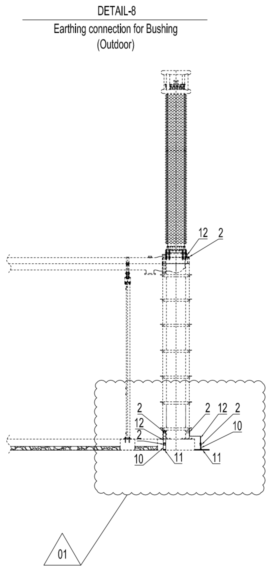
Appendix-1 400kV GIS SWITCHYARD TYPICAL EARTHING CONNECTION

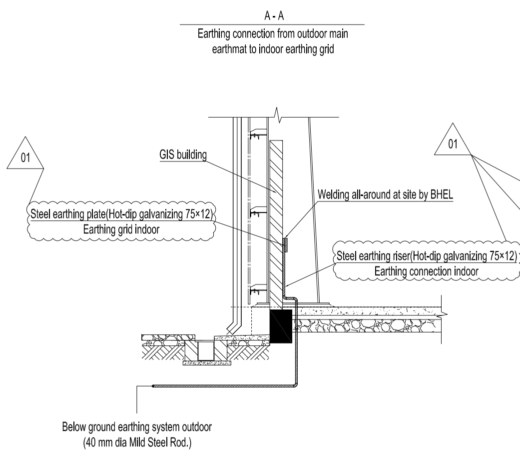
FIRST ANGLE PROJECTION (ALL DIMENSIONS ARE IN MM.)

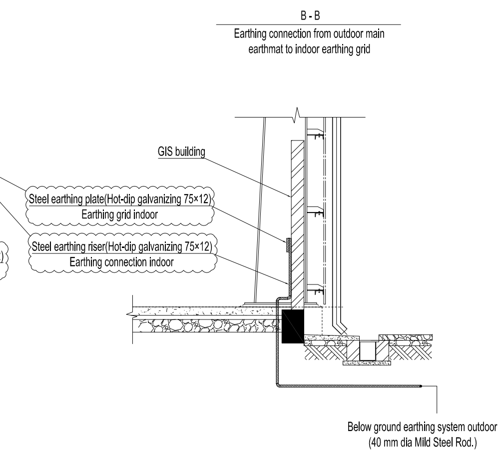












Sl. No.	Description	Material	Size	Qty.	Scope of supply	Connection to Earthing Grid
1	Earthing plate for BAY	Tinned Copper	75×3, 225mm²	21sets (42nos.)	Sieyuan	TYPE-A
2	Fixed bolts and nuts	Hot-dip Galvanizing Steel	M12	7000nos.	Sieyuan	/
3	Earthing grid(Indoor)	Hot-dip Galvanizing steel	75×12, 900mm²	820m	BHEL	/
4	Earthing plate for Local Control Cabinet	Tinned Copper	75×3, 225mm²	22set	Sieyuan	TYPE-A
5	Earthing plate for Bus bar	Tinned Copper	75×3, 225mm²	155set	Sieyuan	Notes-2
6	Earthing plate for Bus bar between phases	Tinned Copper	75×3, 225mm²	100set	Sieyuan	Notes-2
7	Earthing plate for Surge Arrester	Multiple soft copper wires	95mm²	6sets (12nos.)	Sieyuan	TYPE-B
8	Earthing plate for Voltage Transformer	Multiple soft copper wires	95mm²	6sets (12nos.)	Sieyuan	TYPE-B
9	Earthing plate for Steel Support	Tinned Copper	75×3, 225mm²	320set	Sieyuan	TYPE-C
10	Earthing riser	Hot-dip Galvanizing steel	75×12, 900mm²	320nos.	BHEL	/
11	Earthing grid(outdoor)	Hot-dip Galvanizing steel	Ø40, 1256mm²	/	BHEL	/
12	Earthing plate for Bushing	Tinned Copper	75×3, 225mm²	42sets (84nos.)	Sieyuan	/

Notes:
1. This earthing connection plan only shows the measures for earthing of high voltage equipment. It could be ajusted as per actual situation at site.
2. The GIB shall be earthing with steel support as per Earthing System Principle and the steel support shall be connected to Earthing Grid.
3. The quantity of earthing material in table is as reference only. It shall be sufficient for earthing at site.
4. The earhing plate and wires with Earthing Grid shall be brazed by BHEL at site.

CA NO.	01/PVUNL-CS-9585-001-2/NOA-SC DATED 08/03/2018
ADDITIONAL INFORMATION W.O.No.	xzkgd@ifj;kstuk dk uke / NAME OF CUSTOMER/PROJECT: PATRATU VIDYUT UTPADAN NIGAM LTD. PATRATU SUPER THERMAL POWER PROJECT EXPANSION PHASE-I (3x800 MW)
STATUS OF DRAWING	
DISTRIBUTION OF PRINTS	Hkkjr gsoh bysfDV~dYl fyfeVsM V~kalfe'ku ifj;kstuk foHkkx / BHARAT HEAVY ELECTRICALS LTD. TRANSMISSION PROJECTS DIVISION

	नाम /NAME	हस्ता./SIGN.	दि./DATE
बनाया DRAWN			
जँचा CHECKED			
स्वीकृत APPROVED			

REV.	DATE		
01	22.06.2019	ALTERED	Robin WANG
		CHECKED	Honggang FAN
		APPROVED	Maoquan WANG

विभाग DEPT. / कोड CODE

अनुपात / SCALE 1:200 (A1)

कार्ड कोड CARD CODE

शीर्षक/TITLE
400kV GIS SWITCHYARD TYPICAL EARTHING CONNECTION

ड्राईंग.क्र./DRAWING NO.
NTPC DRG NO.
BHEL DRG NO.

पुनः/REV. 01

पृष्ठ क्र./SHEET No. 01 अगला पृष्ठ/NEXT SHEET 01

COMPUTER DRG. PATH NAME
REF. DRG. No.
SIGN. & DATE
INVENTORY No.