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Grounding assessment for Industrial installation and Grid substations

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Content

- Importance of Grounding in Power Quality.
- Why Earthing system assessment.
- Approach and best practices.
- Investigation of transformer failure and fire in GIS substation.
- Interruptions in Power Generation in TPS(Thermal power station) due to poor grounding & wiring.
- Inverter failure in Solar plant due to Poor grounding.
- Safe & cost economic grounding design by CDEGS software.
- Summery.

Power Quality is a Financial problem-not only a technical problem

Economic Impact of Power Quality In India

Data from International R&D Conclave organised by CEA in Feb 2018

Direct costs of power downtime in India is $3.128 million per year (Utilities)

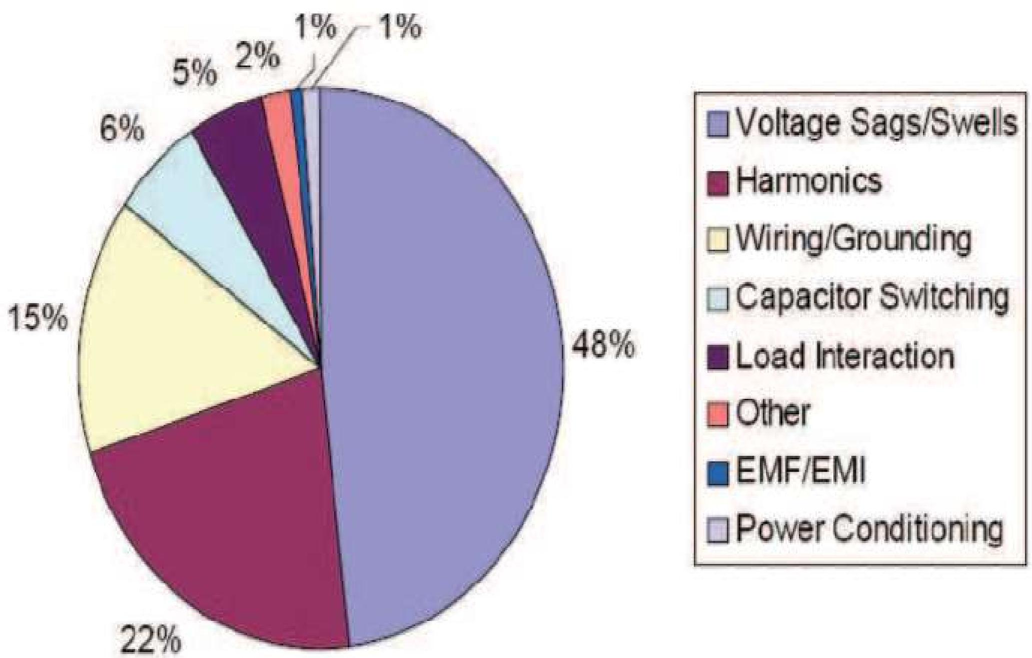
- 57% due to voltage sags and short interruptions
- 35% due to transients and surges.

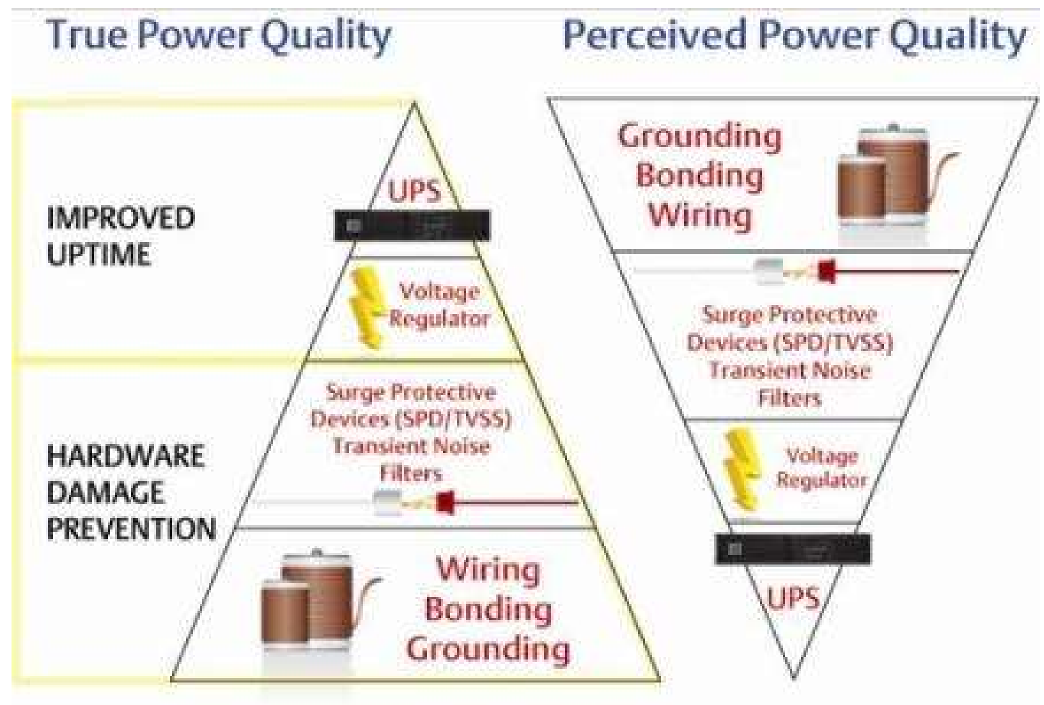
Outage is a major cost.

Recent outage in Mumbai costed 3.5 million **$ per hour**

- Wartsilla Study in India (21 Cities and 1500 respondents)
- 13700 million **$** investment plus annual opex-4100 million **$**
- Directly measureable- DG sets, UPS systems, inverters/Battery
- Indirect Cost (Disruption, opportunity lost etc.)- not easy to measure
- Some Estimate -6% GDP

Grounding – Importance In Power Quality





IEEE standard defines electrical power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment with precise wiring system and other connected equipment".

Grid Resistance - Alone not sufficient

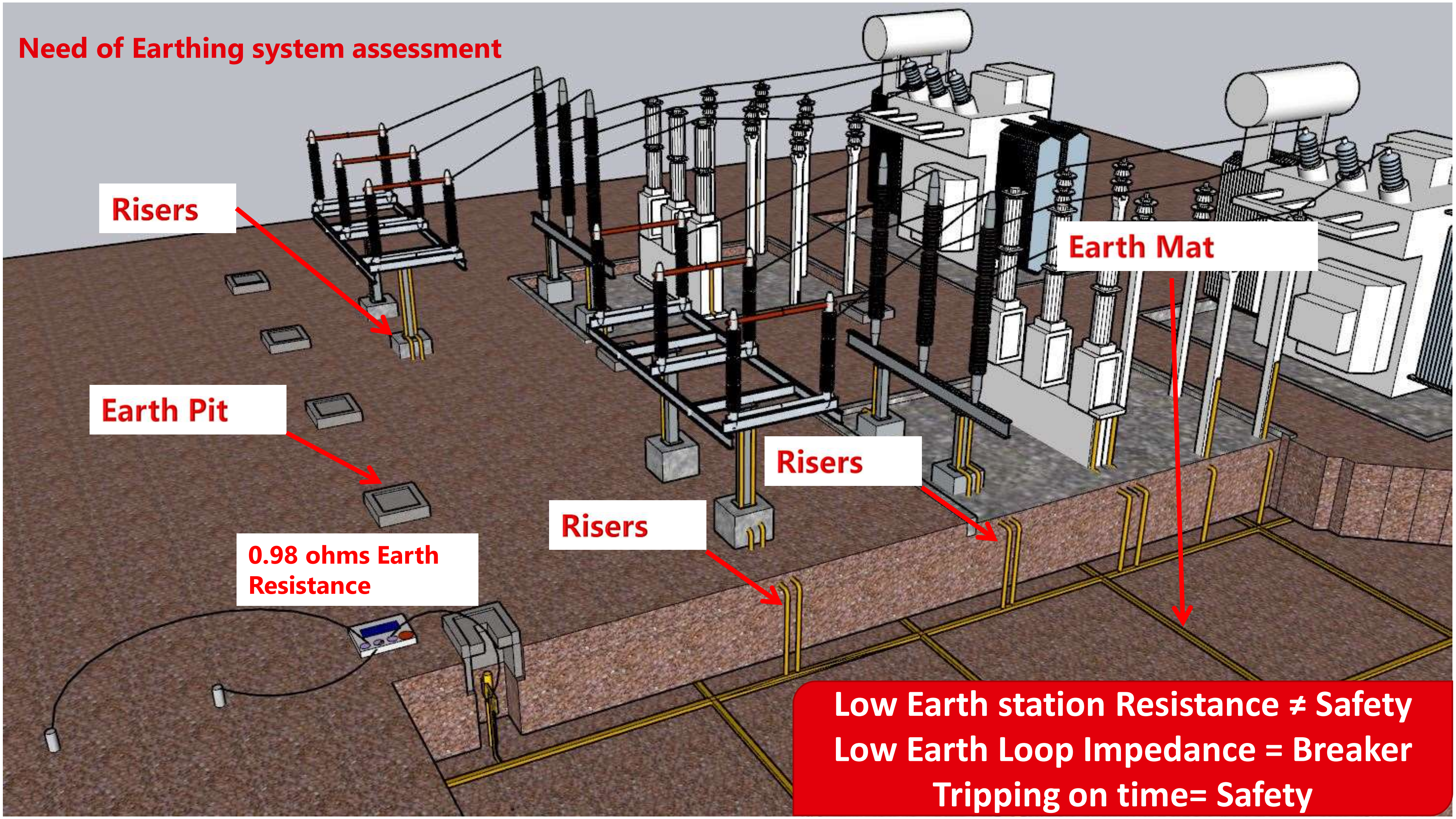
IEEE 80 – 2013 IEEE Guide for Safety in AC Substation Grounding is the latest standard, and we provide below few important extracts:

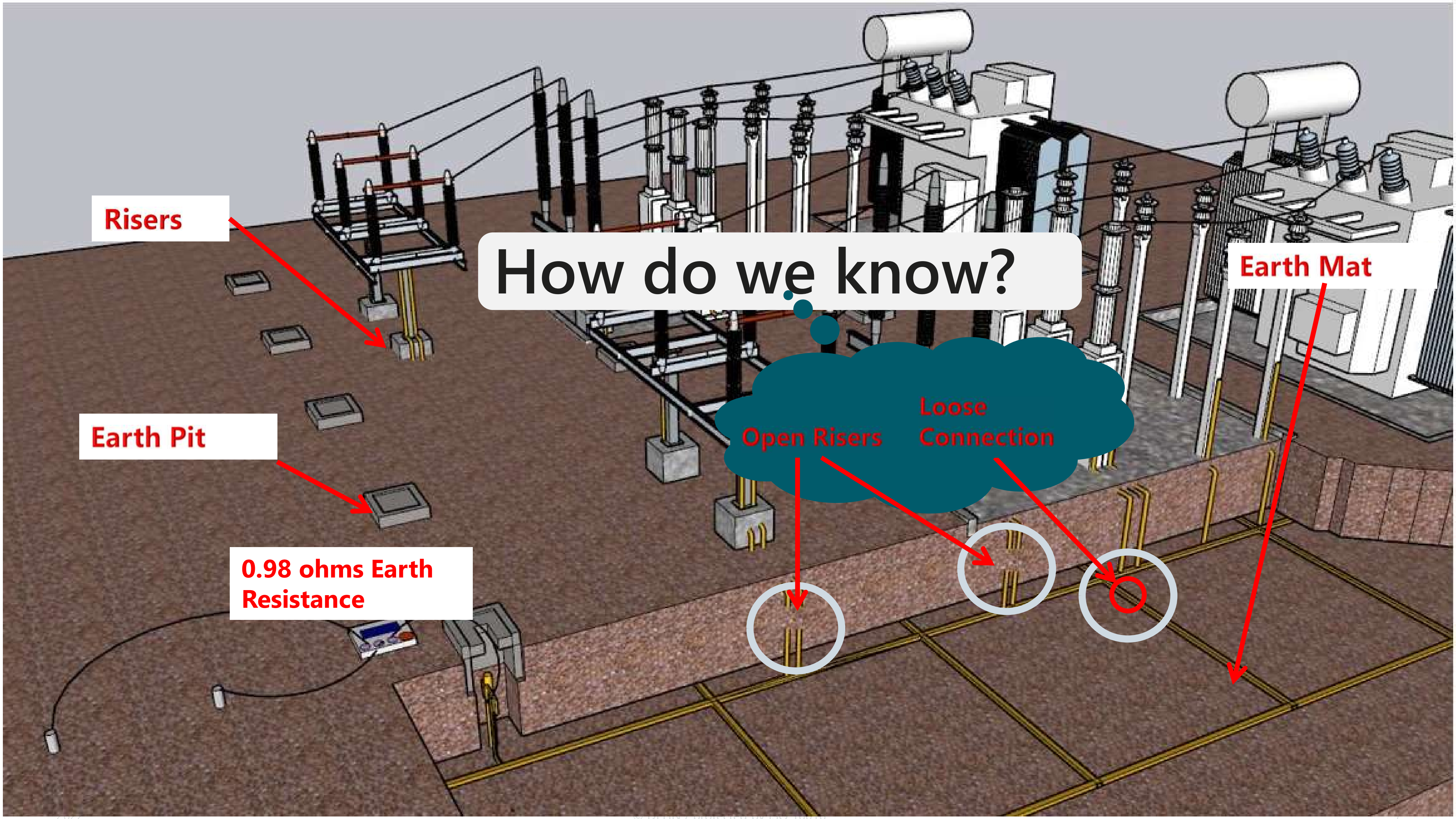
Extract from IEEE 80 2013 – Clause 4.1 – Grid Resistance – <u>Alone Not Sufficient</u>

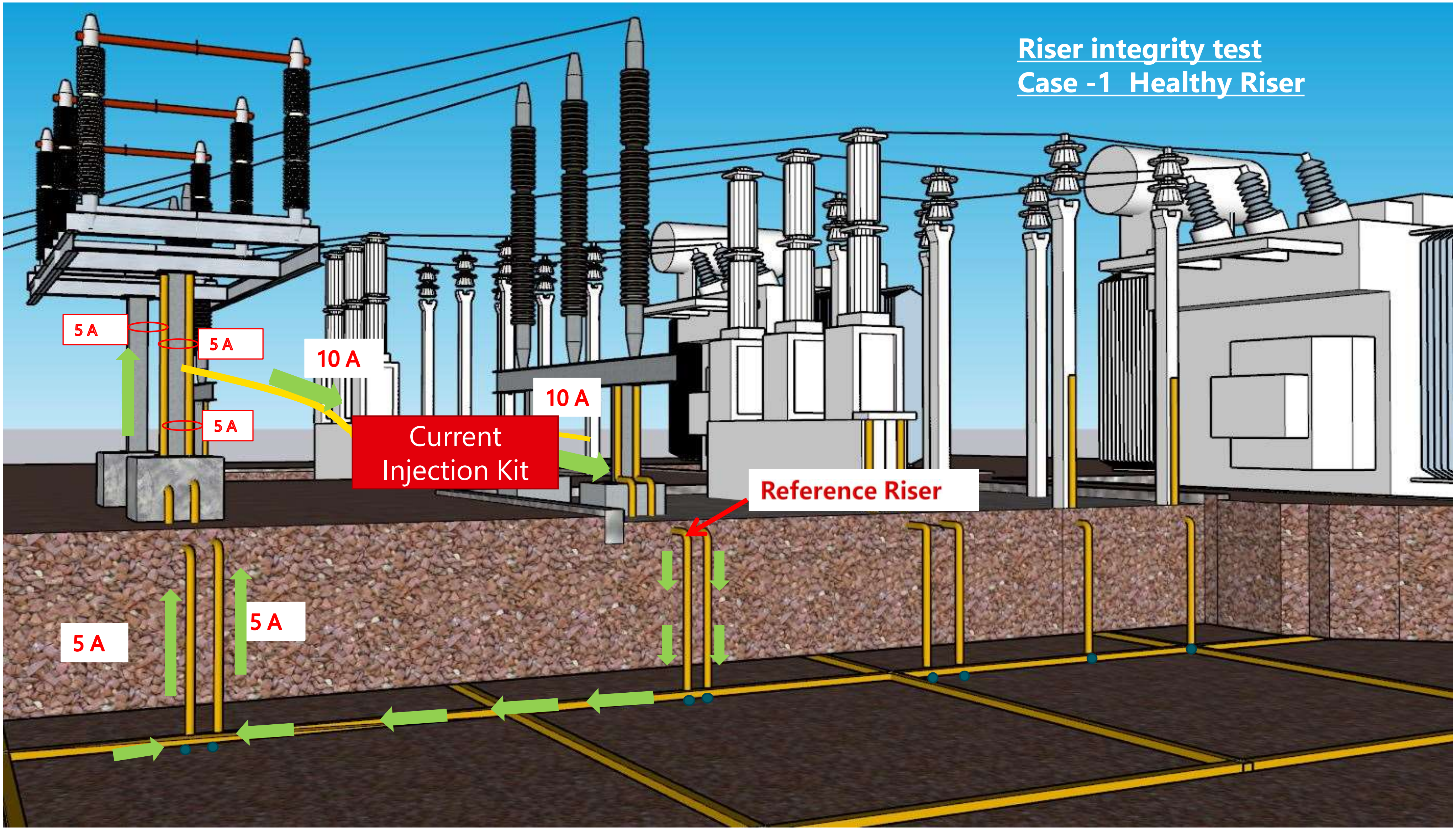
"People often assume that any grounded object can be safely touched. A low earth grid resistance is not, in itself, a guarantee of safety. There is no simple relation between the resistance of earthing system as a whole and the maximum shock current to which a person might by exposed. Therefore, a substation relatively low earth resistance may be dangerous, while another substation with very high resistance may be less dangerous or can be made less dangerous by careful design".

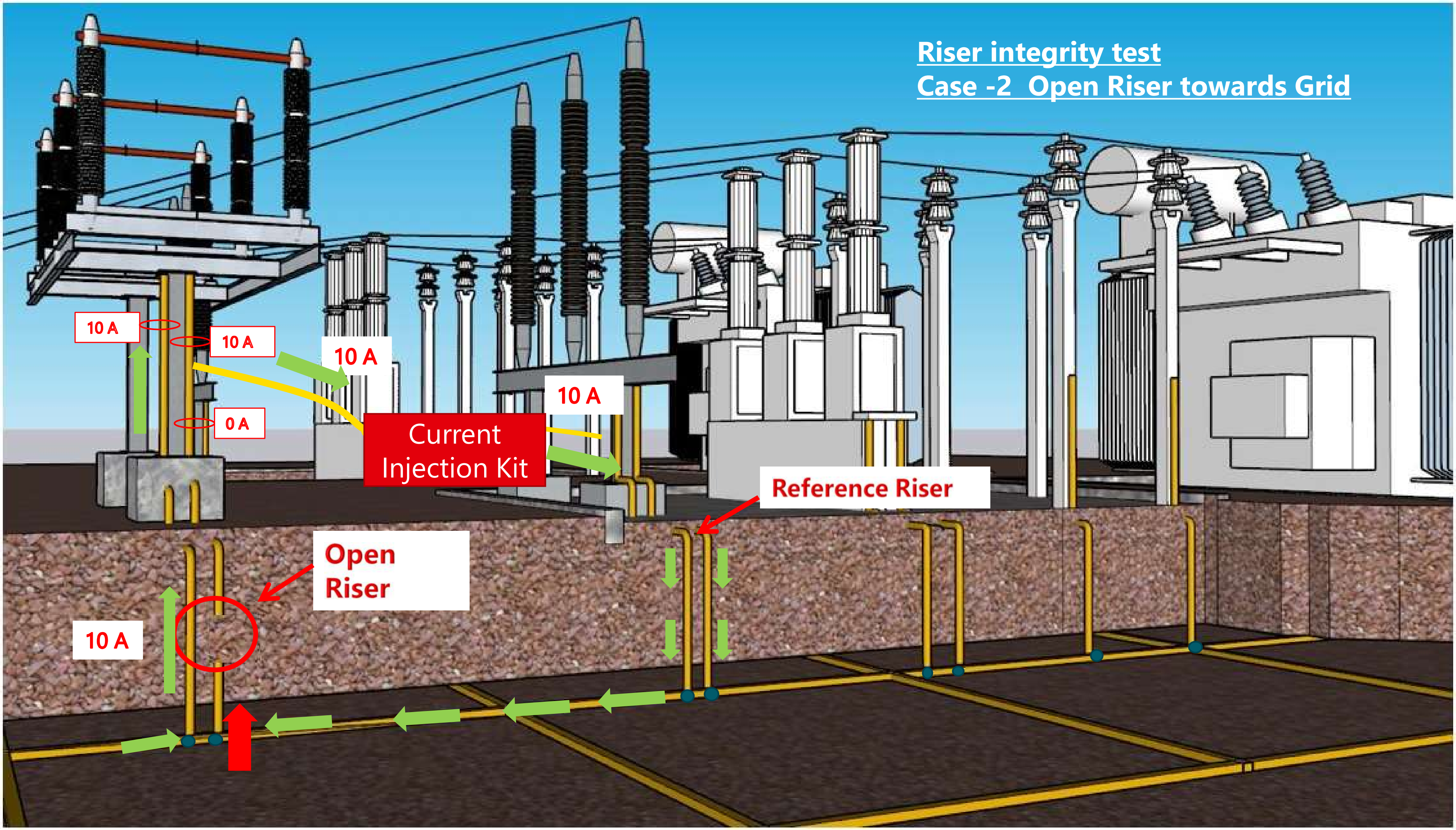
Extract from IEEE 80 2013 – Clause 14.1 – Earlier Stipulation Removed.

~~A good grounding system provides a low resistance to remote earth in order to minimize the GPR. For most transmission and other large substations, the ground resistance is usually about 1 Ohm or less. In smaller distribution substations, the usually acceptable range is from 1 Ohm to 5 Ohms depending on the local conditions.~~


Need of Earthing system assessment
Risers
Earth Mat
Earth Pit
Risers
Risers
0.98 ohms Earth Resistance
Low Earth station Resistance ≠ Safety
Low Earth Loop Impedance = Breaker Tripping on time= Safety


Risers
How do we know?
Earth Mat
Earth Pit
Open Risers
Loose
Connection
0.98 ohms Earth
Resistance


Riser integrity test
Case -1 Healthy Riser
5 A
5 A
10 A
10 A
5 A
Current Injection Kit
Reference Riser
5 A
5 A



Riser integrity test
Case -2 Open Riser towards Grid
10 A
10 A
10 A
10 A
0 A
Current Injection Kit
Reference Riser
Open Riser
10 A

Recommended tests on Earthing system

Earthing Health Assessment	Recommended tests as per IEEE 81-2012
Soil Resistivity	✓
Electrode Resistance	✓
Grid Resistance	✓
Riser Integrity	✓
Pin Point the Faulty Riser (Above Ground)	✓
Pin Point the Faulty Riser (Below Ground)	✓
Discontinuity in Grid Connections (Grid Integrity)	✓
Touch and Step Potential Measurement (Safety of Personnel & Equipment)	✓
Effect of Corrosion	✓
Earth loop impedance and prospective fault current	✓

Transformer failure due to Grounding integrity issues

- SGT-01, 500MVA, 380/132kV Transformer in GIS Substation caught fire after energization and in service for a period of 6 hours. Transformer caught fire due to failed timely operation of the protection device.
- Grounding grid assessment audit was carried out at N-Grid 9008 substation.

Reference standards:

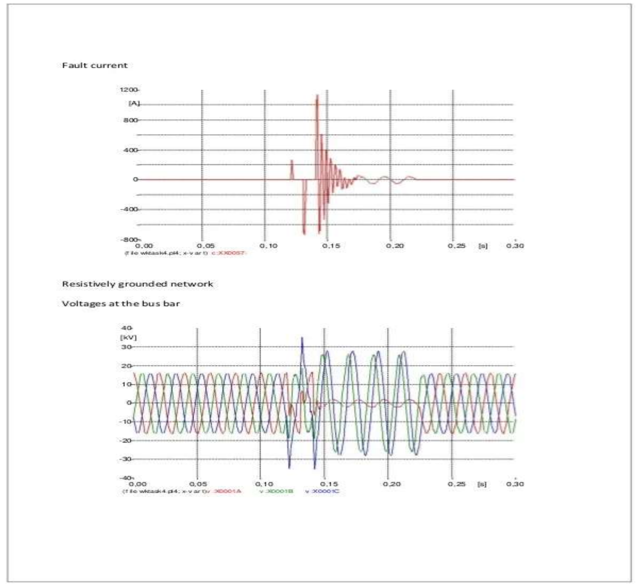
- BS 7430 – 2011 – Code or Practice for Protective Earthing of Electrical Installations.
- IEEE 81 -2012 – IEEE Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of Ground Systems.
- IEEE 80 - 2013 - IEEE Guide for Safety in AC Substation

Activities:

- Soil resistivity test
- Earth pit resistance measurement
- Riser integrity test
- Grid integrity
- Measurement of touch and step potentials

Probable sequence of events for fire and transformer failure

1. GIS feeding the transformer generates **very fast transients(VFT)** during its normal operating which is known to cause higher voltages to occur.
2. **Intermittent over voltages(Arcing ground)** are built up due to transients on weakest point(Cable terminations or winding) ➔ Magnified due to neutral grounding weekly bonded ➔ Low intensity faults develops ➔ Transformer body connection is open; the differential protection will not operate ➔ Low intensity fault cumulatively releases enough energy causes heating of oil.
3. Since the fault is not cleared, heating of oil continuous in porcelain housing and pressure builds up continuously.
4. Fire was originated in the oil filled cable termination as per internal investigation by utility, Due to high pressure, oil is spilled outside porcelain housing and hence led to the fire.
5. After bursting and fusing of cable termination, There is now better connection to ground and high flow of current causes differential relay to trip after cable termination ruptured and fire occurred.



Earth Riser	Direction	Injection(A)	Current split(A)	Observation
Neutral	To Equip.	4	3.9	Condition OK
	To Grid		0.1	Open
Trafo Body	To Equip.	4	3.2	Condition OK
	To Grid		0.9	Weak bonding

Grounding assessment and study in 500MW Thermal power station

- In the upgraded coal feeder system, Since the installation of new system, self rebooting of process controller card by itself in the middle of the process operation without any event of power failure or other commands which is incurring a huge Revenue loss of power production to the customer.
- Electromagnetic interference could be one of the causes for this problem.
- Study of installation aspects at site including earthing/bonding and cabling system in line with the requirements specified in IEC 61000-5-2 & GP 12-65.
- The concept of earthing of cable shield to adequately protect the equipment from the interference and signals are not inadvertently coupled into signal circuits as per GP 12-65.
- Cable armour of multicore cables to be earthed at both ends and earthing is to be done through cable glands in line with IEC 61000-5-2 and GP 12-65.

5.3. Effects of electromagnetic interference

a. By their nature, electrical/electronic instrumentation and control systems are susceptible to electromagnetic interference. Sensitive circuits are employed which operate at low energy values. Without protection this could lead to the mal-operation, malfunction or damage of individual components and complete systems. Typical effects might be: Corrupted outputs from thermocouples, amplifiers, spurious operation of trip amplifiers, corrupted signal levels from transmitters, apparent software faults of microprocessor based equipment and disturbance to the stabilised outputs of dc power supplies. Such faults may lead to serious consequences if Category 1 or 2A plant protective control equipment is affected.

FIGURE-1: SNAPSHOT FROM GP 12-65, CL. 5.3

61000-5-2 © IEC:1997(E) – 15 –

In the past, the power system fault current was generally used to define the earthing system (Kouteynikoff, 1980 [1]; Kuussaari, 1978 [2]; Lu, 1980 [3])[1]. An unfortunate consequence of this situation is the fact that the resistance of this path became the usual criterion. This approach may still be correct for phenomena with a typical frequency of 50 Hz or 60 Hz but is certainly inappropriate for high-frequency aspects, where the inductive phenomena along the path may be predominant. Today, it would be better to characterize the earthing system by its impedance.

5.2 Requirements concerning EMC

The secondary goal of an earthing system is to serve as a common voltage reference and to contribute to the mitigation of disturbances in installations with sensitive and interconnected electronic and electrical systems.

FIGURE-2: SNAPSHOT FROM IEC 61000-5-2, CL.5.2

- Bonding connections shall be provided for the exposed metallic parts as per IEC 61000-5-2.

Site observations

- PE bar of remote power cabinet(RPC) located at control room is not earthed with the plant earthing system.

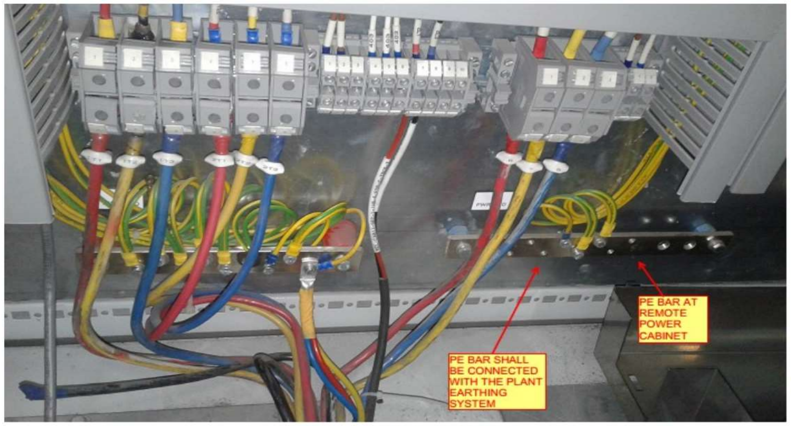


FIGURE-4: PE BAR EARTHING AT REMOTE POWER CABINET IS MISSING

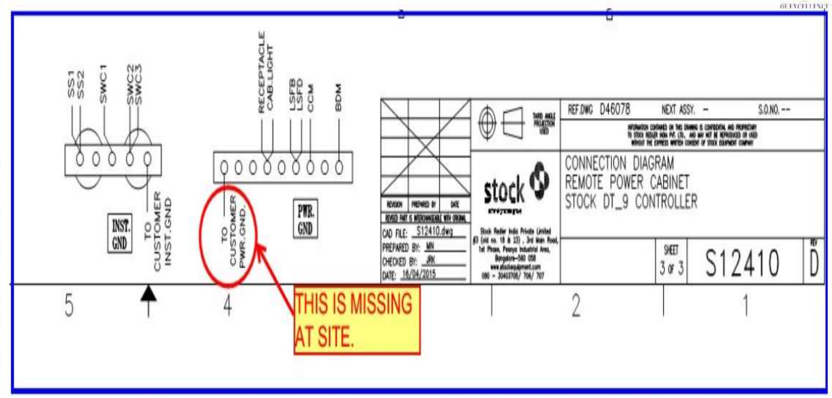


FIGURE-5: REQUIREMENT OF PE BAR EARTHING AT REMOTE POWER CABINET

- Cable enter into the remote power cabinet through cable glands at the bottom. Cable armour earthing is to be carried out through cable glands.

- Signal grounding is found to be in contact with the power system earthing inside the panel.

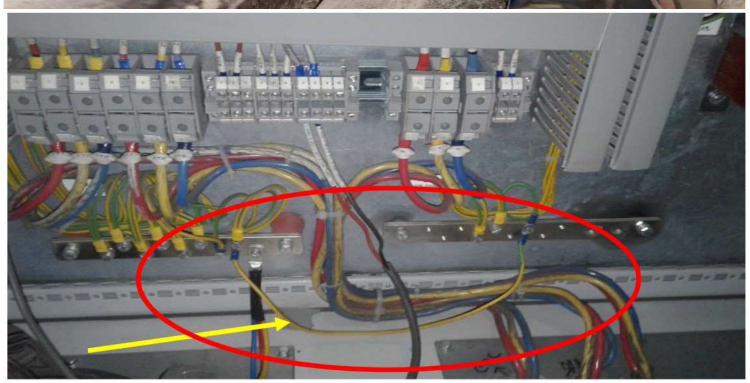


FIGURE-7: LOOPING OF PE BAR & IE BAR TO BE REMOVED

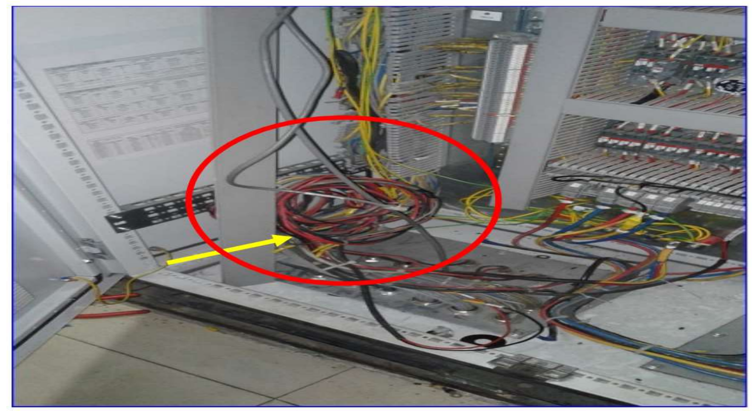


FIGURE-8: BUNDLE OF CABLE IN PANEL TO BE REMOVED

- Bundle of unused cables inside the panel to be removed inside the panel.

Site observations

- PE bar and IE bar inside the cabinet are earthed with the plant Power earthing system & Instrument earthing system respectively.
- Earth connection for the enclosure of the same feeder is found missing.

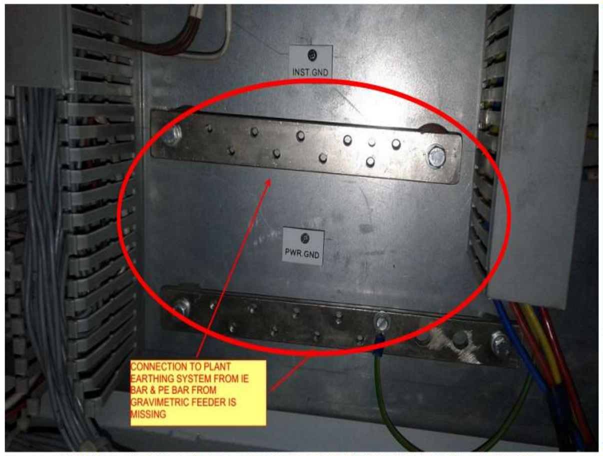


FIGURE-9: PE BAR & IE BAR EARTHING AT GRAVIMETRIC FEEDER IS MISSING

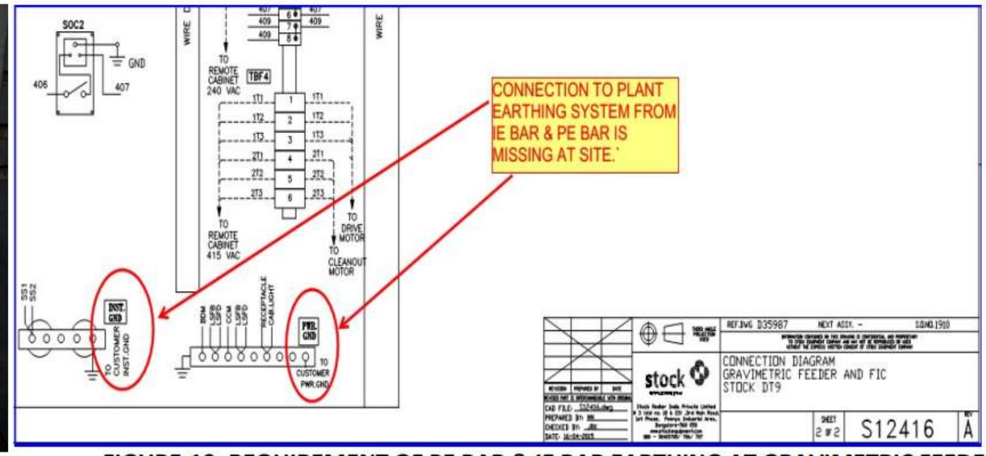


FIGURE-10: REQUIREMENT OF PE BAR & IE BAR EARTHING AT GRAVIMETRIC FEEDER

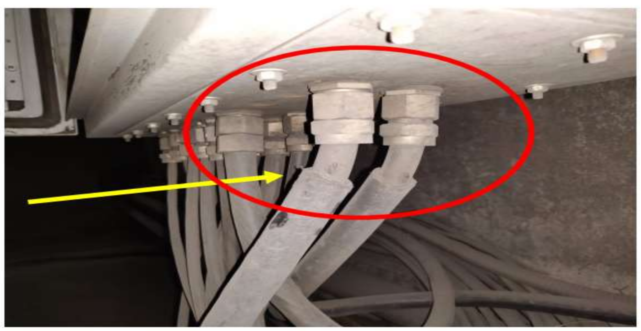


FIGURE-11: CABLE GLAND EARTHING IS MISSING AT GRAVIMETRIC FEEDER

- Cable enter into the feeder through glands where cable armour earthing is found to be missing & armour earthing to be carried out thorough cable gland.

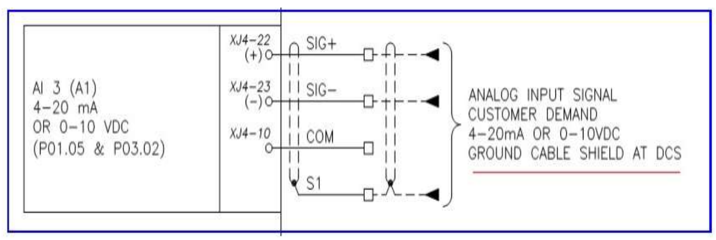
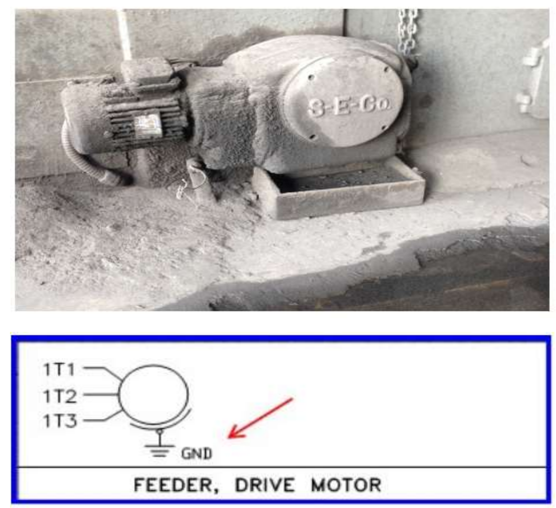


FIGURE-12: SHIELD EARTHING REQUIREMENT AT DCS END

- Input signal cables from remote power cabinet to DCS, it is observed that the shield earthing is not done at DCS end.

FIGURE-13: EARTHING REQUIREMENT OF DRIVE MOTOR



- Earthing connection for drive motor is missing.

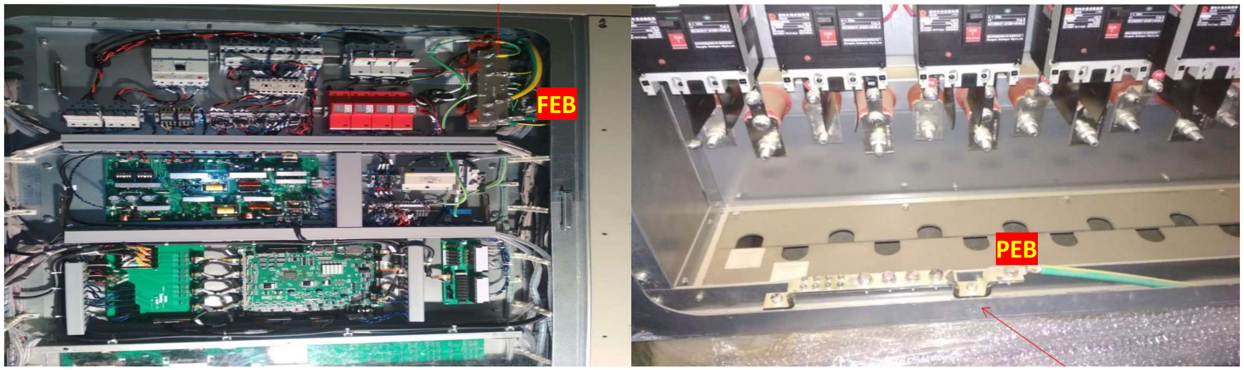
Root cause for inverter failure at Solar site

Tests and measurements:

- Earth electrode resistance test.
- Continuity resistance test.
- Verify equipotential bonding and connections.
- Transfer potential analysis.

Finding and Analysis:

- AC & DC Earth grids are not interconnected.
- Earth electrodes for electronics earthing not connected with AC Earthing grid.
- Substation earthing is not interconnected to the Gantry earthing.
- Gantry earthing is not connected with ICR Earthing grid.
- ICR Earthing grid is not burried.
- HT Cable tray earthing is not completed from ICR to Gantry.
- FE bus & PE bus is interconnected inside inverter



FE bus and PE bus is interconnected inside inverter.

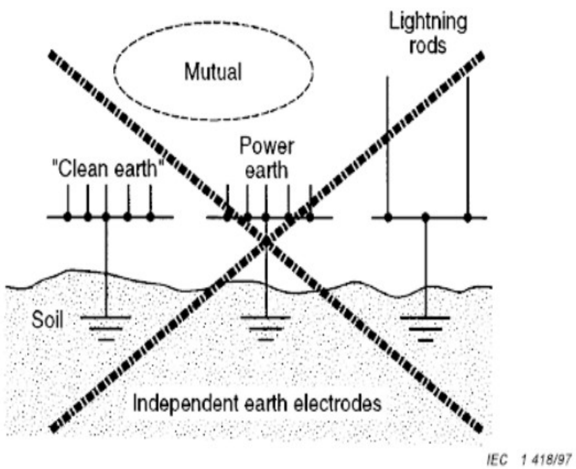
Earthing strip for the gantry and for the AC grid laid above ground.

All the inverter Earthing risers are connected to the single earth electrodes.

Individual earth electrode resistance at various locations ranges from 57.5 ohms to 216 ohms.

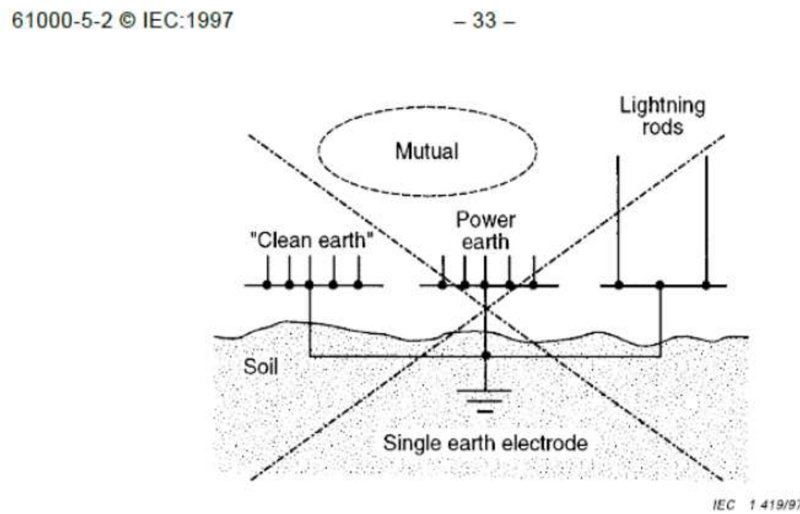
SRT values varies from 483 ohm-meter to 1450 ohm-meter, ERT values within limit of BS calculation.

Wrong practice of "dedicated", "independent", or isolated earth electrodes as per IEC 61000-5-2 Cl. No. 5.3.1.



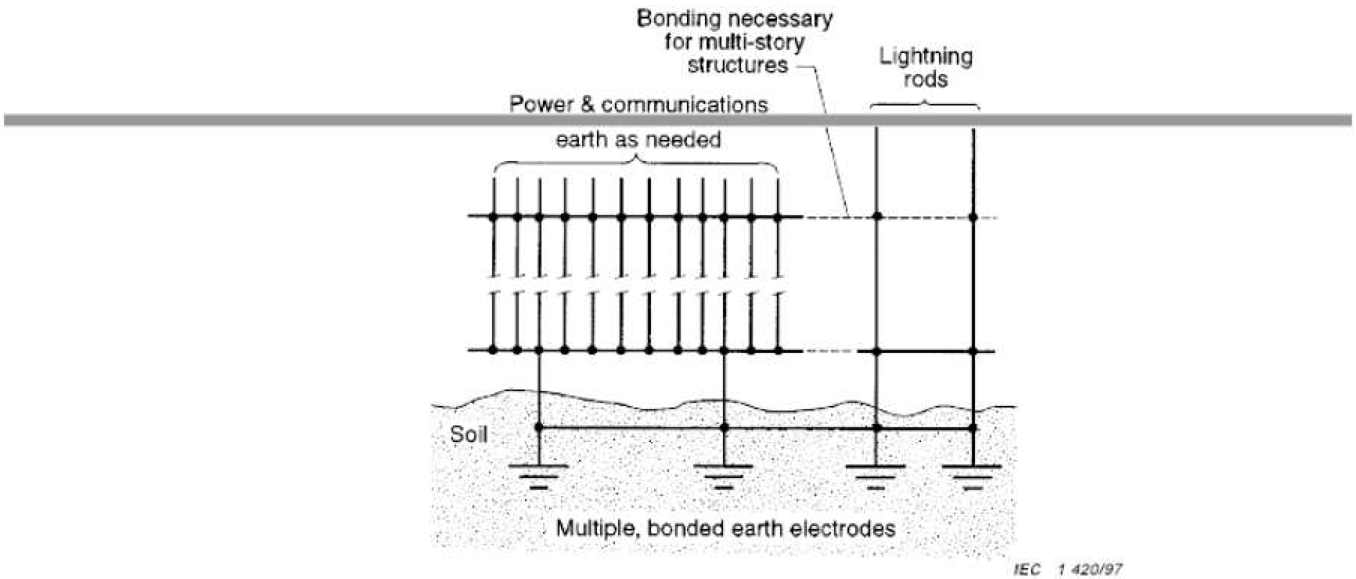
- Use of independent, "Isolated" earth electrodes for computer or electronic system is not recommended.
- Always links by the soil or by parasitic elements(Capacitance and mutual inductances) in the installation.
- In case of lightning or power system fault, dangerous transient voltage can occur.

Wrong practice of single earth electrode system as per IEC 61000-5-2 cl.no. 5.3.1.



- This arrangement is not Suitable for high frequency EMC concerns.
- It is not possible to attend desired resistance with a single earth electrode in all soil condition.

Recommended configuration for the earth electrodes and earthing network



NOTE – This two-dimensional conceptual representation, similar in format to figures 3 and 4, is actually a three-dimensional network, as shown in figure 7. It is the recommended approach in the general case, for safety as well as for EMC. As noted for figure 4, this recommendation does not exclude other, well-demonstrated and well-maintained special configurations.

Figure 5 – Recommended configuration for the earth electrodes and earthing network

- It is the recommended approach in the general case, for safety as well as for EMC.

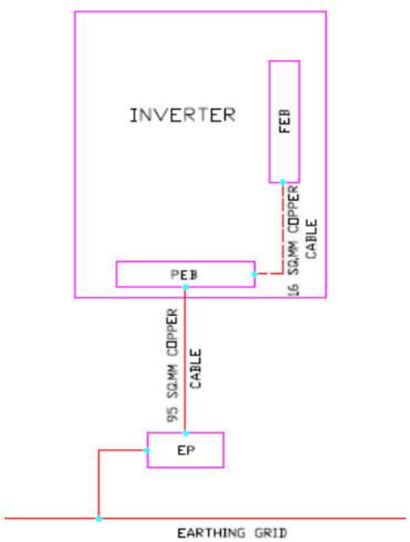
Electronics equipment earthing in power station

- Single point earthing system.

Suggested earthing system for inverters which is operating below 300kHz frequency

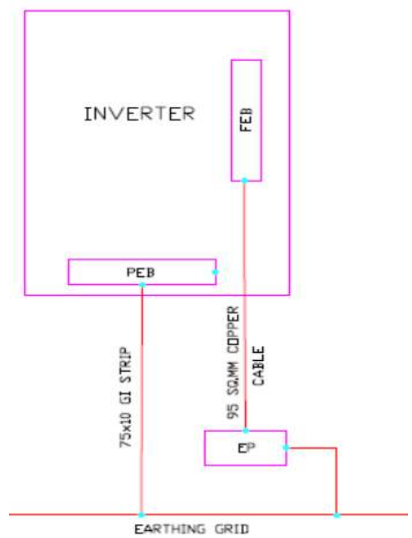
DEHN

Existing inverter earthing arrangement

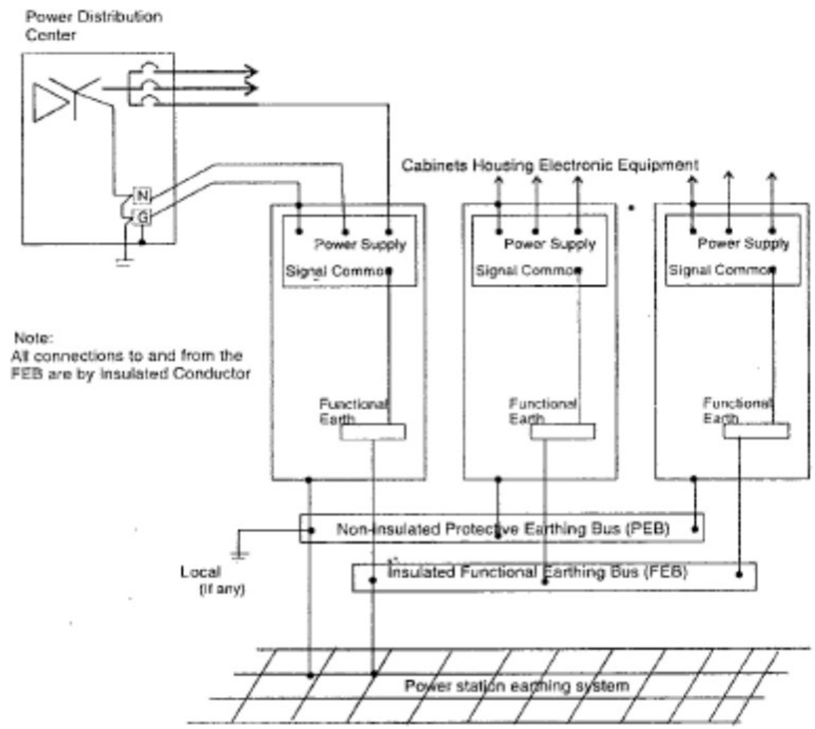


FE & PE bus are interconnected inside the cabinet.

Proposed inverter earthing arrangement



FE & PE are separated inside the cabinet.



Proper FE stabilizes circuit reference potential, protects the circuit against static charge and over voltage and minimizes interference from unwanted noise.

Limiting transferred earth potential

Extracts from IEEE-142 – 2007 on transfer potential

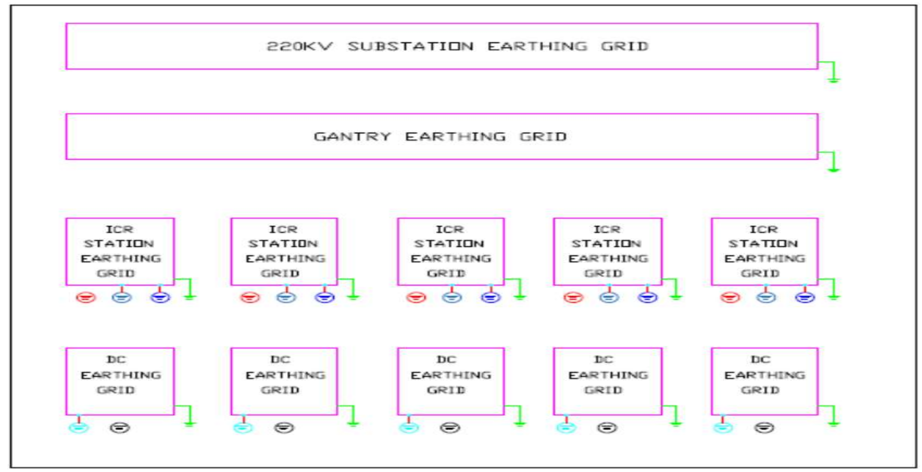
<u>Transferred earth potential is</u>

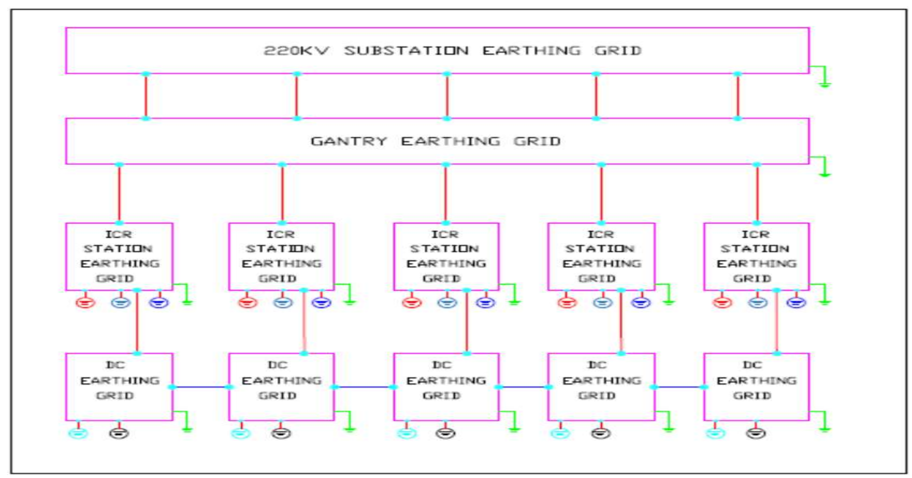
- The Voltage to earth of grounding systems that will appear on conductors as a result of the source system grounding electrode being above normal earth potential.

- The larger voltages are developed by the ground fault current returning to their source through earth.

<u>Example</u> – If the grounding of secondary transformer neutral is not connected to the high voltage source system ground, there can be a significant voltage rise above earth as the fault current flows into the earth.

Low voltage leaving the area where ground voltage has been affected will have that voltage added to the nominal voltage and may exceed insulating rating of the conductor or equipment connected.



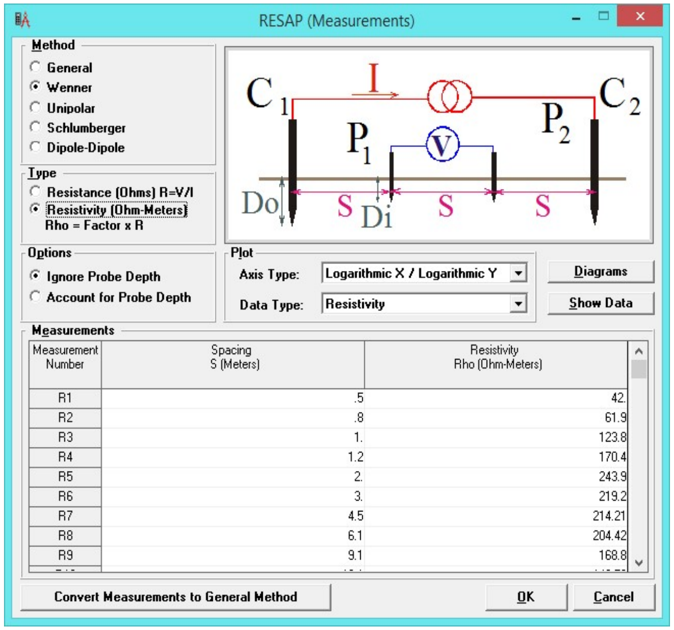


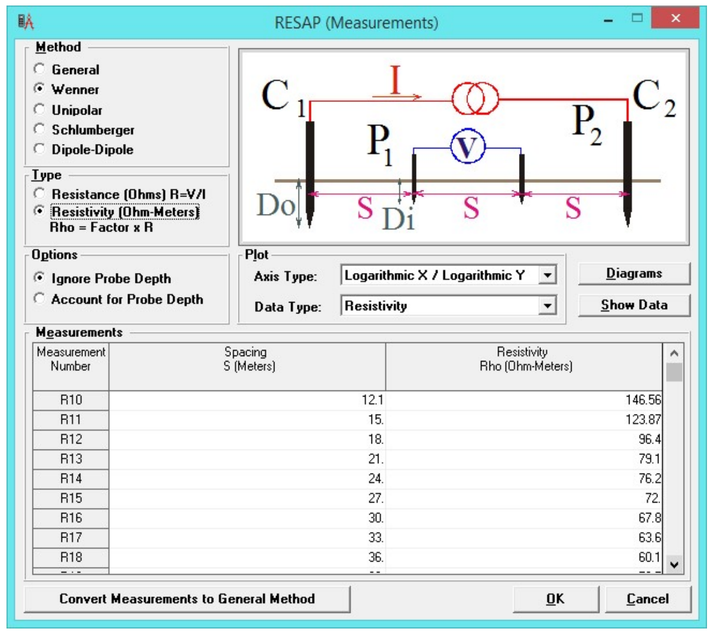
CDEGS – Multilayer soil modeling & simulation for Safety criteria

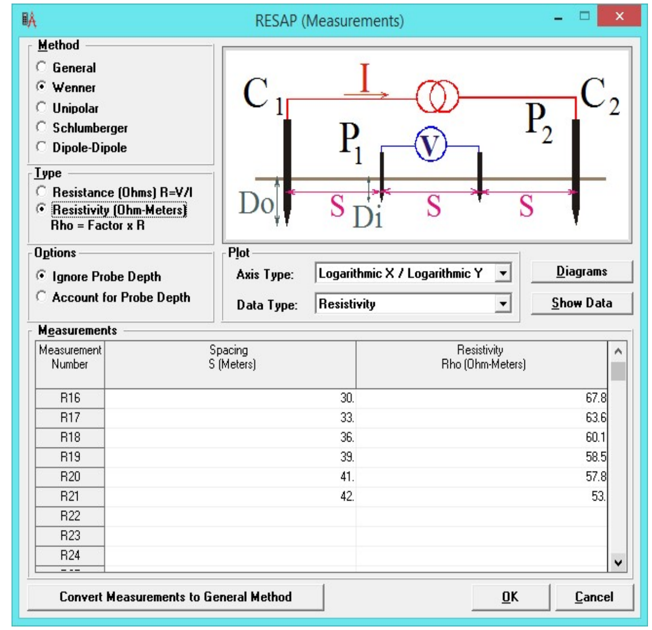
Soil resistivity measurement by 4-point wenner method

SL NO	Spike spacing	LOCATION-1		LOCATION-2		LOCATION-3		LOCATION-4		Mean Soil Resistivity
		N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	
1	0.5	48.04	44.59	44.59	37.99	37.24	49.83	47.82	25.91	42
2	0.8	89.88	78.78	78.78	73.3	77.42	27.93	35.07	34.06	61.9
3	1	133.89	126.48	126.48	116.18	112.91	124.41	123.4	126.67	123.8
4	1.2	169.56	162.78	162.78	163.15	192.92	179.36	177.4	155.24	170.4
5	2	246.8	242.41	242.41	224.82	213.27	265.9	278.2	237.38	243.9
6	3	236.63	198.57	198.57	224.01	247.37	198.2	232.86	217.41	219.2
7	4.5	241.62	194.43	194.43	222.12	230.88	252.64	219.3	158.26	214.21
8	6.1	174.68	216.44	216.44	250.53	162.04	215.67	176.98	222.57	204.42
9	9.1	146.3	145.16	145.16	202.88	166.87	199.45	203.45	141.16	168.8
10	12.1	118.54	93.47	93.47	127.66	131.46	247.72	193.77	166.41	146.56
11	15	109.27	121.52	121.52	102.68	108.33	110.21	201.59	115.87	123.87
12	18	110.23	105.89	88.23	89.42	105.53	85.65	89.78	110.48	96.4
13	21	68.89	73.87	79.87	76.58	88.78	76.68	77.58	80.4	79.1
14	24	75.68	73.23	79.47	89.54	72.27	75.65	75.23	72.58	76.2
15	27	85.19	80.69	81.65	0	61.59	75.13	60.1	59.81	72
16	30	67.98	68.78	56.85	65.87	78.65	71.94	61.85	65.79	67.8
17	33	63.24	65.25	68.23	65.45	50.56	69.85	65.32	63.25	63.6
18	36	56.58	0	47.89	55.13	60.11	68.28	70.24	0	60.1
19	39	56.23	58.98	63.56	57	59.89	55.47	55.97	0	58.5
20	41	57.89	58.69	53.84	57.69	61.85	59.68	52.68	59.14	57.8
21	42	52.69	49.87	45.89	43.85	58.41	59.25	54.89	58.96	53
										114.455

CDEGS-RESAP


RESAP (Measurements)
Method
General
Wenner
Unipolar
Schlumberger
Dipole-Dipole
Type
Resistance (Ohms) R=V/I
Resistivity (Ohm-Meters)
Rho = Factor x R
Options
Ignore Probe Depth
Account for Probe Depth
Plot
Axis Type: Logarithmic X / Logarithmic Y
Data Type: Resistivity
Diagrams
Show Data
Measurements
Measurement Number | Spacing S (Meters) | Resistivity Rho (Ohm-Meters)
R1 .5 42.
R2 .8 61.9
R3 1. 123.8
R4 1.2 170.4
R5 2. 243.9
R6 3. 219.2
R7 4.5 214.21
R8 6.1 204.42
R9 9.1 168.8
Convert Measurements to General Method
OK
Cancel


RESAP (Measurements)
Method
General
Wenner
Unipolar
Schlumberger
Dipole-Dipole
Type
Resistance (Ohms) R=V/I
Resistivity (Ohm-Meters)
Rho = Factor x R
Options
Ignore Probe Depth
Account for Probe Depth
Plot
Axis Type: Logarithmic X / Logarithmic Y
Data Type: Resistivity
Diagrams
Show Data
Measurements
Measurement Number | Spacing S (Meters) | Resistivity Rho (Ohm-Meters)
R10 12.1 146.56
R11 15. 123.87
R12 18. 96.4
R13 21. 79.1
R14 24. 76.2
R15 27. 72.
R16 30. 67.8
R17 33. 63.6
R18 36. 60.1
Convert Measurements to General Method
OK
Cancel


RESAP (Measurements)
Method
General
Wenner
Unipolar
Schlumberger
Dipole-Dipole
Type
Resistance (Ohms) R=V/I
Resistivity (Ohm-Meters)
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Ignore Probe Depth
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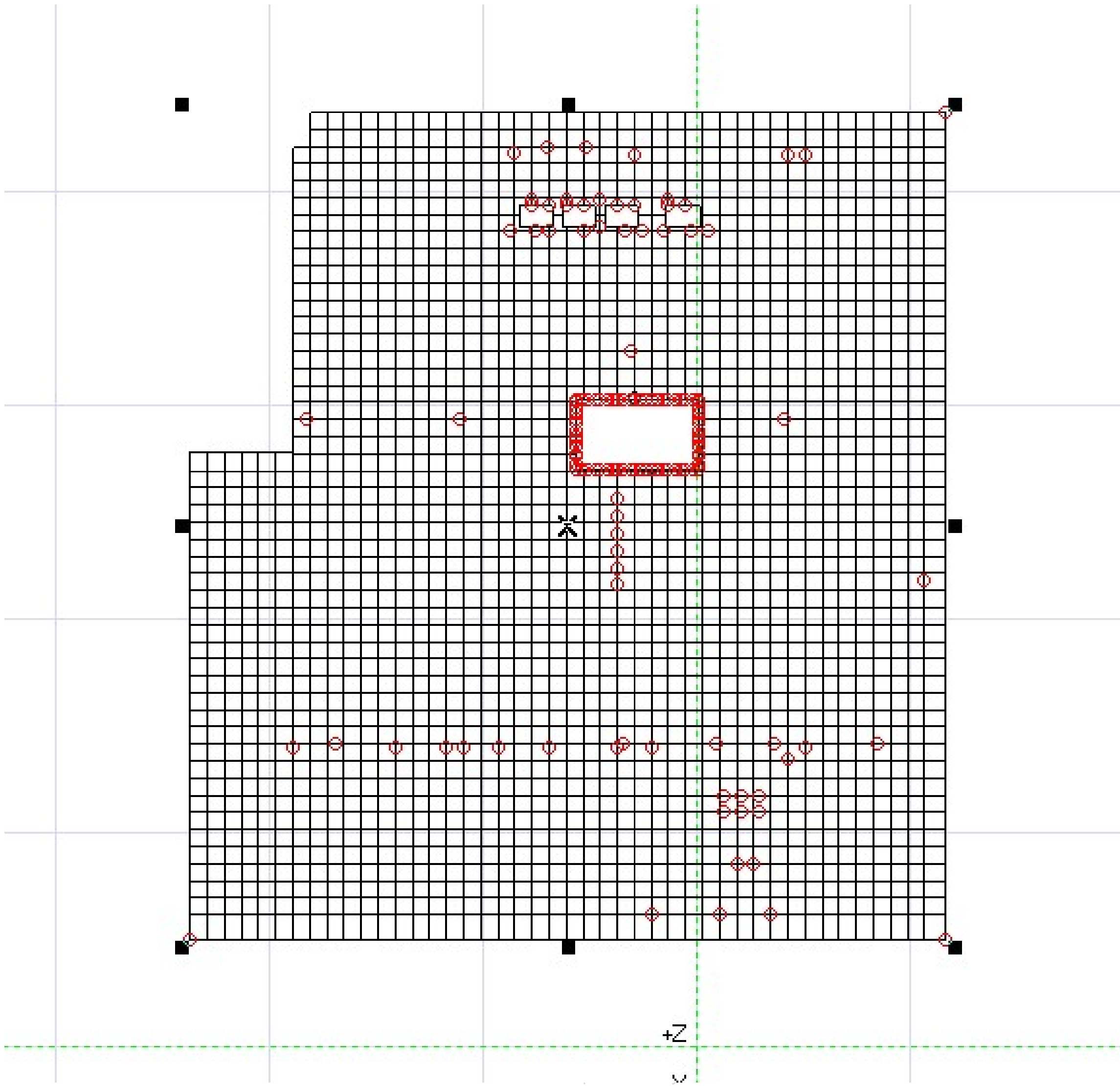
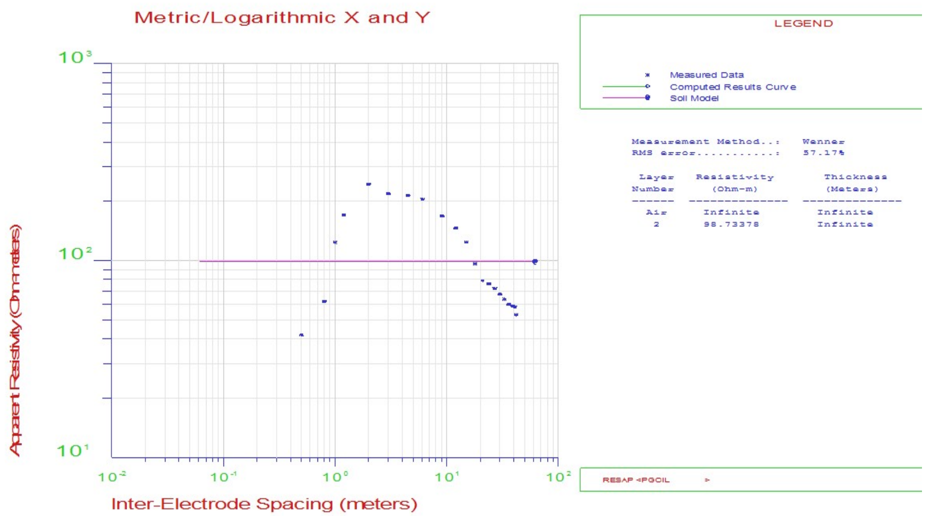
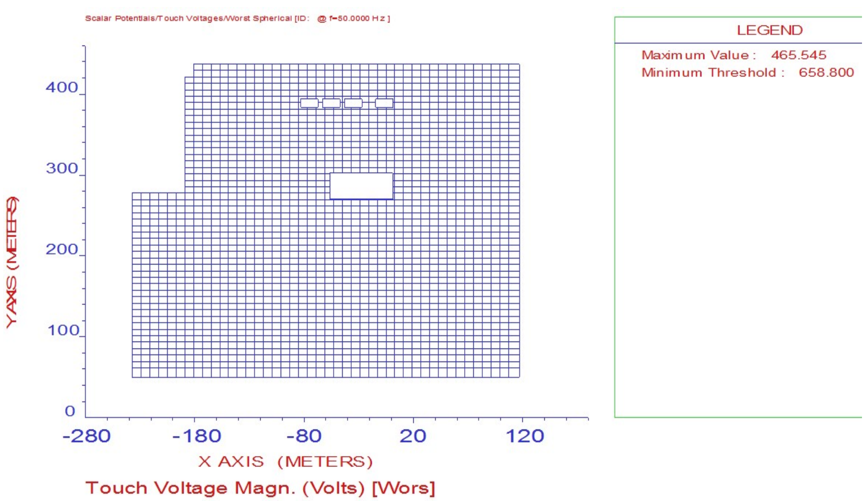
Plot
Axis Type: Logarithmic X / Logarithmic Y
Data Type: Resistivity
Diagrams
Show Data
Measurements
Measurement Number | Spacing S (Meters) | Resistivity Rho (Ohm-Meters)
R16 30. 67.8
R17 33. 63.6
R18 36. 60.1
R19 39. 58.5
R20 41. 57.8
R21 42. 53.
R22
R23
R24
Convert Measurements to General Method
OK
Cancel

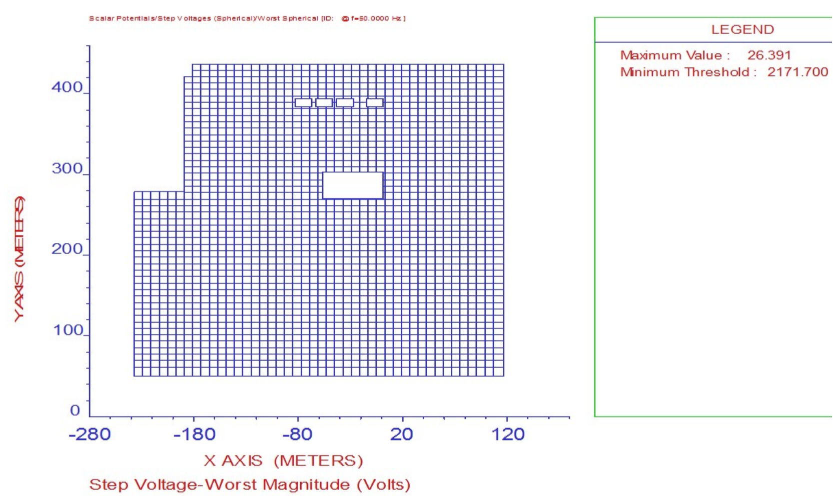
Earth Grid modeling



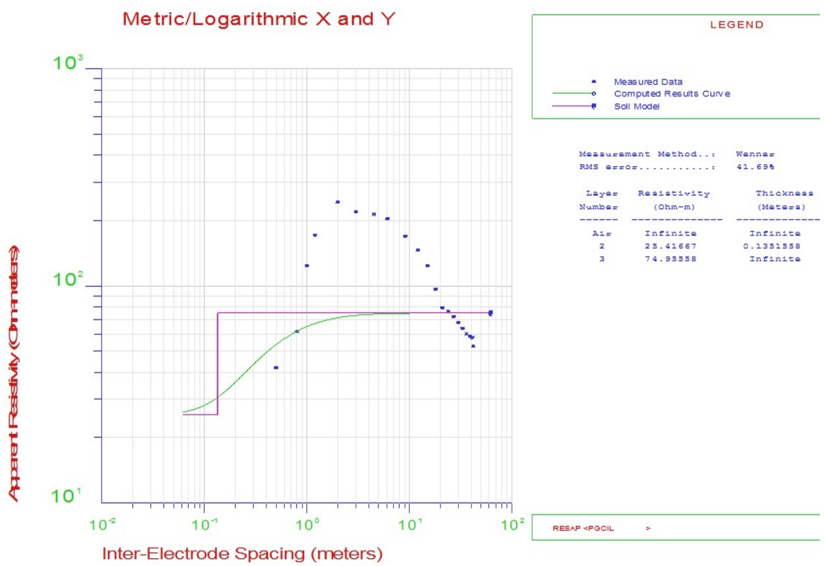
Uniform Soil modeling and safety criteria results

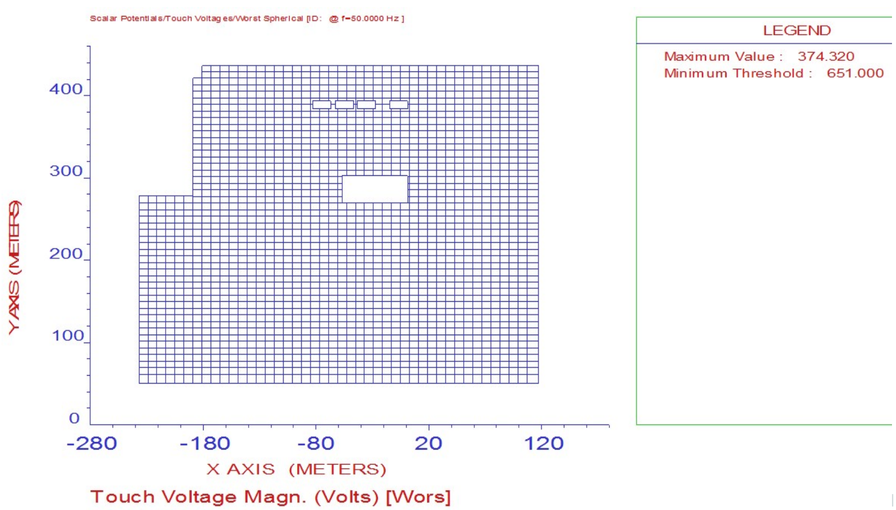


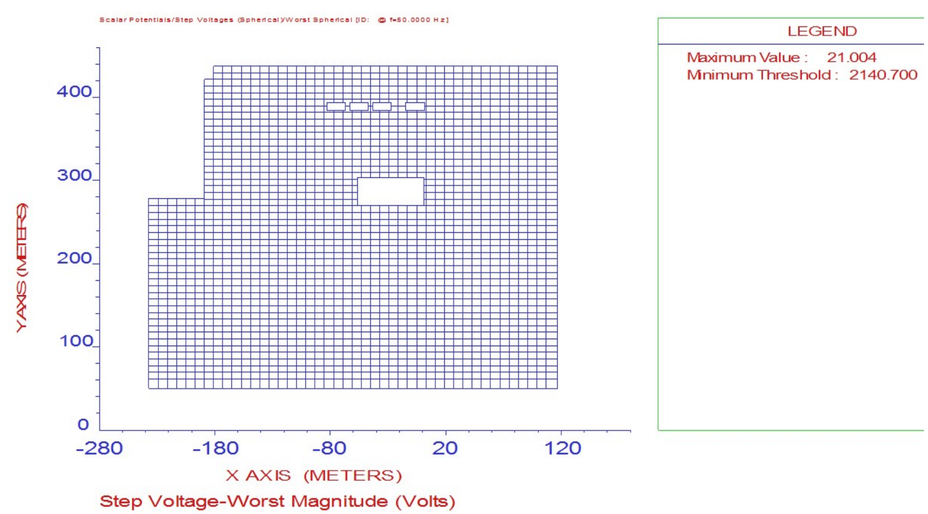




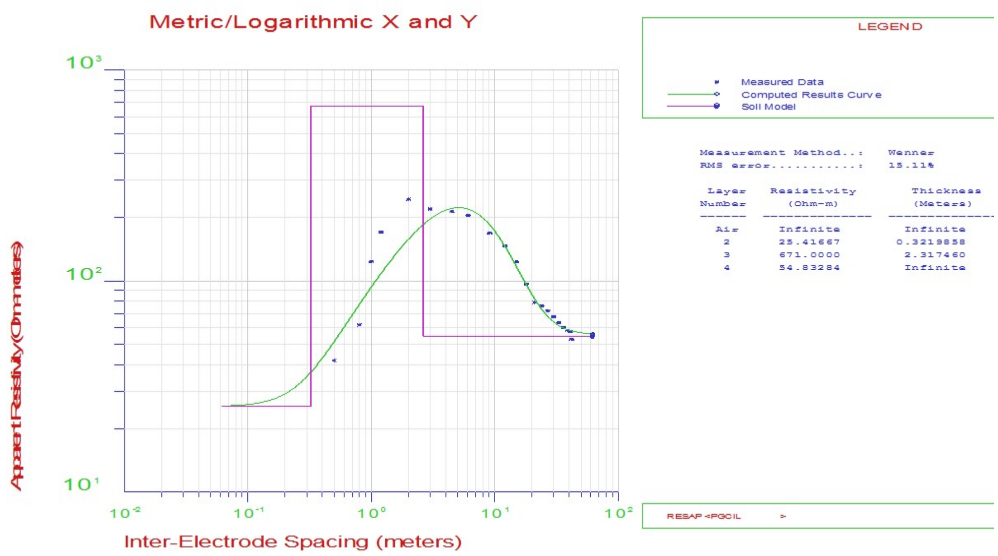
Two-layer Soil modeling and safety criteria results

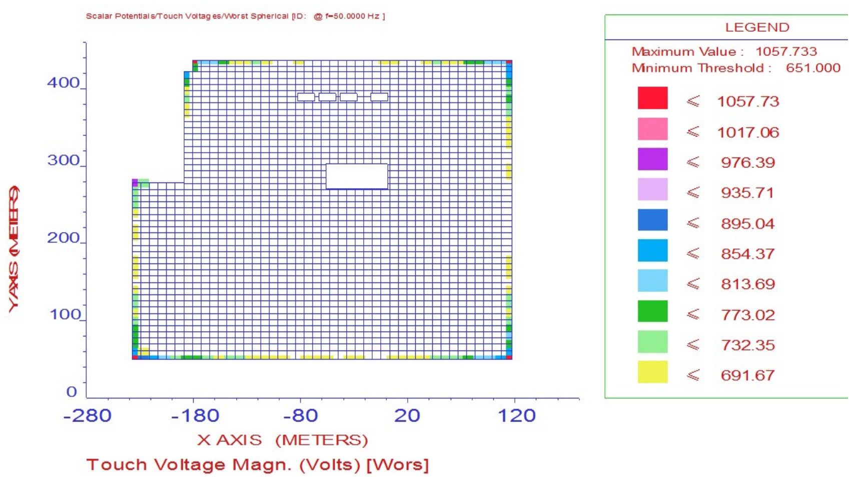


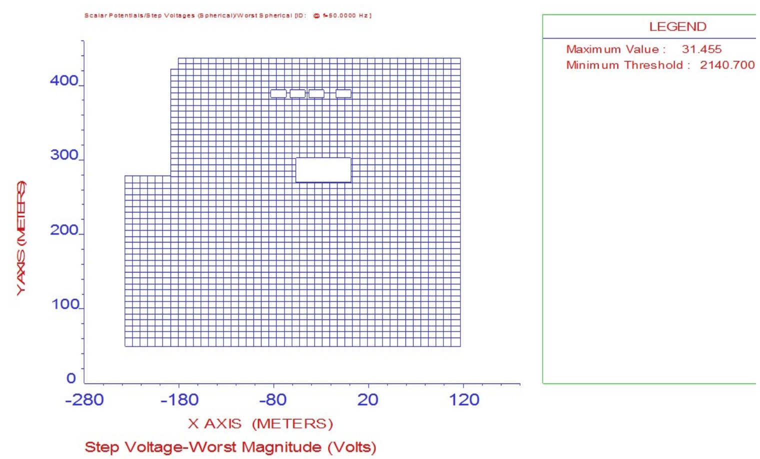




Three-layer Soil modeling and safety criteria results(Recommended by IEEE-80-2013)



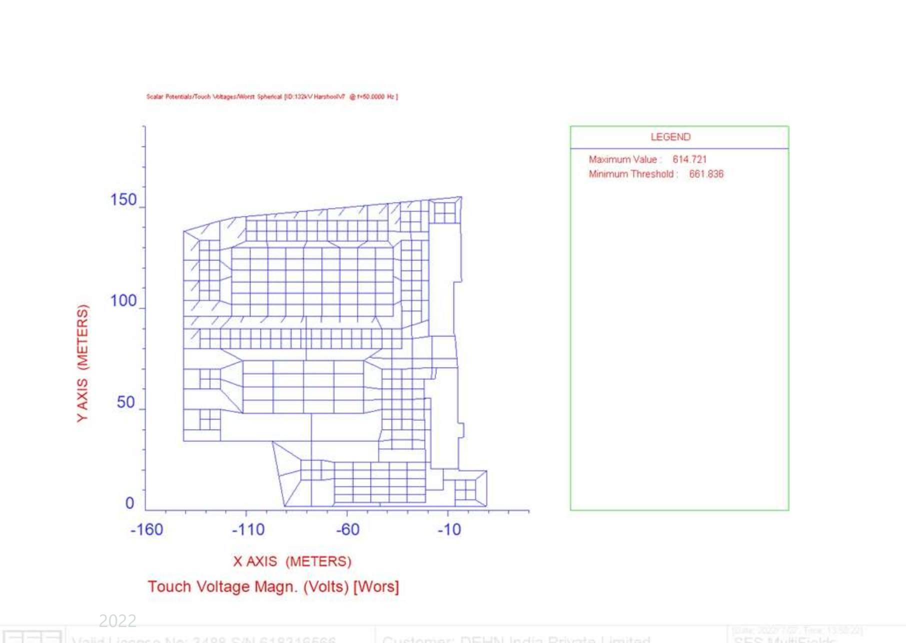


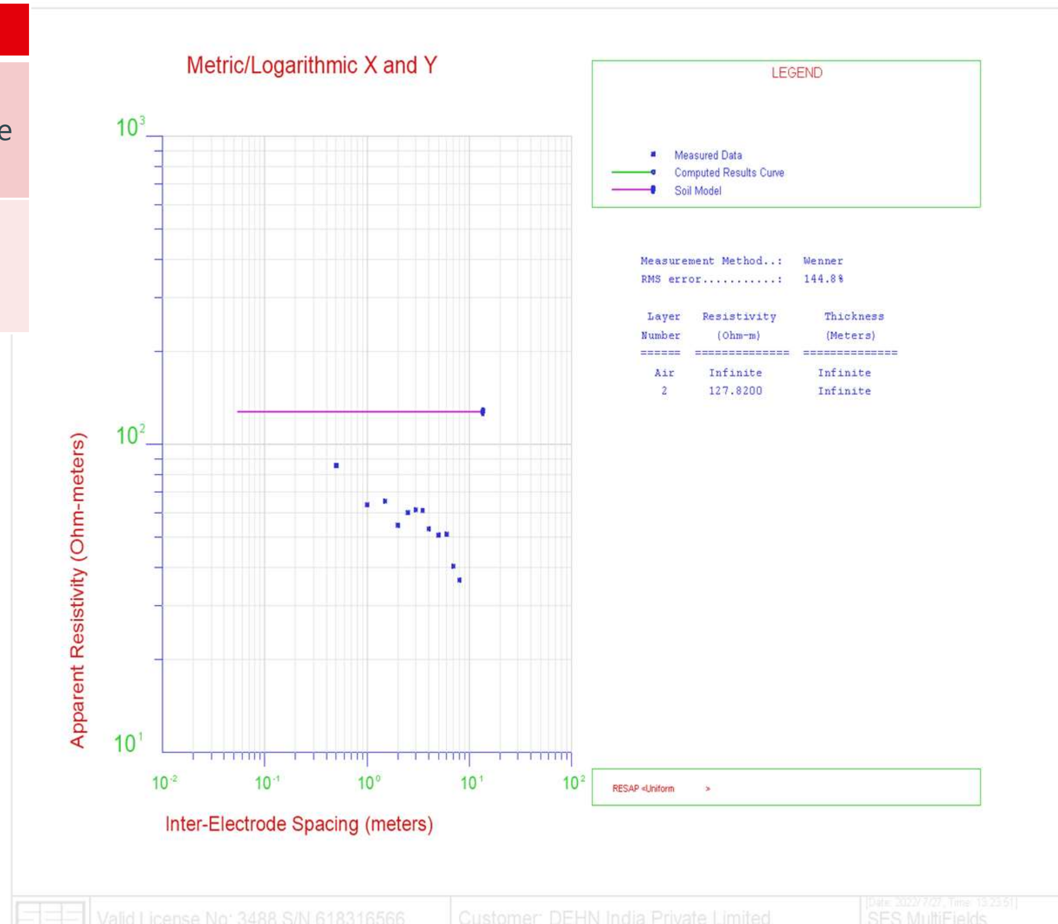


Sl No.	Parameter	Unit	Types of Soil				
			Uniform	Two Layer	Three Layer	Four Layer	Five Layer
1	RMS Error	%	57.10	41.69	15.11	14.94	14.84
2	Touch Voltage Safe Limit	Volts	650.50	650.50	650.50	650.50	650.50
3	Actual Touch Voltage	Volts	465.55	374.32	1,057.73	1,196.54	1,167.22
4	Step Voltage Safe Limit	Volts	2,138.60	2,138.60	2,138.60	2,138.60	2,138.60
5	Actual Step Voltage	Volts	26.39	21.00	31.46	30.68	31.27
6	Grid Impedance	Ohms	0.12	0.09	0.09	0.09	0.09

Uniform Soil Model with RMS Error of 144.84 % !

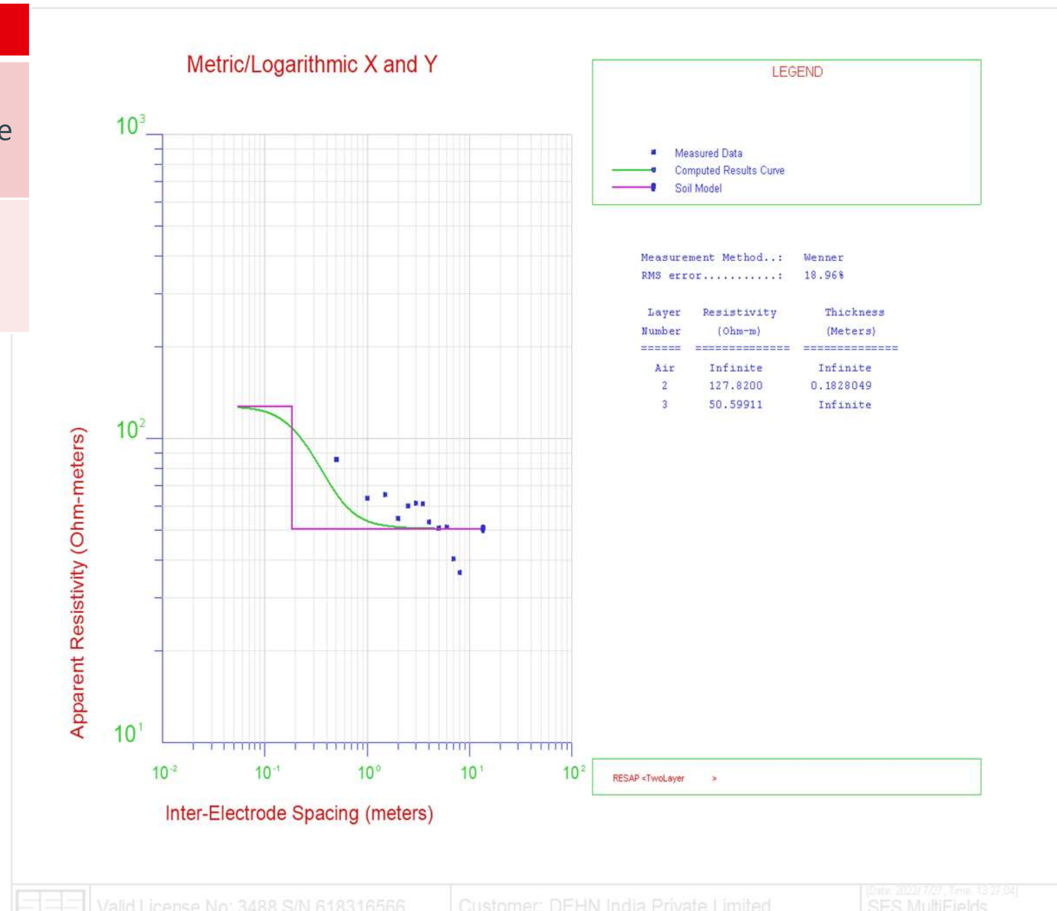
Area	Touch Voltage		Step Voltage	
	Safety Threshold (V)	Maximum Simulated Voltage (V)	Safety Threshold (V)	Maximum Simulated Voltage (V)
132kV EHV SS	661.836	614.721	2332.06	368.56





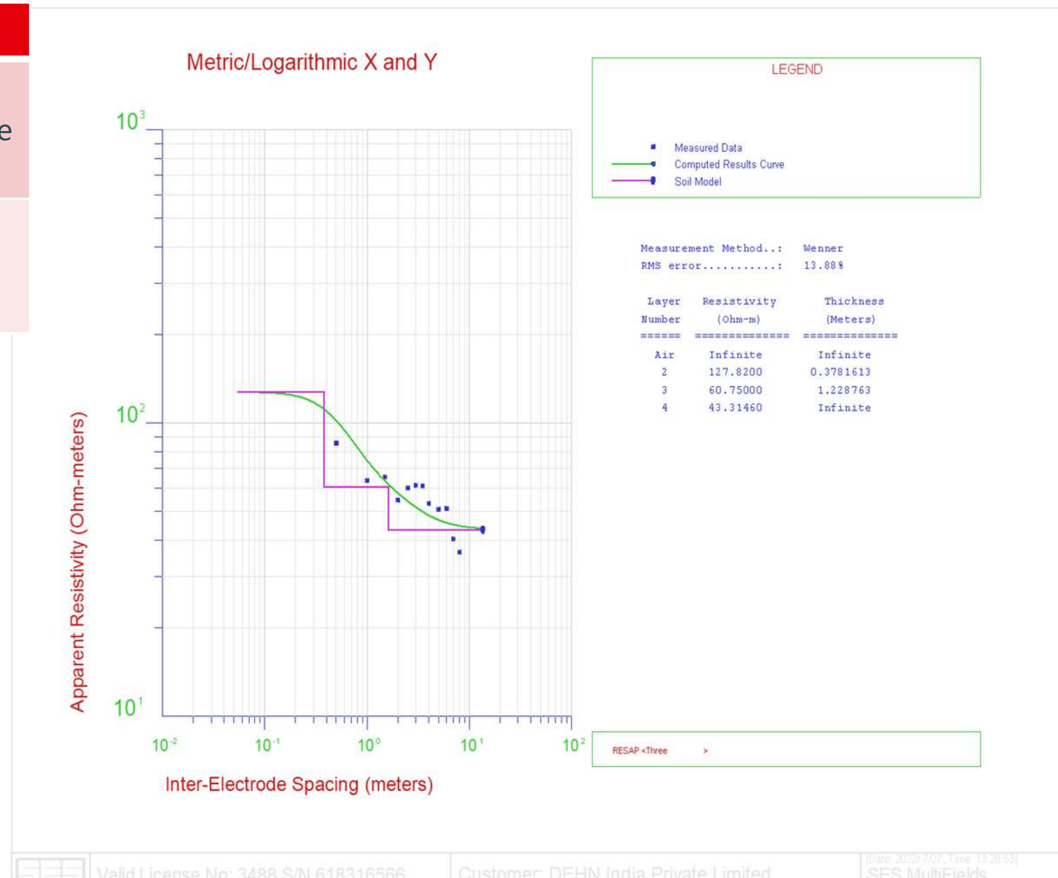
Two Layer Soil Model with RMS Error of 18.96 %

Area	Touch Voltage		Step Voltage	
	Safety Threshold (V)	Maximum Simulated Voltage (V)	Safety Threshold (V)	Maximum Simulated Voltage (V)
132kV EHV SS	661.836	617.821	2332.06	177.937



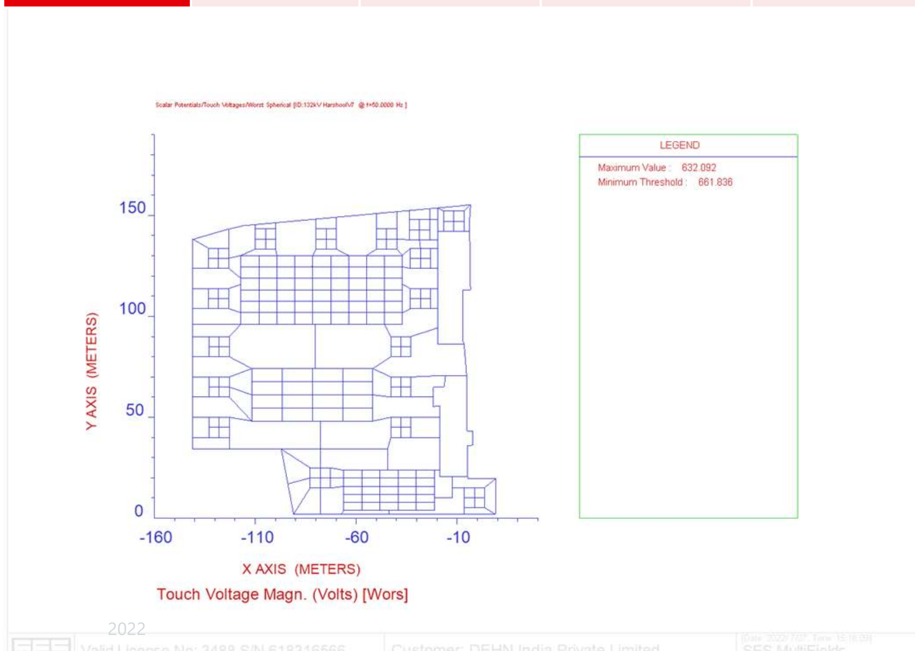
Three Layer Soil Model with RMS Error of 13.88 %

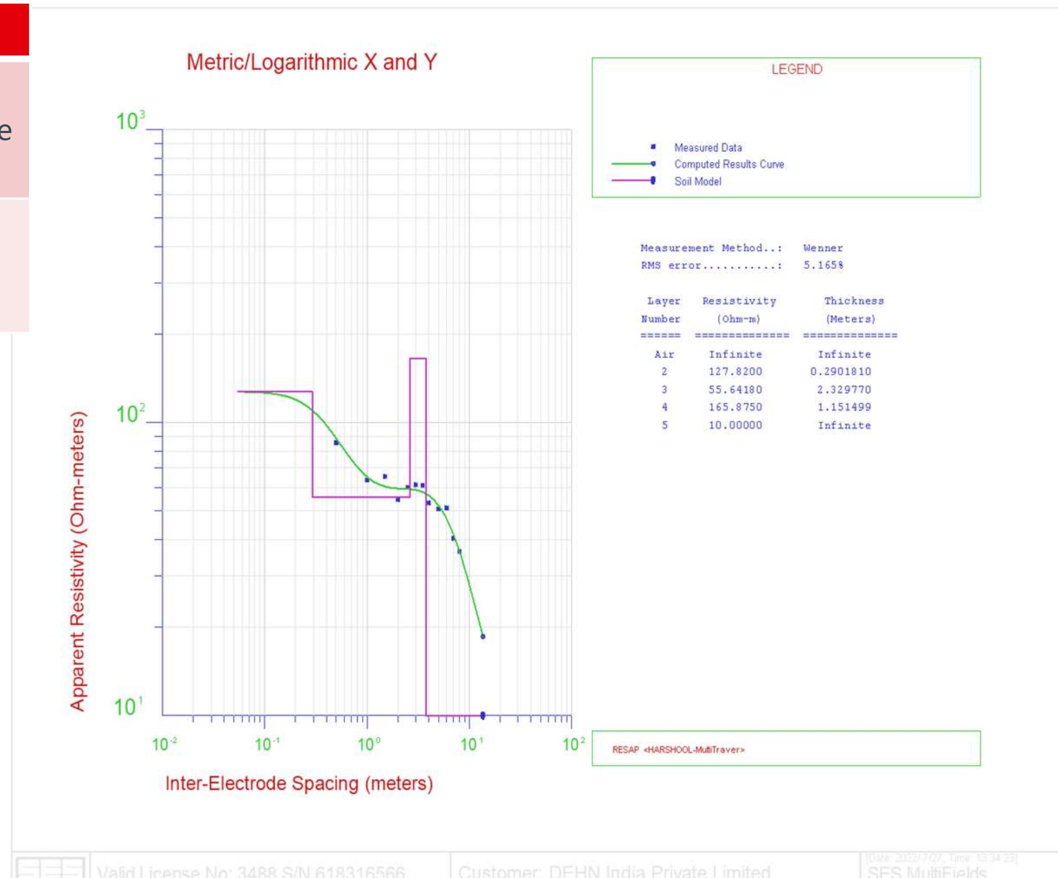
Area	Touch Voltage		Step Voltage	
	Safety Threshold (V)	Maximum Simulated Voltage (V)	Safety Threshold (V)	Maximum Simulated Voltage (V)
132kV EHV SS	661.836	652.65	2332.06	182.99



Multilayer Four Layer Soil Model with RMS Error of 5.1 %

Area	Touch Voltage		Step Voltage	
	Safety Threshold (V)	Maximum Simulated Voltage (V)	Safety Threshold (V)	Maximum Simulated Voltage (V)
132kV SS	661.836	632.092	2332.06	262.328





BOQ Obtained in Achieving Safety for Different Apparent Soil Models

Substation Area	Apparent Soil Model		Touch Voltage		Step Voltage		BOQ for Number of Rods Required for Safety
	Description	RMS Error (in %)	Safety Threshold (V)	Maximum Simulated Voltage (V)	Safety Threshold (V)	Maximum Simulated Voltage (V)	
Within 132kV EHV SS (With 10 cm thick, 3000 ohm-m Crushed Rock)	Uniform Soil Model	*144.84*	**661.836**	614.721	**2332.06**	368.56	174
	Two Layer Soil Model	*18.96*		617.821		177.937	62
	Three Layer Soil Model	*13.88*		652.65		184.996	57
	Four Layer Soil Model	*5.1*		632.092		262.328	23

Summery

- Alone Earth resistance measurement does not guarantee the efficient protection. It is necessary to design the Earthing system considering the safety criteria like GPR, Touch & Step potential, Earth loop impedance as an important factors.

- Overall Earthing system health assessment and periodic inspection is essential requirement for the satisfactory performance of the protection systems as proper Earthing systems are required in any electrical system for safe equipment operation.

- As per Earthing assessment and study survey for 50+ Power stations, 30-40% equipments have missing integrity of earth connections, and 20-30% Substations installations are unsafe touch & Step potential, which may lead to unsafe incidents for human and equipments damage in the event of the steady state and transient faults.

- To avoid major fire and equipment damage, earthing system audit and health assessment shall be the part of maintenance plan and detailed earthing audit shall be carried out at least once in a 3 years.

- For Safe, accurate and cost economical Earthing system design, Multilayer soil modeling analysis by the IEEE 80-2013 recommended software simulation and calculations shall be performed.

Thank you!

Q&A