Whyes of Earthing and Grounding

- Why Earthing ?
  - To provide discharge path for lightning over voltages coming from rod-gaps, surge arrestors and shielding wires etc.
  - To ensure safety of operating staff by limiting voltage gradient at ground level
  - To provide low resistance path so as to discharge the trapped charge to earth prior to maintenance.
  - To provide adequate path for earth fault current to return to neutral
- Why Grounding ?
  - Protection of Electrical equipments - through faults
  - Safety of operating staff

Earthing – Connection of the passive parts of electrical components to earth potential

Grounding – Connection of active part of electrical circuit to earth potential

Objectives of Earthing Systems

- There are no Thermal or Mechanical stresses on equipments within Substation

- An Equipotential Bonding which ensures that potential gradient within and around substation are safe

Switchyard Fence Earthing (Two Separate) Practices

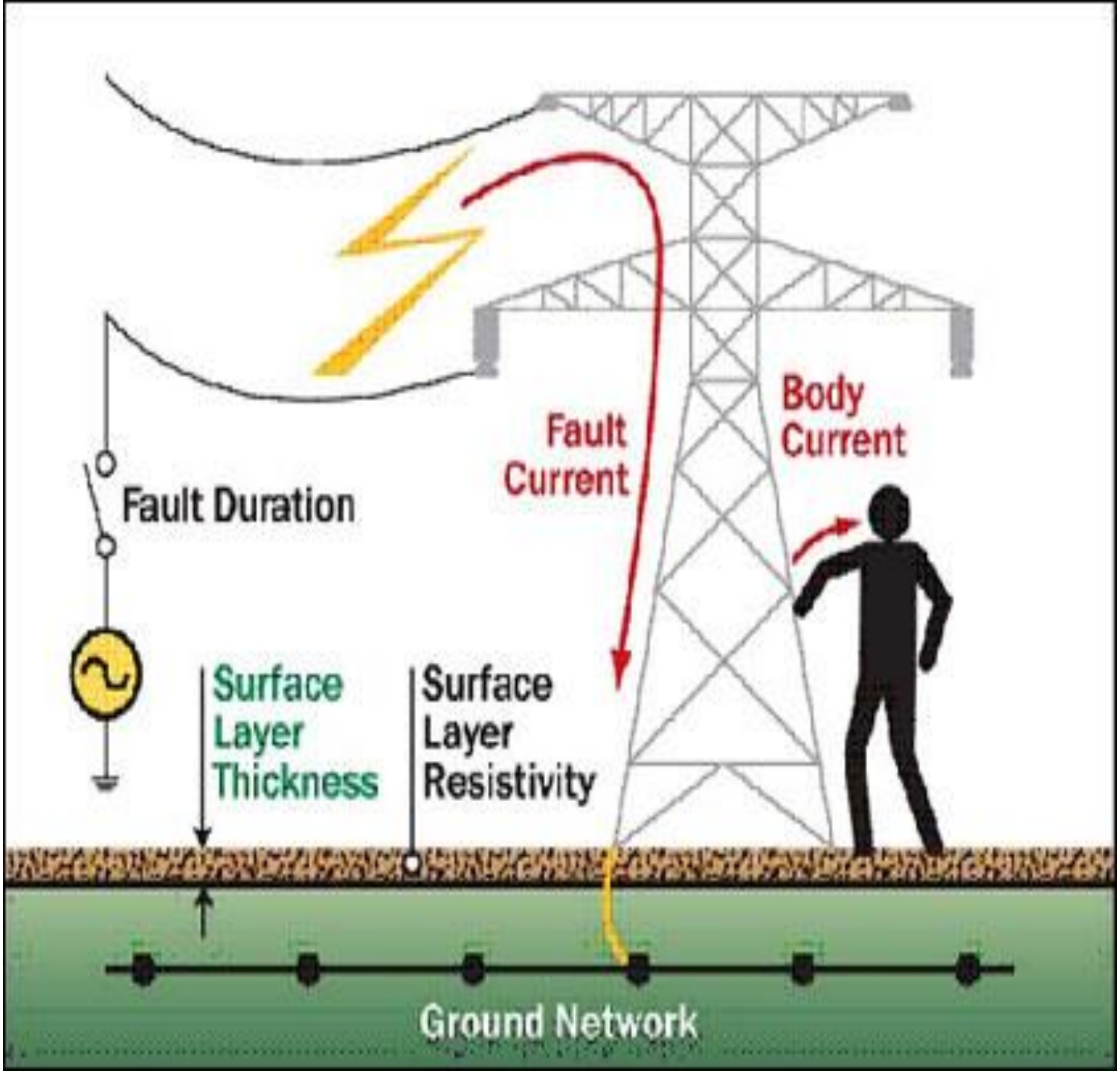
- Extend the substation earth grid beyond the fence by 0.5-1.5 Mtr. The fence is bonded to the earth mat at regular intervals

- Place the fence beyond the perimeter of the earth mat and bond the fence by its own earthing rod system, which is not coupled to earth mat.

Definitions

- **Ground** – A conductive connection, whether intentional or accidental, by which an electric circuit or equipment is connected to earth or to some conducting body of relatively large extent that serves in the place of earth. (IEEE 1050)
- **Equipment Ground** – The safety ground connection to the conductive, non current-carrying parts of electrical requirement.
- **Neutral** – That part of active circuit which has similar voltage with respect to other circuit conductor (s)
- **Decrement Factor** – It is a factor that is used in conjunction with Symmetrical Earth
- Ground Current, Conductor, Electrode, Connection, Grid, Mat , System and resistance
- **Earth** – Common point in circuit used as a reference Zero Potential. It is also referred to as ground

Electrocution – How and Why?


Fault Duration
Fault Current
Body Current
Surface Layer Thickness
Surface Layer Resistivity
Ground Network

SHOCK EFFECTS

- Electrically human body is a system of resistances
  - Flow of electric current **causes burns on skin and muscles**
- Normal functioning of human body is a system governed by electrical pulses and responses.
  - Flow of Electric Current causes irregular and uncontrolled contraction of the Cardiac Muscles of the ventricles in the heart is called **Ventricular Fibrillation**.

Circumstances-Shock Effects

- Fault current, which is high enough relative to area of ground system, and its resistance to zero earth
- High potential gradients at earth's surface caused by distribution of ground current and soil resistivity
- Bridging of two points of high potential difference by a body
- Absence of insulating material at surface of contact of body
- Duration of body contact, at the instance of fault

Effects of Electric Current- Magnitude and Duration

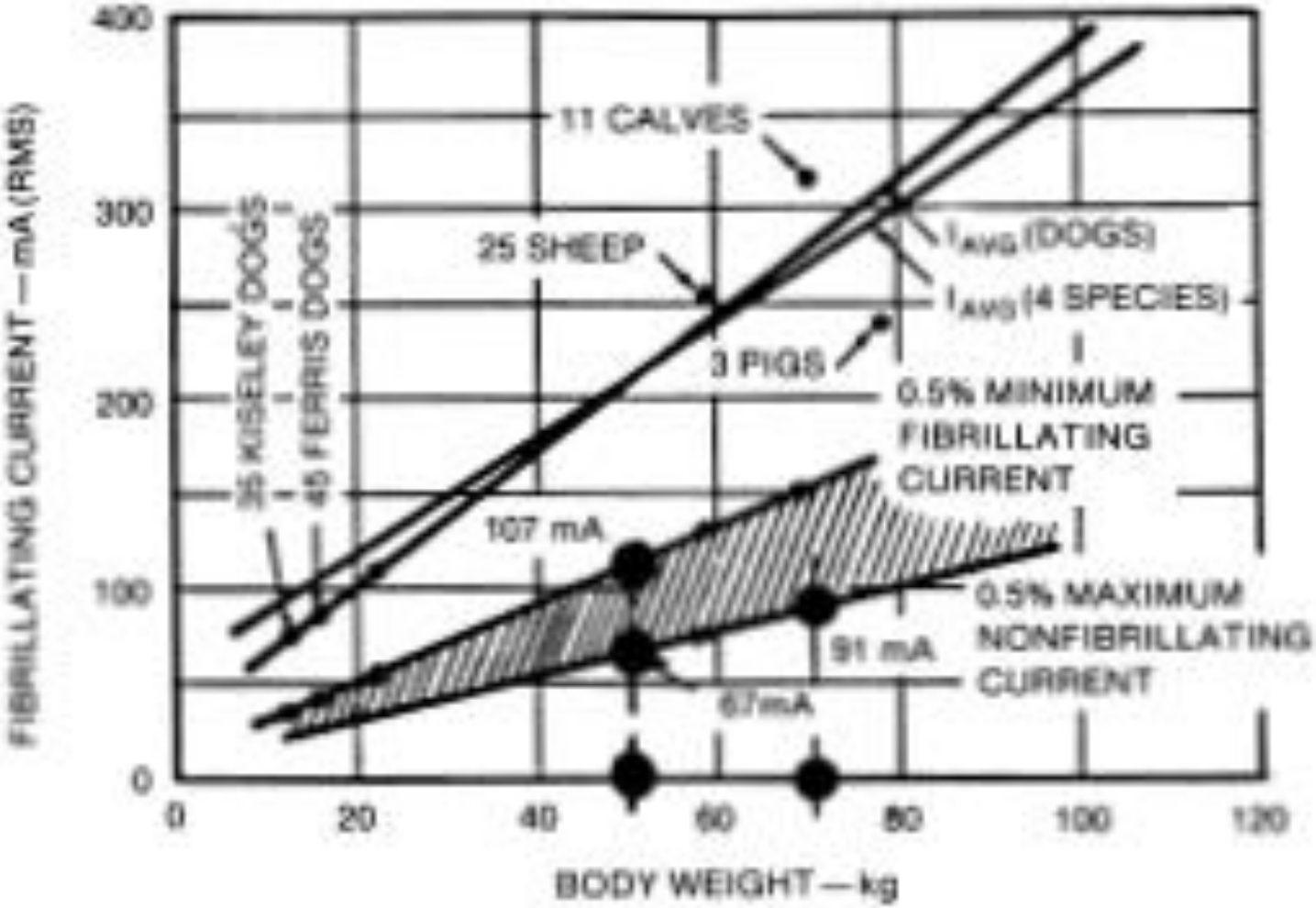
a. 1mA current is threshold of perception- a tingling sensation in hands and finger tips

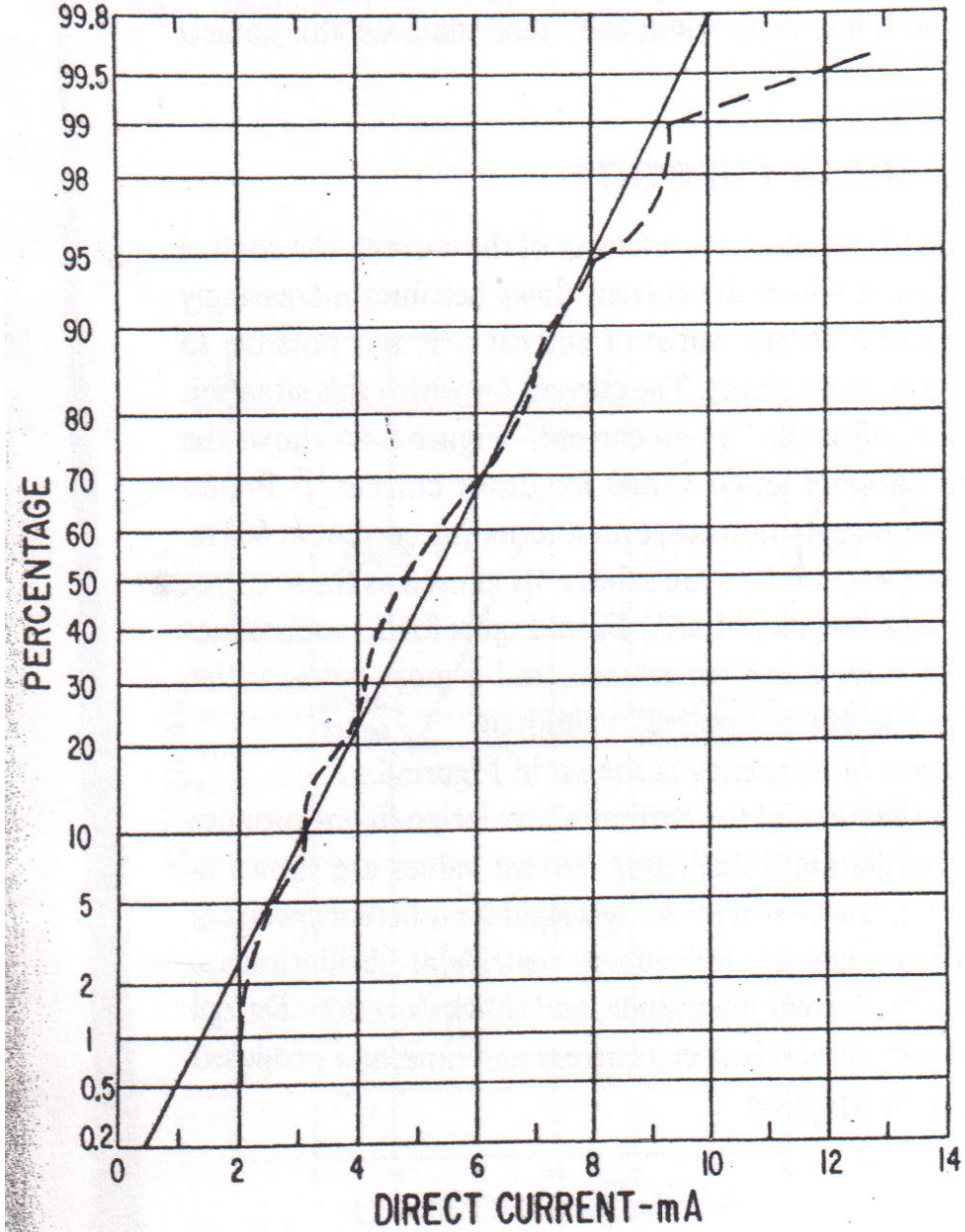
b. 1-6 mA current is unpleasant to sustain, but does not impair biological control to leave energized object.

c. 9-25 mA becomes painful and adversely affects biological control, but, the effects disappear when current is interrupted, provided prolonged flow has not caused stoppage of breathings for minutes.

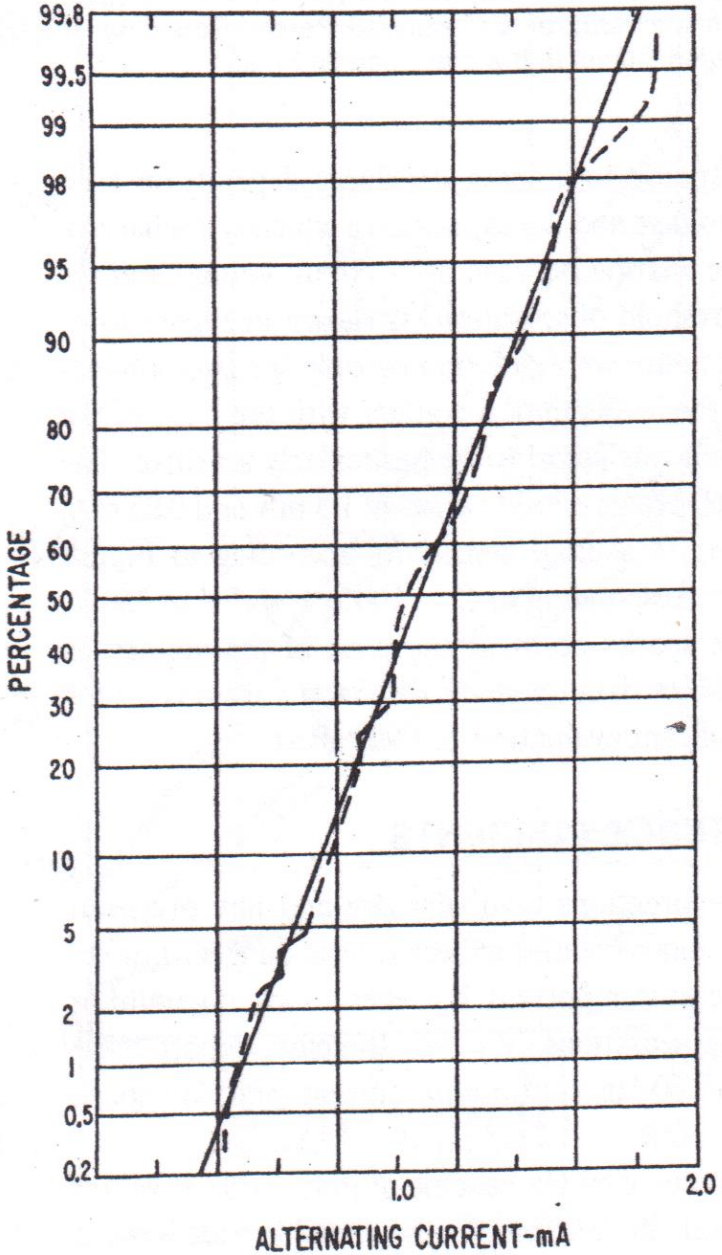
d. 60-100 mA cause ventricular fibrillation which is fatal.

Effect of Body Weight of Fibrillation Current

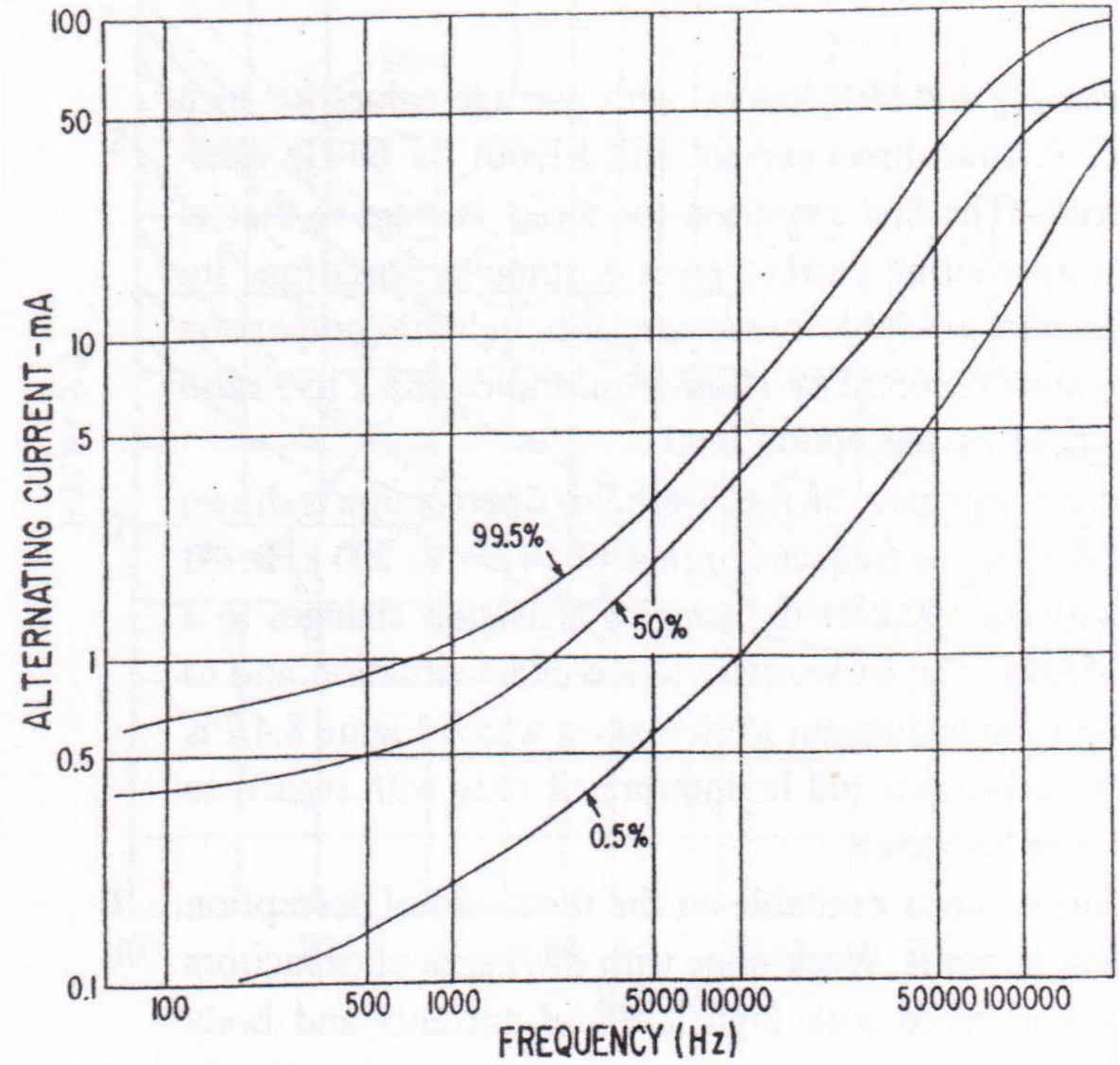


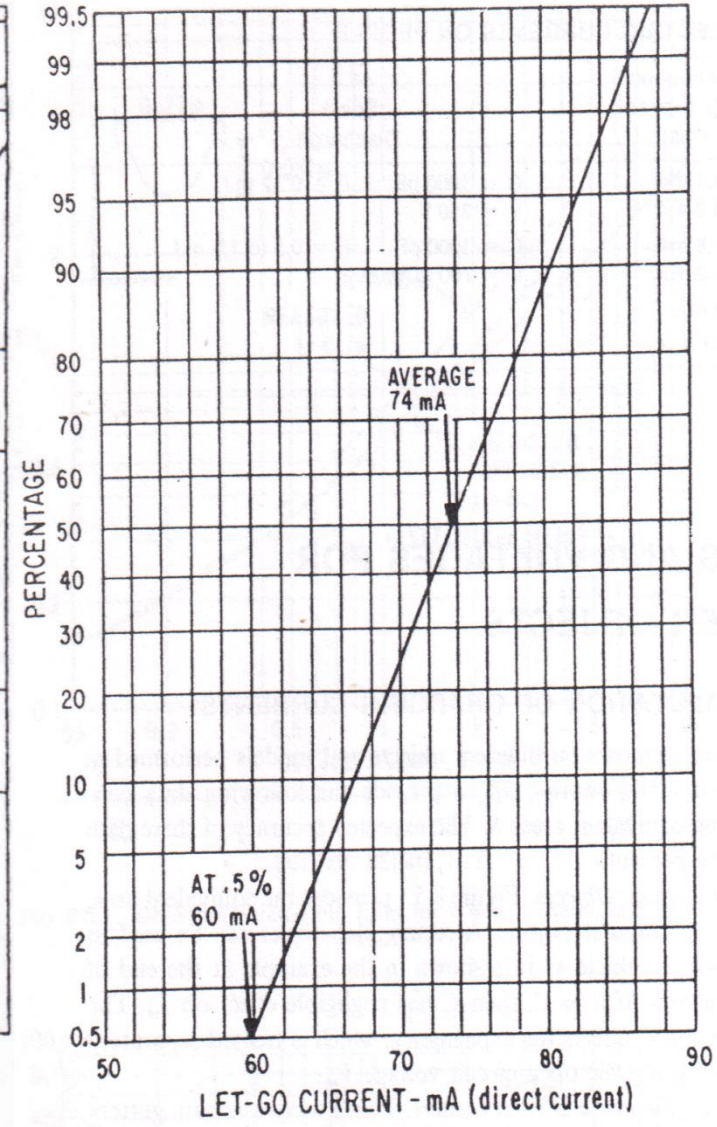


Distribution Curve of Minimum Direct Current



Distribution Curve of Minimum AC Current





Effect of Frequency on Threshold Perception

Distribution of Let-Go Current (DC)

Fibrillation current

$$I_B = \frac{k}{\sqrt{t_s}} \; ; \; k = \sqrt{S_B}$$

For 50 kg body weight $I_B = \frac{0.116}{\sqrt{t_s}}$ For 70 kg body weight $I_B = \frac{0.157}{\sqrt{t_s}}$

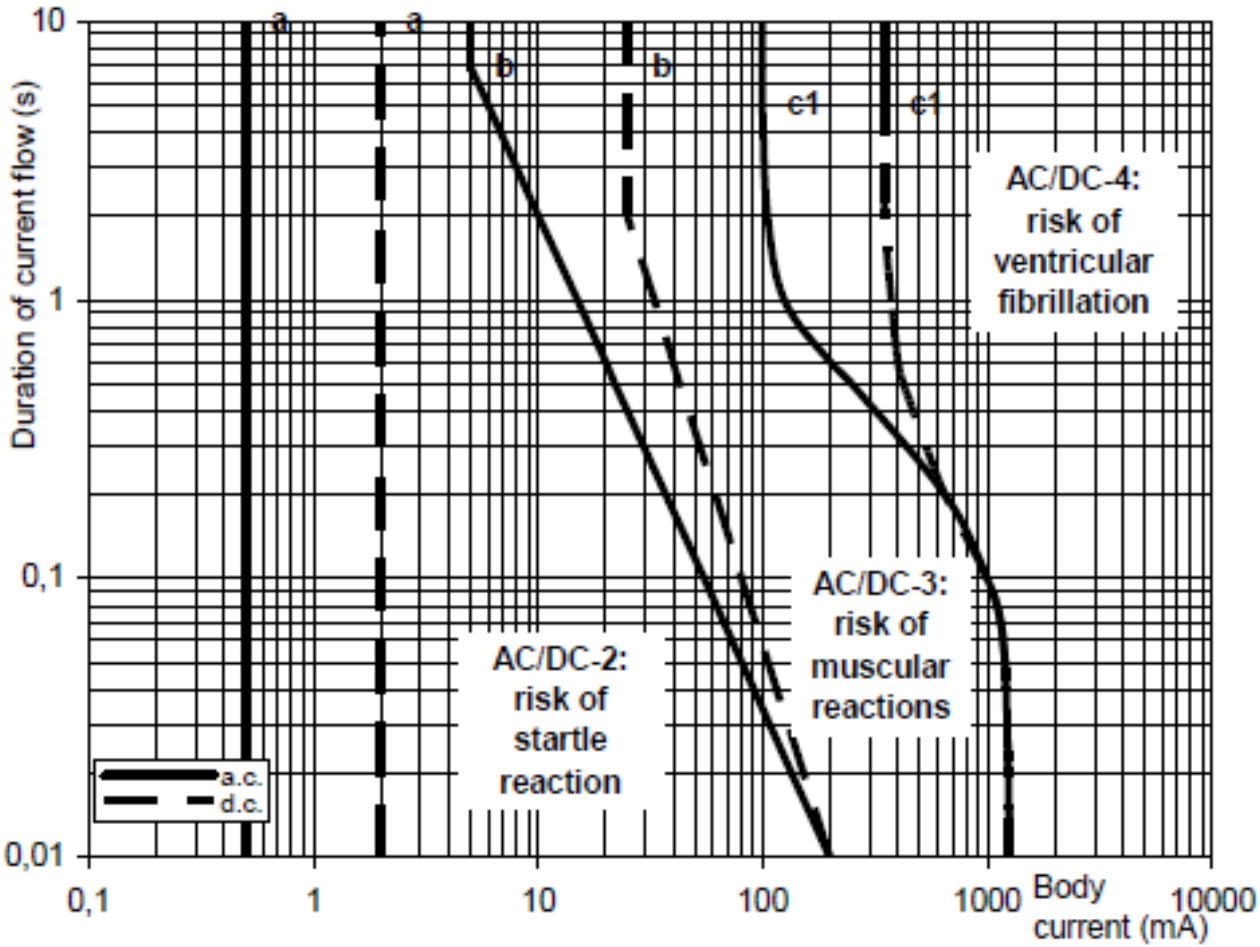
Typically for 50 kg body weight I_B is 116 mA for t_s =1 sec and 367 mA for t_s =0.1 sec

Typically it is related to capacity of body to external electrical absorb energy

Damage to Human Life by Current or Voltage?

Comparison of AC/DC current magnitudes causing fibrillation

$$\frac{I_{d.c.-fibrillation}}{I_{a.c.-fibrillation(r.m.s.)}} = \frac{300\,mA}{80\,mA} = 3.75$$



More damage by AC or DC Current?

ALLOWABLE BODY CURRENT I_B

AS PER IEEE STD- 80

T_S : DURATION OF CURRENT EXPOSURE
(FAULT CLEARENCE TIME)

T_S	I_B (50 Kg)	I_B(70 Kg)
0.2 SEC	259 mA	351 mA
0.5 SEC	164 mA	222 mA
1 SEC	116 mA	157 mA

FIG_EA_32

Typical Impedance voltage for Transformers`	
Rated Power (in KVA)	Impedance Voltage (in %)
Upto 630	4.0
631 to 1250	5.0
1,251 to 3,150	6.25
31,501 to 63,000	7.15
6,301 to 12,500	8.35
12,501 to 25,000	10.0
25,001 tp 200,000	12.5

Typical Short Circuit Levels		
Highest System Voltage (in kV)	Short-Circuit Apparent Power (in MVA)	Short Circuit Current (in kA)
7.2, 12, 17.5, 24	500	40, 24,17,12
36	1,000	16
52, 72.5	3,000	33, 24
100, 123	6,000	35, 28
145	10,000	40
245	20,000	47
300	30,000	58
420	40,000	55

Rated System Voltage (in kV)	Power Frequency (in kV)	Basic Insulation Level (in kV)
11	28	75
22	-	125
33	70	170
47	-	250
66	140	352
110	-	550
132	230	650
220	-	950
220	-	1050
400	-	1425
800	-	1950

Lightning impulse :1.2/50 µs

Switching Impulse : 250/2500 µs pulse

Use of Material in Construction

Material	Ion Open Air	In Soil	In Concrete
Copper	Solid, Stranded or as a coating	Solid, Stranded or as a coating	Do not use
Hot Galvanized Steel	Solid or Stranded	Solid	Solid
Stainless Steel	Solid or Stranded	Solid	Do not use
Aluminum	Solid or Stranded	Do not use	Do not use
Lead	Solid or as a coating	Solid or as a coating	Do not use

Data Required for Earthing Design

- Length and Breadth of Area Occupied by Earthing Grid
- Fault level at Incoming Bus
- Incoming Voltage
- Outgoing Voltage
- Soil Resistivity
- Resistance of Main Earthing Mat
- Resistance of Surface Material (Crushed Rock)
- Thickness of Surface Material (Crushed Rock)
- Depth of Earthing Grid Conductor
- Diameter of Earthing Grid Conductor
- Reference Depth of Grid
- Spacing between Parallel Conductor of Grid

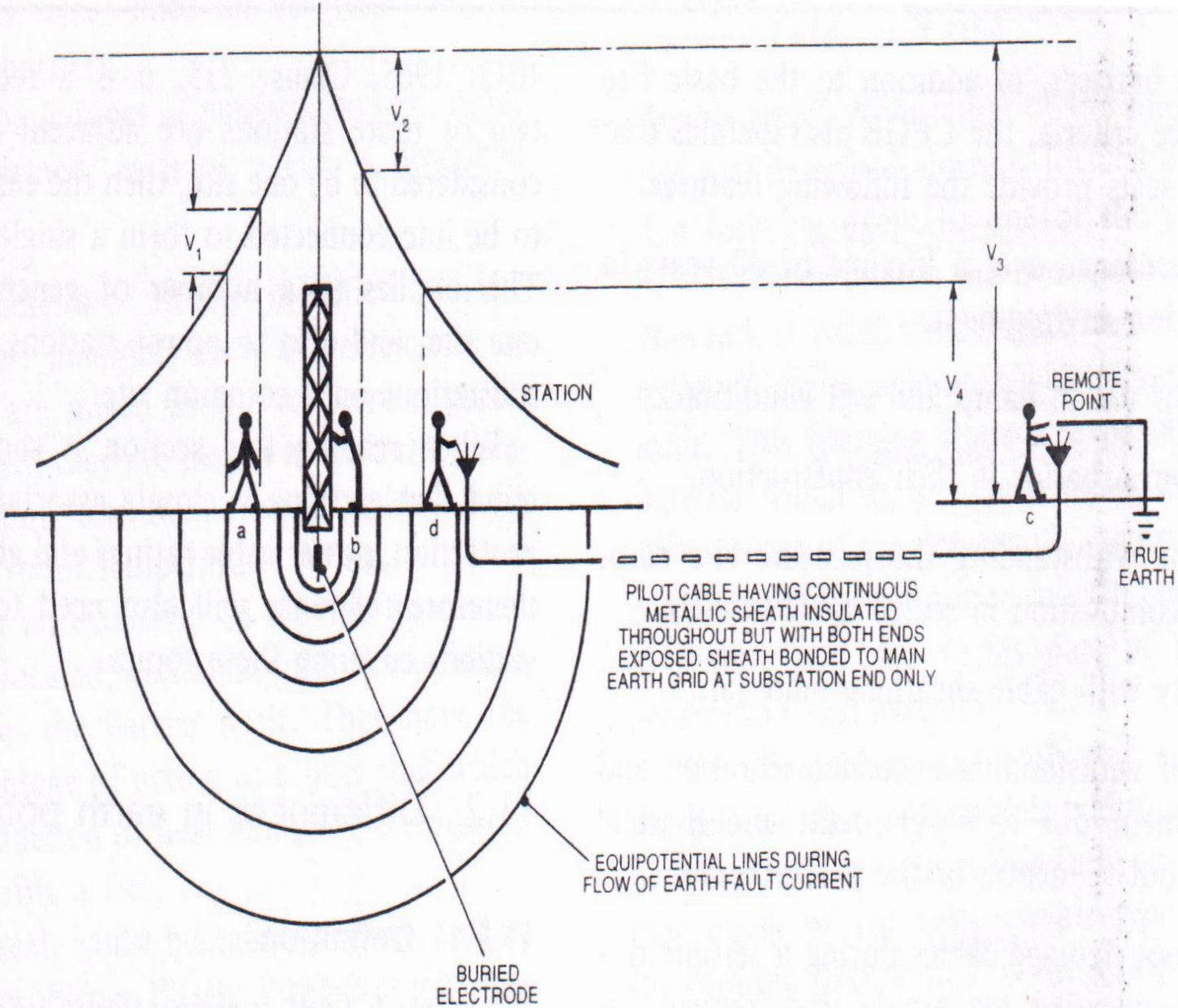
EARTHING OF ISOLATOR / DISCONNECT

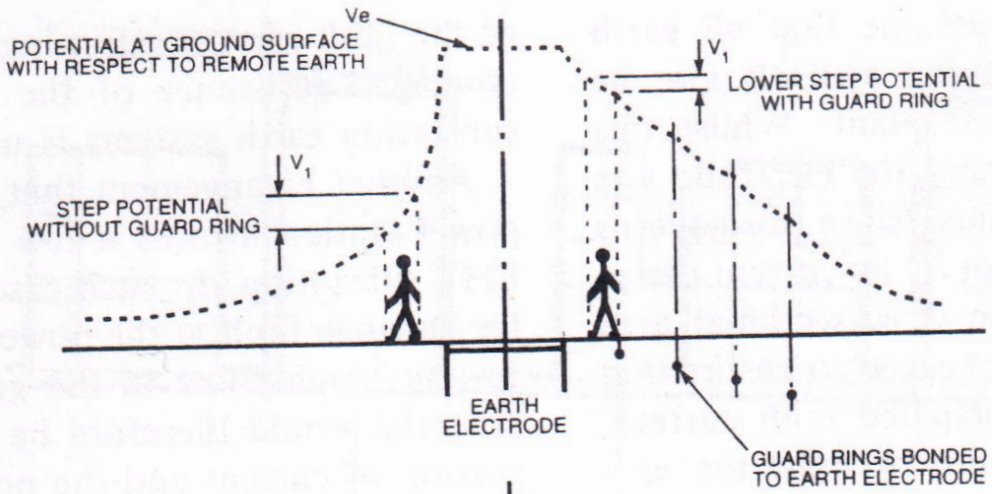
- MANUAL OPERATION OF SWITCH REQUIRES PRESENCE OF OPERATOR NEAR THE EQUIPMENT

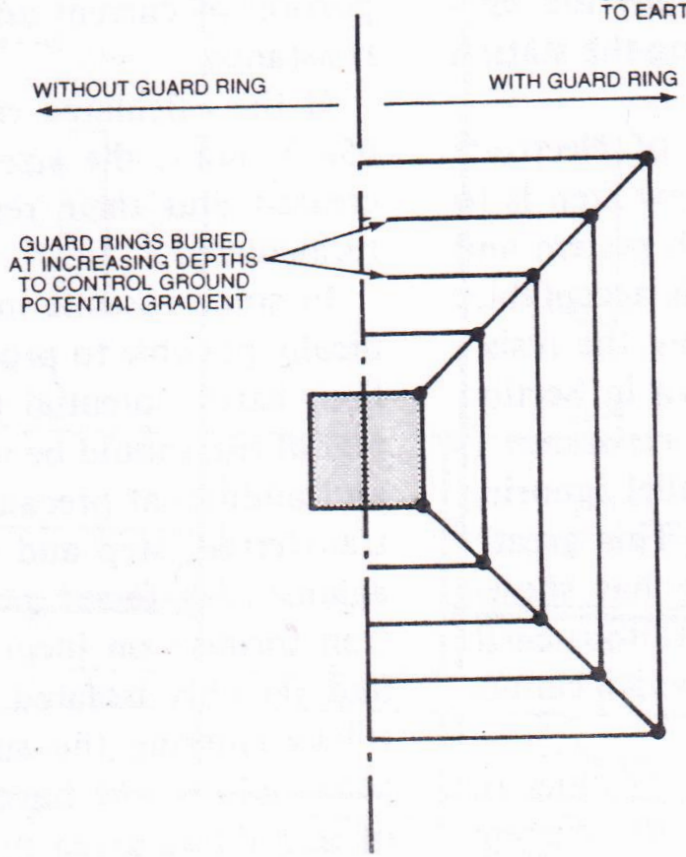
- REASONS THAT COULD LEAD TO FAULT IN EQUIPMENT

  - OPENING AN ENERGIZED CIRCUIT
  - MECHANICAL FAILURE
  - ELECTRICAL BREAKDOWN OF INSULATOR OF SWITCH
  - ELECTRICAL BREAKDOWN DURING INTERRUPTION -
    - LINE CHARGING CURRENT
    - TRANSFORMER MAGNETIZING CURRENT

- Safety Requirements
  - Step Potential
  - Touch Potential
  - Mesh Potential
  - Transferred Potential


V2
V1
V3
V4
STATION
REMOTE POINT
a
b
d
c
TRUE EARTH
PILOT CABLE HAVING CONTINUOUS METALLIC SHEATH INSULATED THROUGHOUT BUT WITH BOTH ENDS EXPOSED. SHEATH BONDED TO MAIN EARTH GRID AT SUBSTATION END ONLY
EQUIPOTENTIAL LINES DURING FLOW OF EARTH FAULT CURRENT
BURIED ELECTRODE


Ve
POTENTIAL AT GROUND SURFACE
WITH RESPECT TO REMOTE EARTH
V_1
LOWER STEP POTENTIAL
WITH GUARD RING
V_1
STEP POTENTIAL
WITHOUT GUARD RING
EARTH
ELECTRODE
GUARD RINGS BONDED
TO EARTH ELECTRODE


WITHOUT GUARD RING
WITH GUARD RING
GUARD RINGS BURIED
AT INCREASING DEPTHS
TO CONTROL GROUND
POTENTIAL GRADIENT

DESIGN TOUCH POTENTIAL $E_{touch_{design}}$

$$K_T = \frac{1}{2\pi}\left[\ln\left\{\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dh} - \frac{h}{4d}\right\} + \frac{1}{\sqrt{(1+h)}}\ln\left\{\frac{8}{\pi(2n-1)}\right\}\right]$$

$$K_I = (0.656 + 0.172 \times n)$$

$$E_{touch_{design}} = \frac{\rho \times I_G \times K_T \times K_I}{L_H + 1.15 \times L_V}$$

D = SPACING BETWEEN PARALLEL GRID CONDUCTORS (in Meter)

d = DIAMETER OF GRID CONDUCTOR (in Meter)

h = DEPTH OF GROUNDING GRID (in Meter)

n = NUMBER OF PARALLEL CONDUCTORS IN ONE DIRECTION

ρ = SOIL RESISTIVITY (in Ω – Meter)

I_G = CURRENT DISCHARGED INTO THE EARTH (in Ampere)

L_H = TOTAL LENGTH OF HORIZONTAL CONDUCTORS (in Meter)

L_V = TOTAL LENGTH OF VERTICAL RODS (in Meter)

DESIGN STEP POTENTIAL $E_{step_{design}}$

$$K_S = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1-0.5^{N-2}}{D}\right]$$

K_I= Same as in Design Touch Potential

$$E_{step_{design}} = \frac{\rho \times I_G \times K_S \times K_I}{L_H + 1.15 \times L_V}$$

$$E_{step_{design}} = \frac{\rho \times I_G \times K_S \times K_I}{L_H + 1.15 \times L_V}$$

D = SPACING BETWEEN PARALLEL GRID CONDUCTORS (in Meter)

h = DEPTH OF GROUNDING GRID (in Meter)

N = MAX. NUMBER OF PARALLEL CONDUCTORS IN ONE DIRECTION

ρ = SOIL RESISTIVITY, (in Ω – Meter)

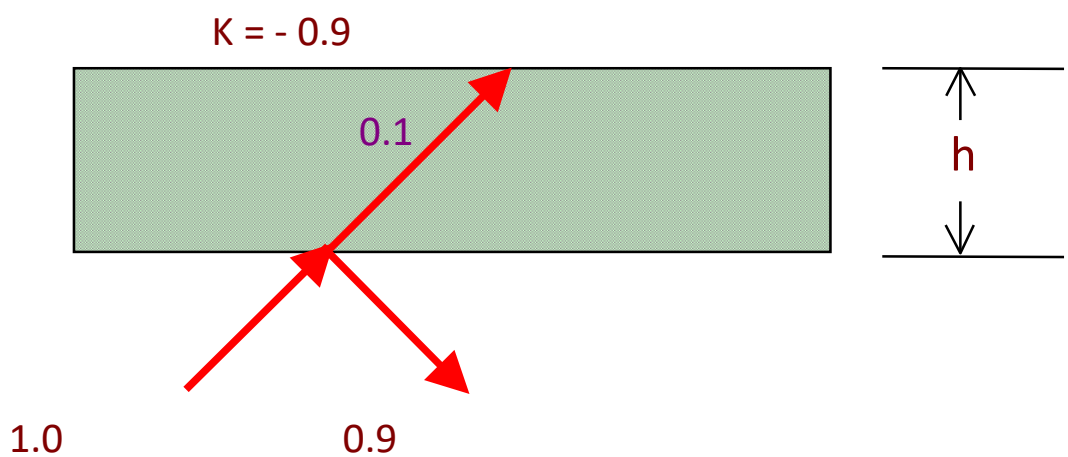
I_G = CURRENT DISCHARGED INTO THE EARTH (in AMP)

L_H = TOTAL LENGTH OF HORIZONTAL CONDUCTORS (in Meter)

L_V = TOTAL LENGTH OF VERTICAL RODS (in Meter)

K : REFLECTION FACTOR WITH DIFFERENT TOP SURFACE LAYER

GRAVEL	$K = (\rho - \rho_{SL}) / (\rho + \rho_{SL})$				
ρ_{SL} (ΩM)	ρ : 50 ΩM	ρ : 100 ΩM	ρ : 150 ΩM	ρ : 200 ΩM	ρ : 300 ΩM
1000	- 0.826	- 0.818	- 0.739	- 0.667	- 0.539
1500	- 0.936	- 0.875	- 0.818	- 0.765	- 0.667
2000	- 0.951	- 0.905	- 0.879	- 0.818	- 0.739
2500	- 0.961	- 0.923	- 0.887	- 0.852	- 0.786
3000	- 0.967	- 0.935	- 0.905	- 0.875	- 0.818



SWITCHYARD GROUNDING DESIGN

1. GPR, SV AND TV

- *GPR* : GROUND POTENTIAL RISE
- MAXIMUM VOLTAGE THAT STATION GROUNDING GRID MAY ATTAIN RELATIVE TO DISTANCE GROUNDING POINT ASSUMED TO BE AT THE POTENTIAL OF REMOTE EARTH
- GPR PROPORTIONAL TO I_{GRID} & R_{GRID}
- $I_{GRID} = S_F \times I_{FAULT}$

S_F: PERCENTAGE OF FAULT CURRENT DISCHARGED BY GROUNDING GRID TO EARTH

- $GPR = I_{GRID} \times R_{GRID}$

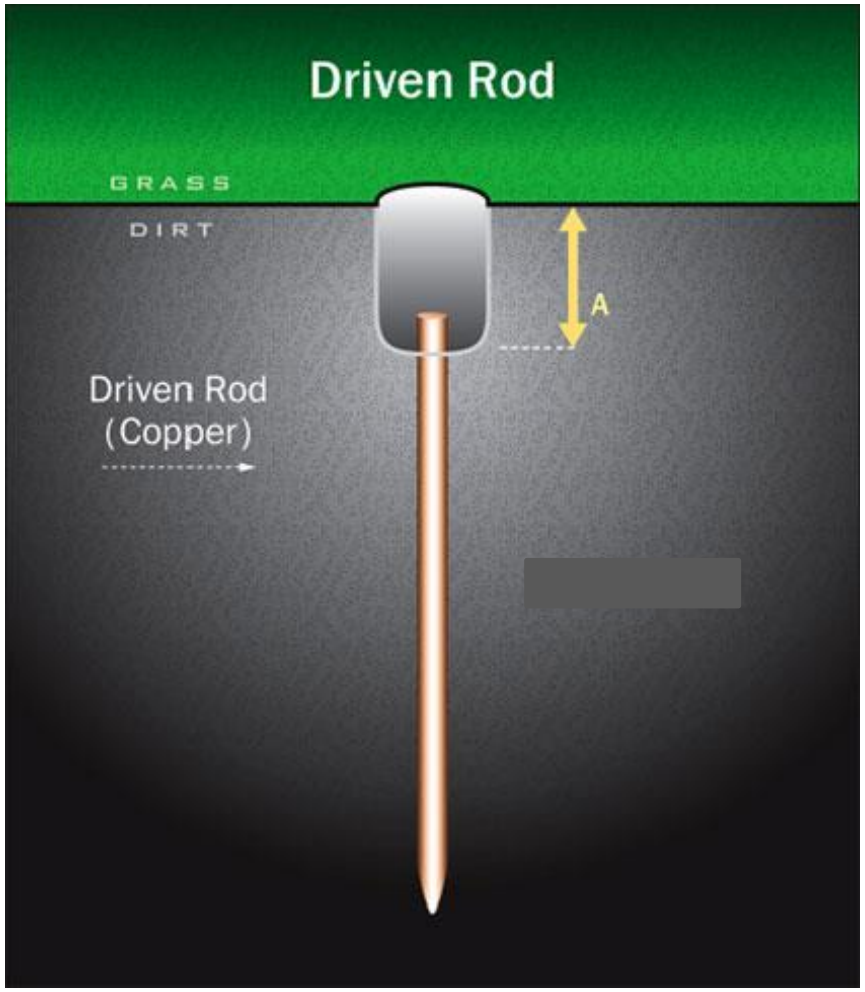
- CONCLUSION

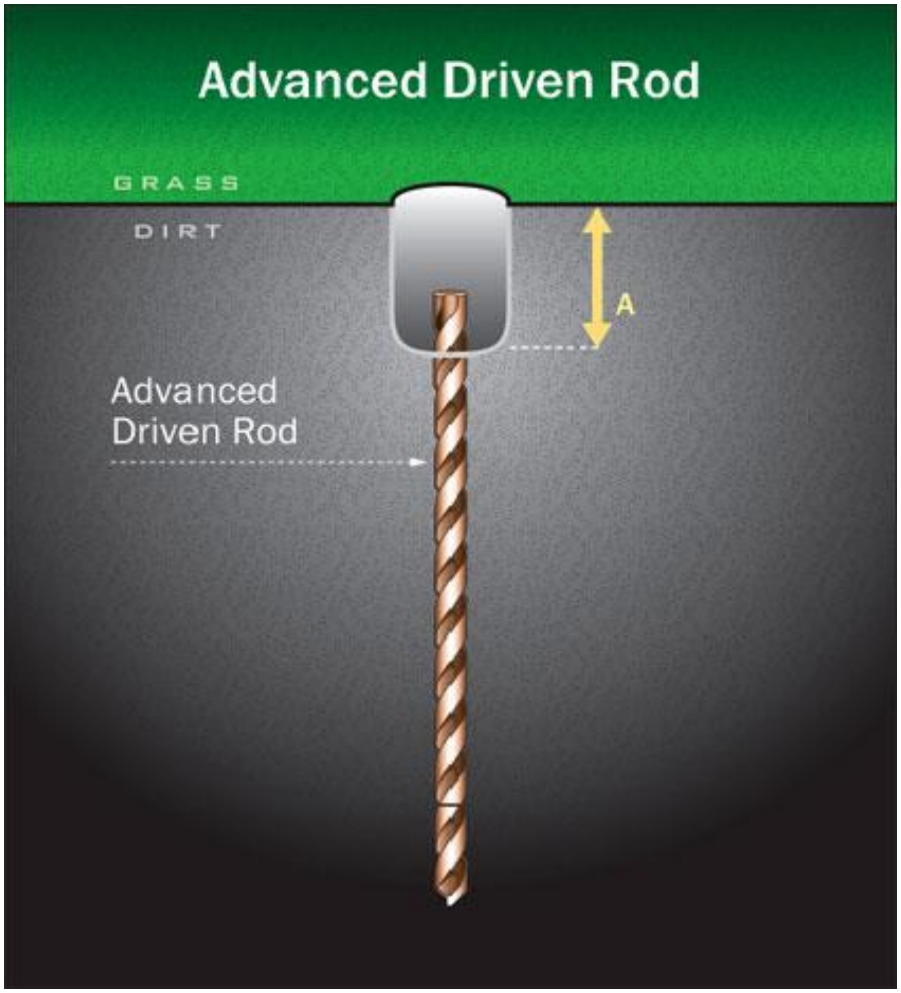
  - EFFECT OF ELECTRODE DIAMETER ON

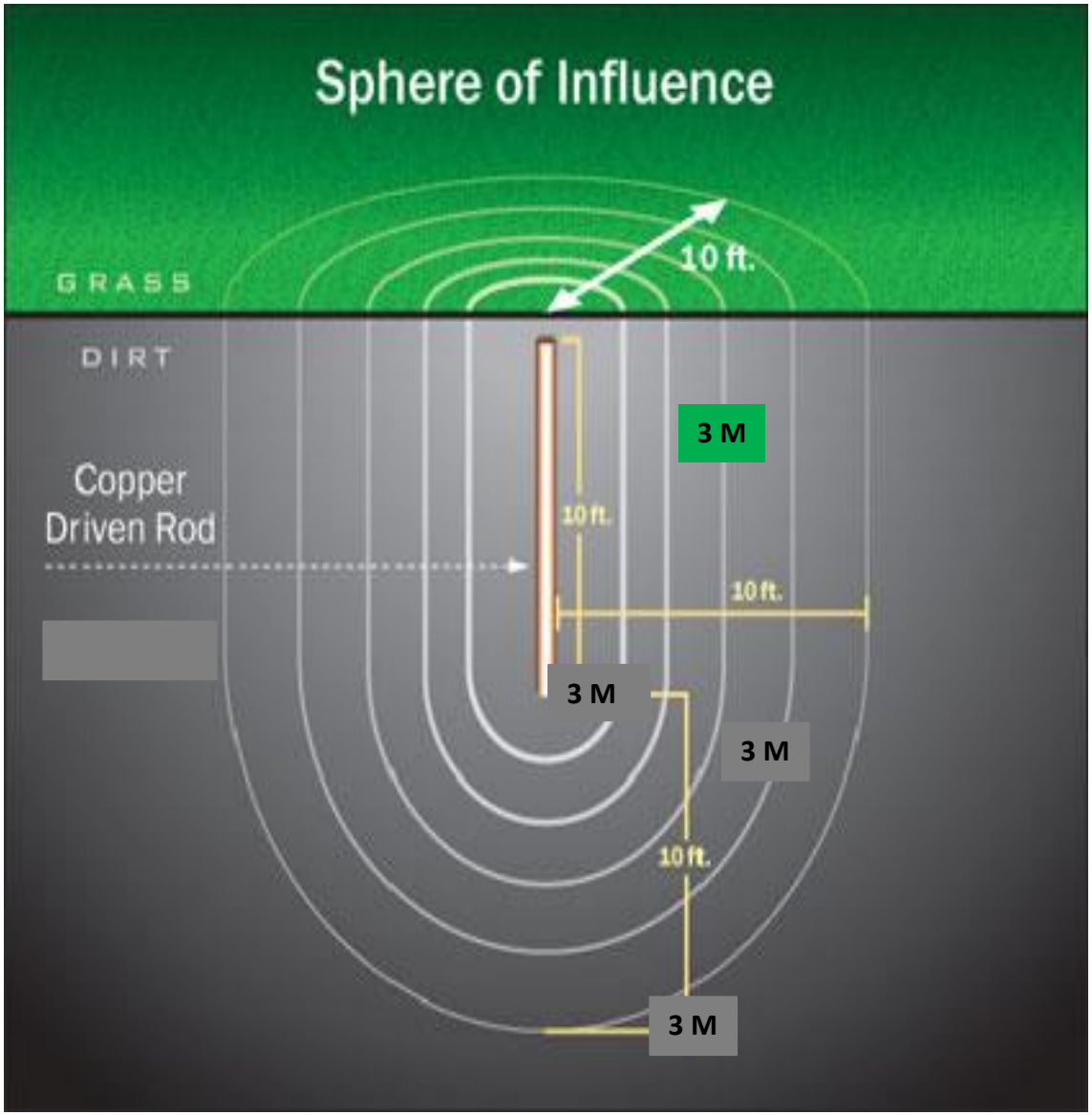
    GRID RESISTANCE
    STEP POTENTIAL
    TOUCH POTENTIAL

    } VERY MARGINAL

  - EXCEPT FOR CARRYING THE FAULT CURRENT FOR SPECIFIED TIME, CONDUCTOR CROSS SECTION PLAYS VERY MINOR PART IN GROUND GRID DESIGN.


Driven Rod
GRASS
DIRT
A
Driven Rod
(Copper)


Advanced Driven Rod
GRASS
DIRT
A
Advanced
Driven Rod


Sphere of Influence
GRASS
DIRT
10 ft.
3 M
Copper
Driven Rod
10 ft.
10 ft.
3 M
3 M
10 ft.
3 M

Volume Formula

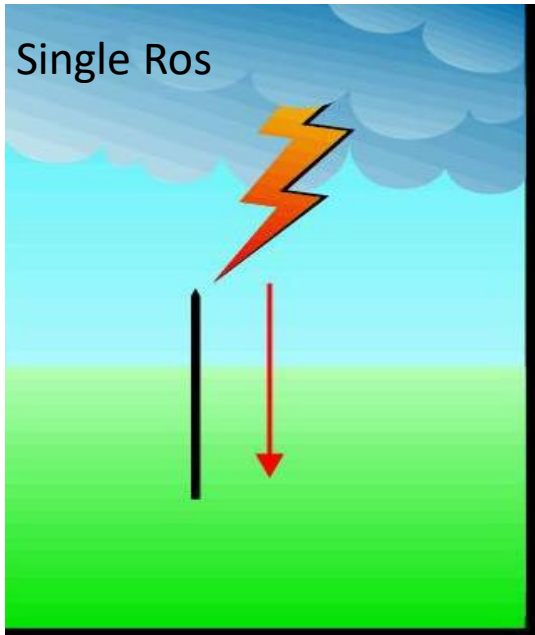
$$V = \frac{5\pi L^3}{3}$$

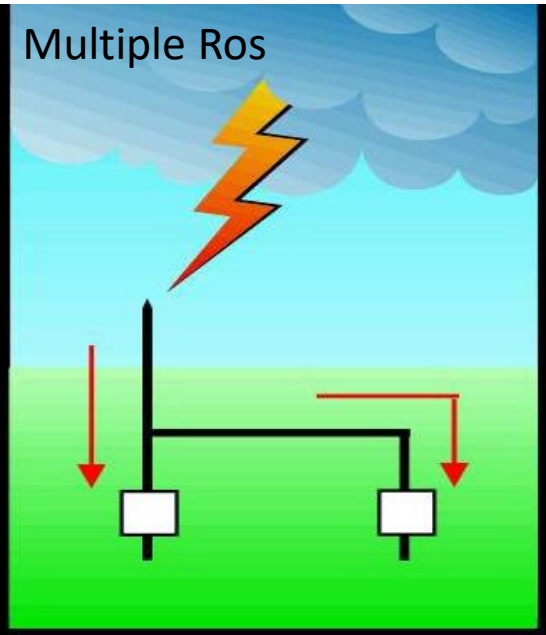
WHERE:

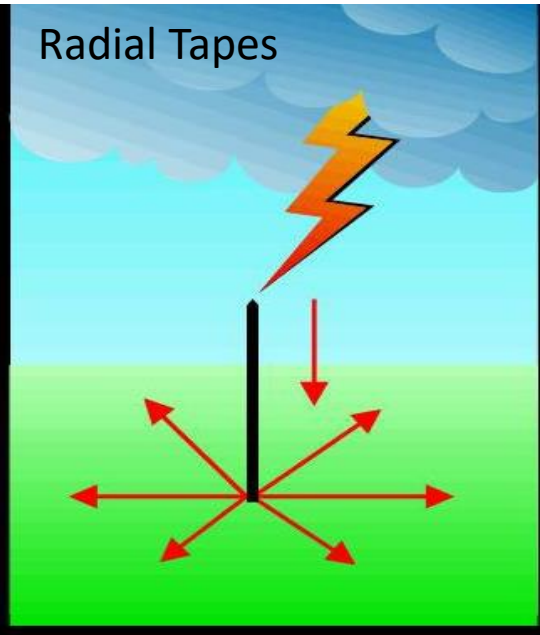
V = volume of soil in the sphere of influence

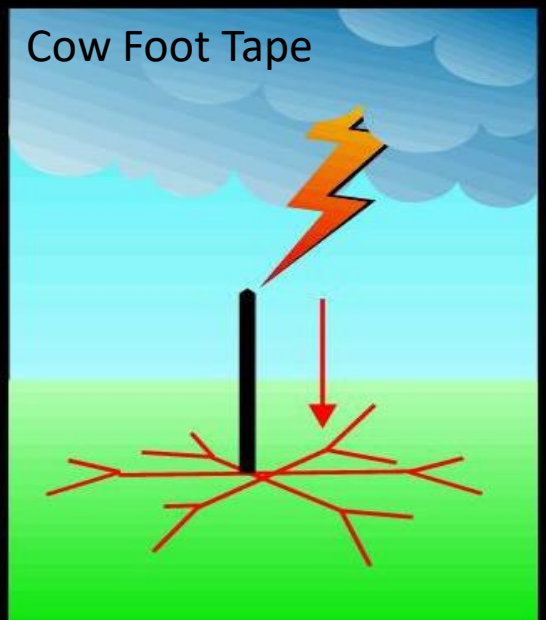
L = the length or depth of electrode

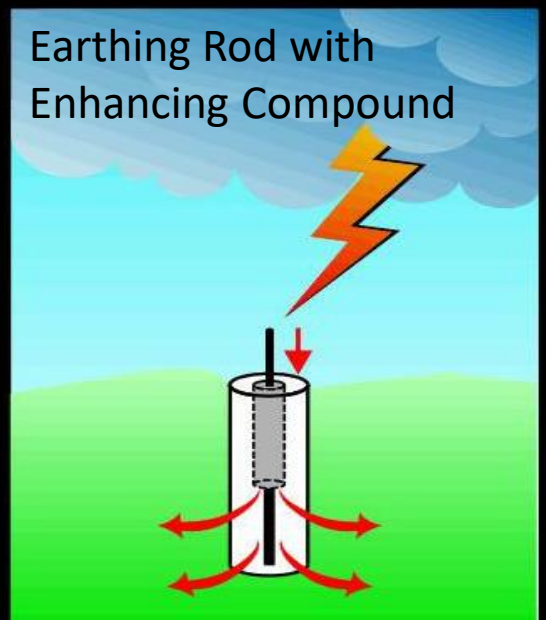
Methods of Earthing for Lightning Protection [Earthing.pdf]

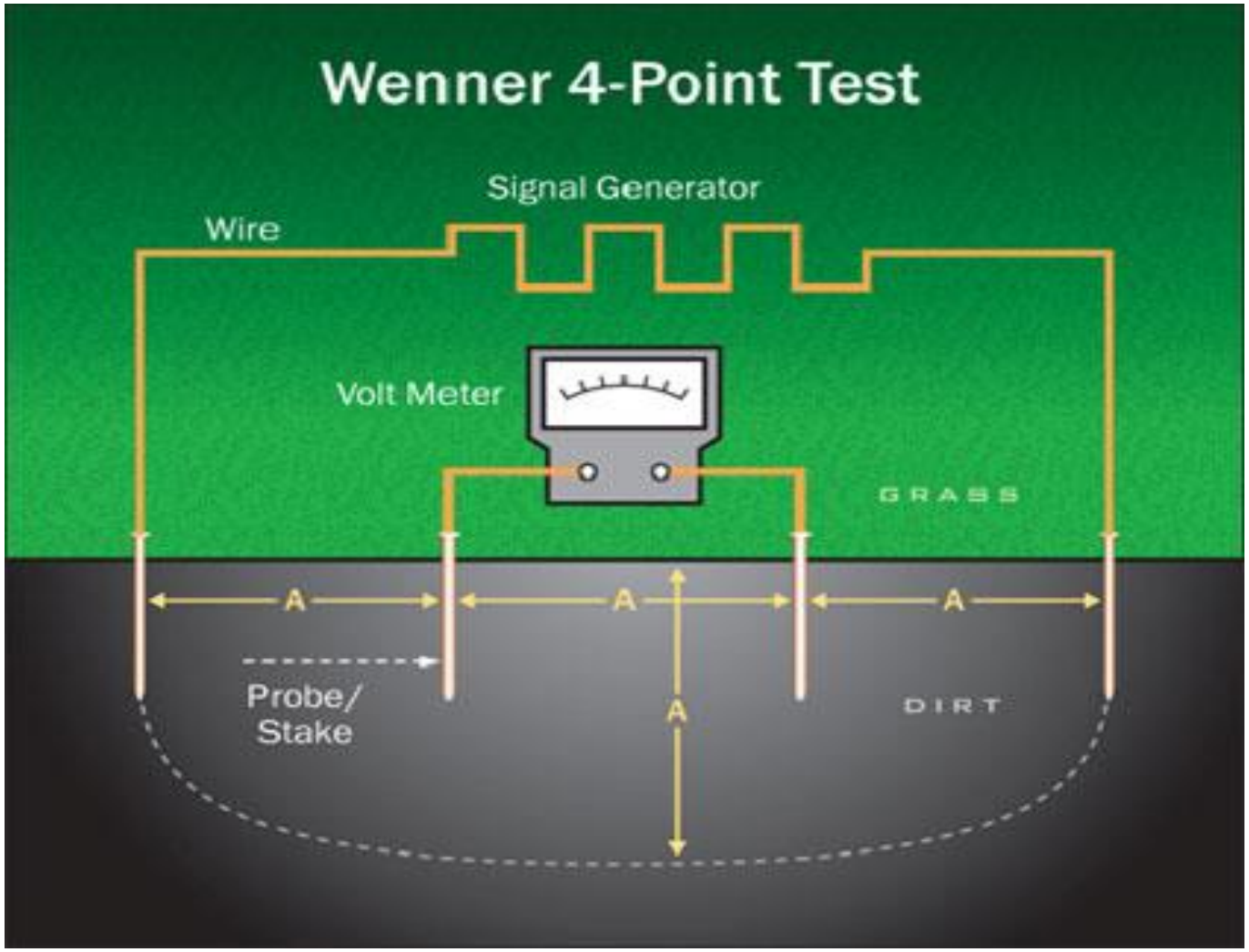











Wenner 4-Point Test
Signal Generator
Wire
Volt Meter
GRASS
A
A
A
A
Probe/
Stake
DIRT

- Earth Resistance
  - Resistivity
  - Moisture
  - Chemical Composition of soil
  - Geometry

Soil Resistivity
4-Point Data Interpretation

$$\rho = \frac{4\pi AR}{1 + \frac{2A}{\sqrt{\left(A^2 + 4B^2\right)} - \left(A^2 + B^2\right)}}$$

Here,

ρ Resistivity;

B - Depth of Probes in Meter

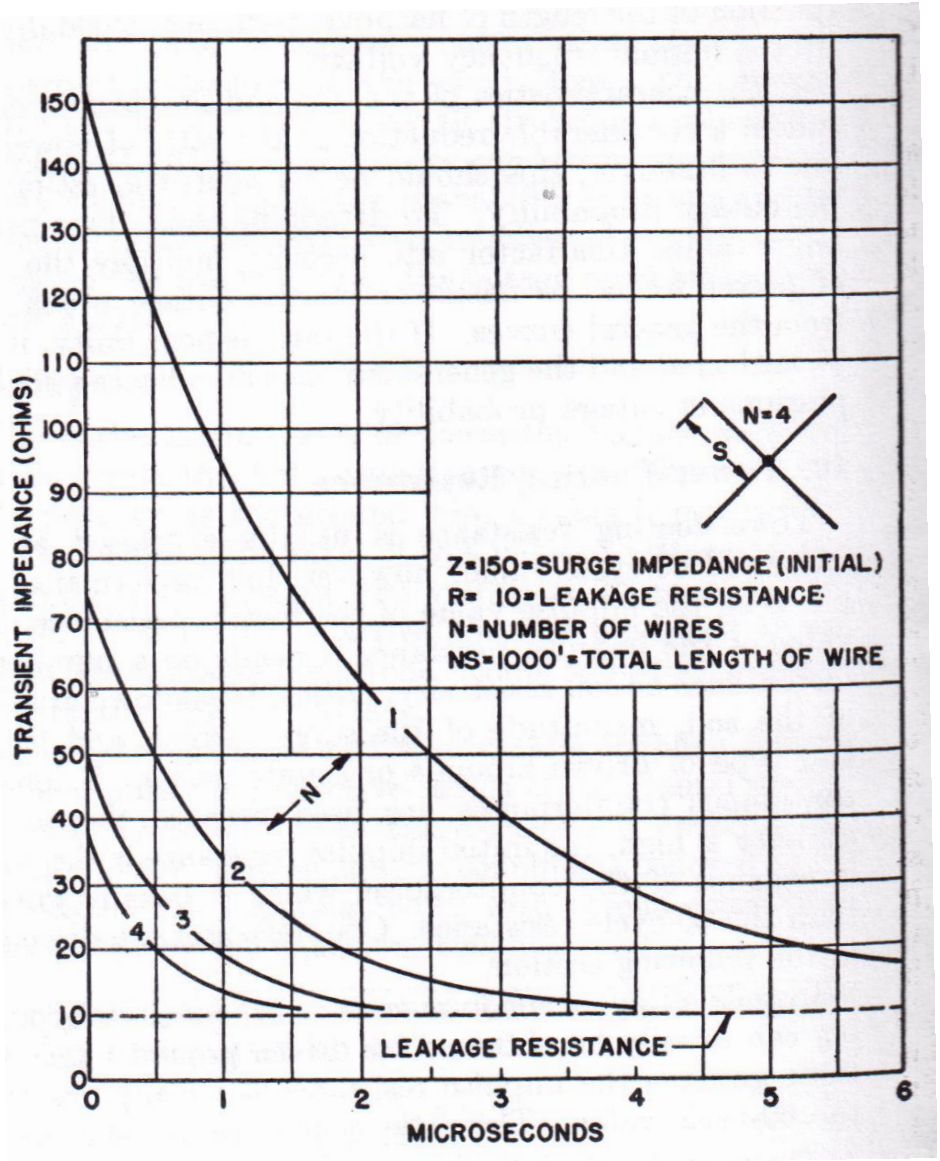
A – Spacing between probes in Meter ;

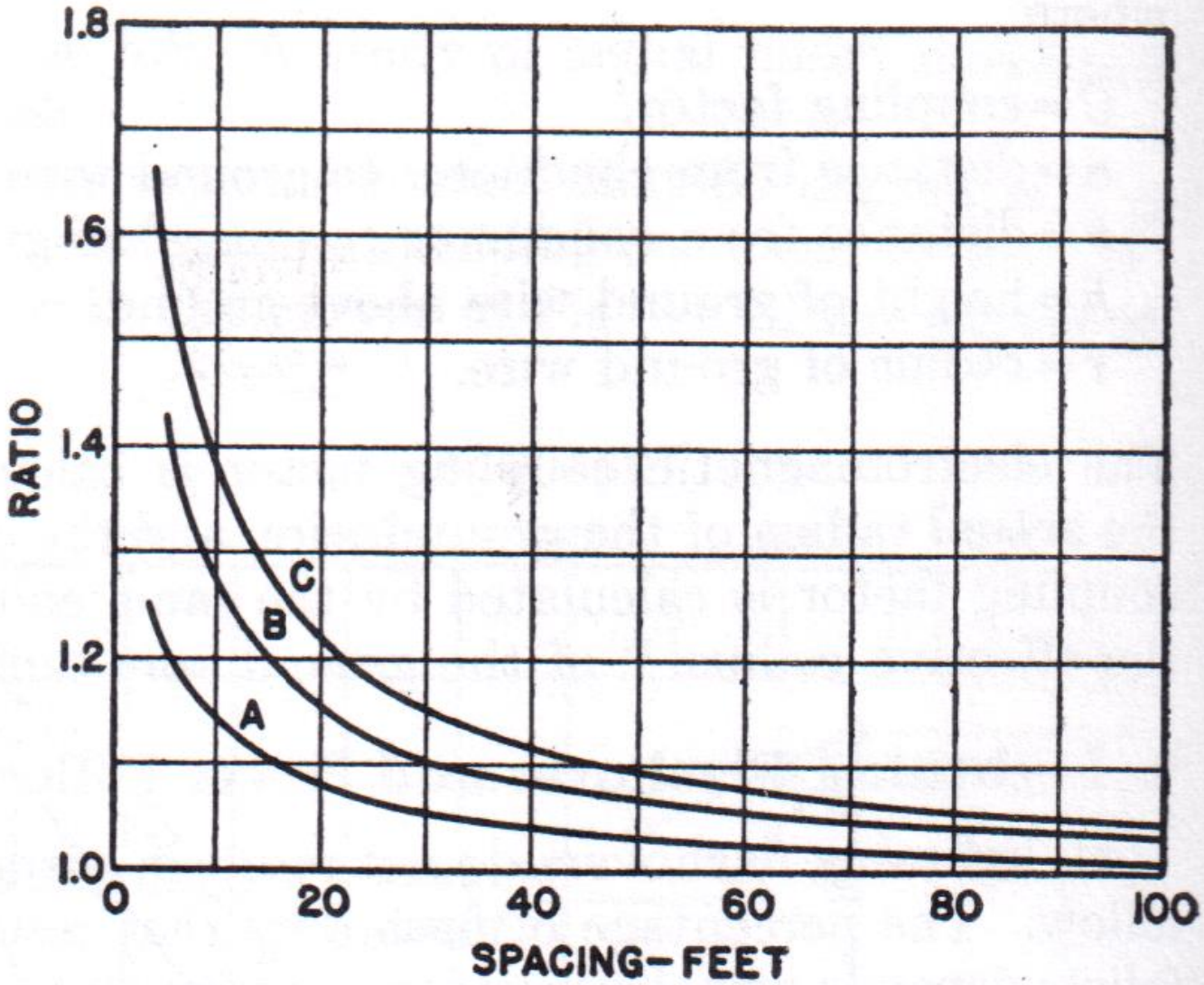
R – Resistance measured in Ω

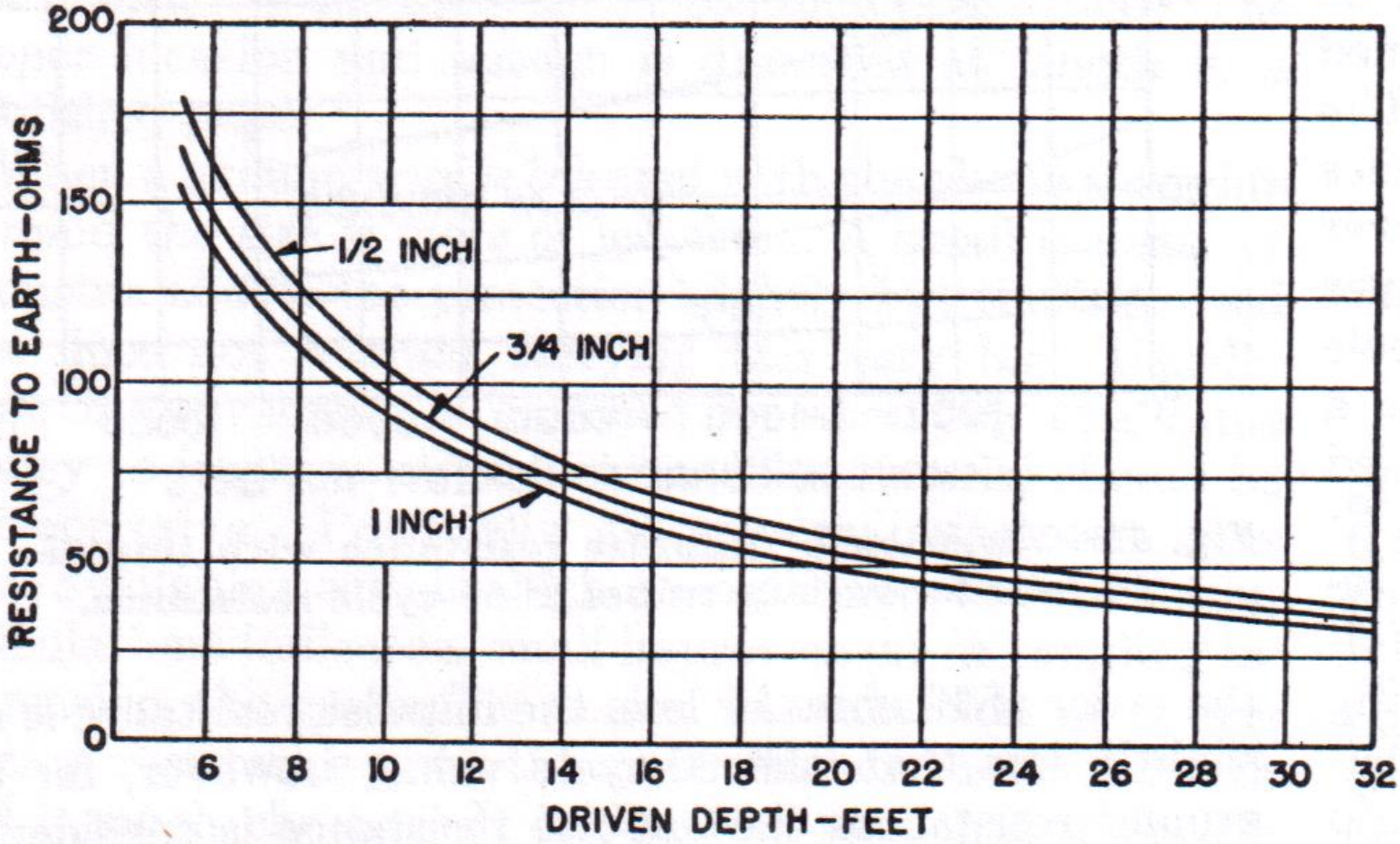
if *A*>20*B*, then ρ 1.915 *AR*

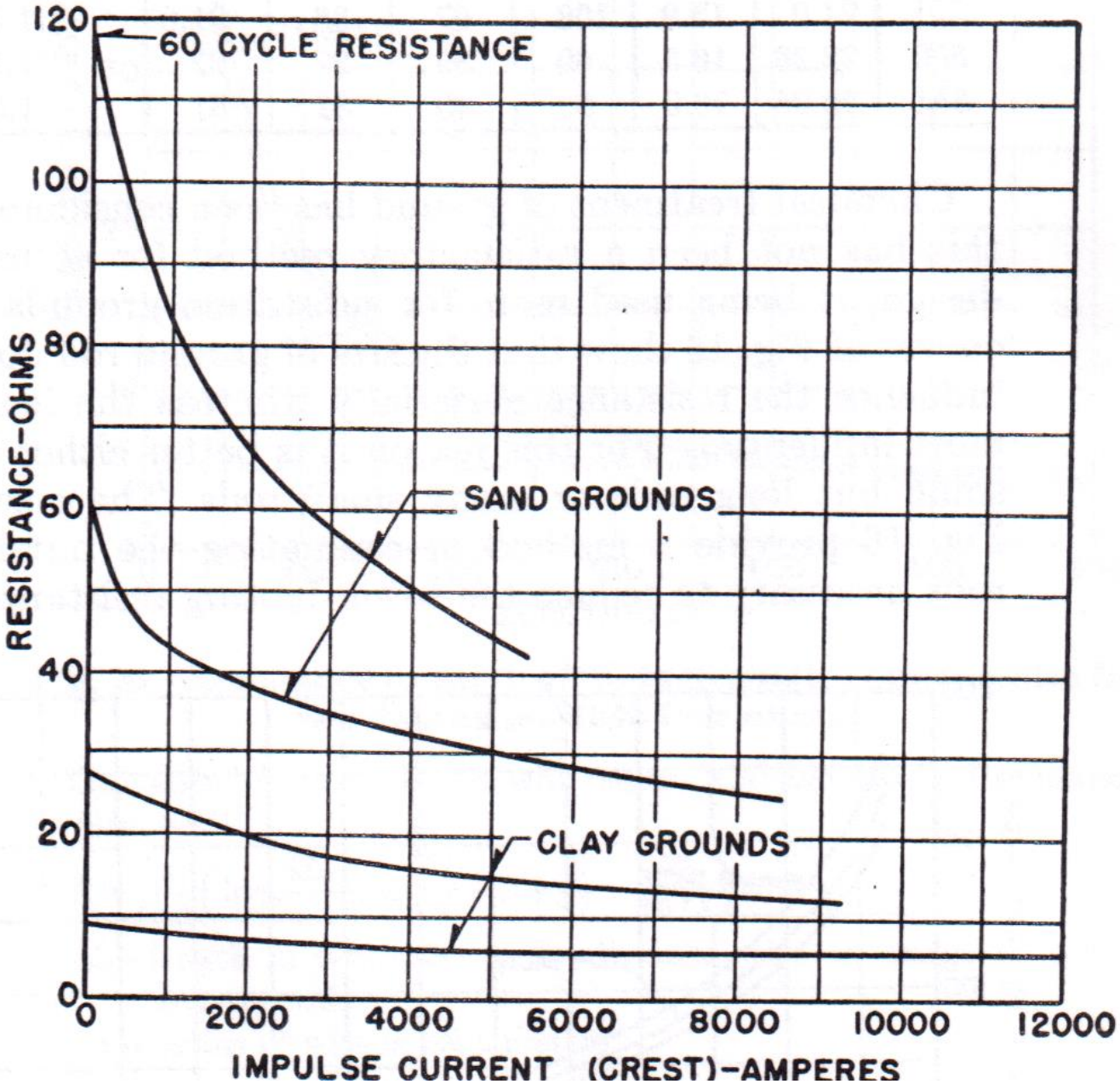
$$R = \rho \frac{L}{A}$$

- R- Resistance for a straight conductor, in Ω
- L – Length of conductor, in m
- A- Area of conductor, in m^2
- Soil Resistivity 'ρ '- specific resistivity in Ω/m


TRANSIENT IMPEDANCE (OHMS)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
MICROSECONDS
N=4
S
Z=150=SURGE IMPEDANCE (INITIAL)
R= 10=LEAKAGE RESISTANCE
N=NUMBER OF WIRES
NS=1000'=TOTAL LENGTH OF WIRE
1
2
3
4
N
LEAKAGE RESISTANCE


1.8
1.6
1.4
1.2
1.0
RATIO
C
B
A
0
20
40
60
80
100
SPACING-FEET


200
150
100
50
0
RESISTANCE TO EARTH—OHMS
1/2 INCH
3/4 INCH
1 INCH
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DRIVEN DEPTH—FEET


120
100
80
60
40
20
0
RESISTANCE-OHMS
60 CYCLE RESISTANCE
SAND GROUNDS
CLAY GROUNDS
0
2000
4000
6000
8000
10000
12000
IMPULSE CURRENT (CREST)-AMPERES

Different Equipment and Grounding Connection

Apparatus	Connection to Earthing System
Power Transformer	1. Earthing bolt of transformer 2. Neutral
HV Circuit Breaker	1. Operating mechanism 2. Earthing bolt on frame
Surge Arrester	Directly
Support of bushing and lightning arrester	Earthing bolt on device flange or base plate
Potential Transformer	1. Earthing bolt on tank 2. LV Neutral of phase leads terminated through flexible copper conductor to case of transformer
Isolator	1. Welded Base frame 2. Bolt on operating mechanism 3. Base plate
Current Transformer	1. Earthing Bolt 2. Secondary Winding terminated through flexible copper conductor top case of transformer

Human body resistance

Body Conditions	**Resistance (in Ω)**
A. Dry Skin	100K to 600 K
B. Wet Skin	1K
C, Internal Body	
a. Hand to foot	400 to 600
b. Ear to Ear	≈100

Current Involved in Electric Shock

- **Will the 120 volt common household voltage produce a dangerous shock? It depends!**
- If your body resistance is 100,000 ohms, then the current which would flow would be:

$$I = \frac{120 \text{ volts}}{100{,}000\ \Omega} = .0012\ \text{A} = 1.2\ \text{mA}$$

This is just about at the threshold of perception, so would produce only a tingle.

Paths of Flow of Current through Human Body

1. Hand to Head
2. Hand to Hand
3. Head to Leg
4. Hand to Leg
5. Leg to Leg

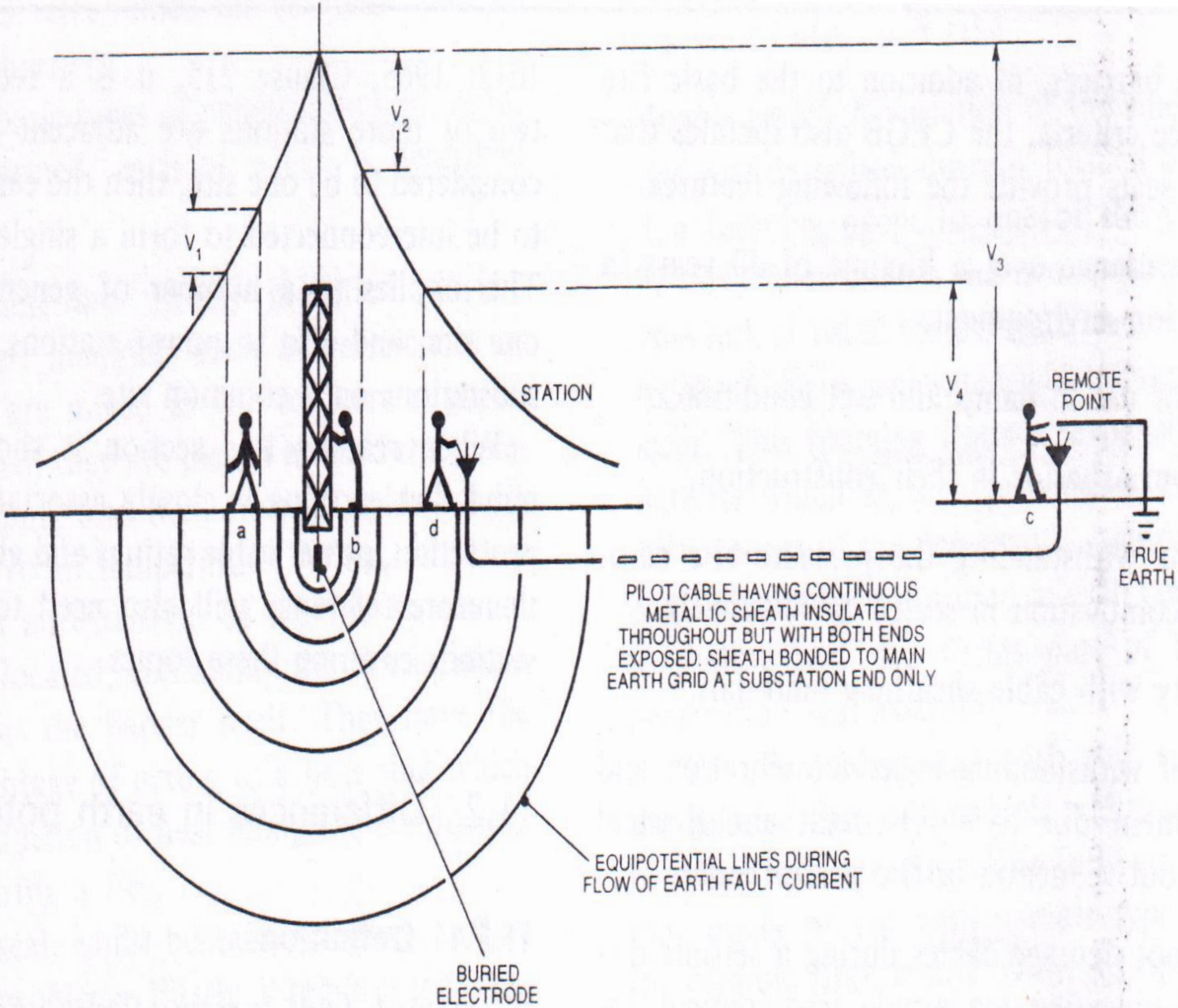
ALLOWABLE BODY CURRENT I_B

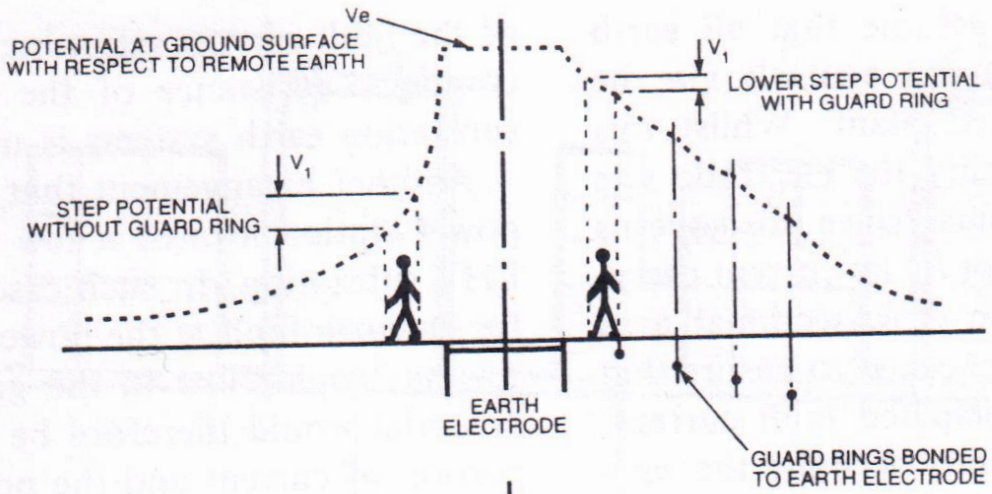
[AS PER IEEE STD- 80]

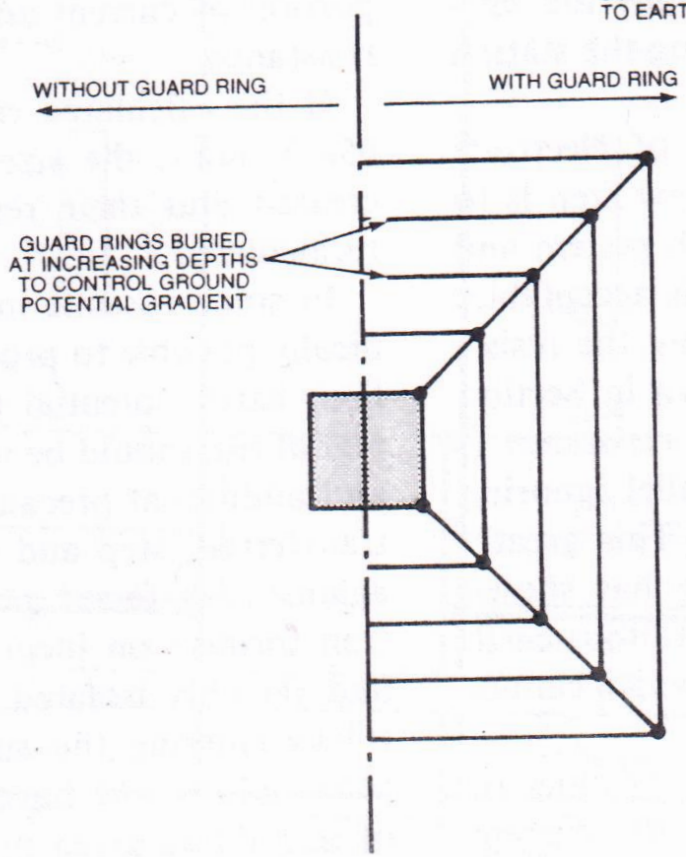
T_S : DURATION OF CURRENT EXPOSURE
(FAULT CLEARENCE TIME)

T_S	I_B (50 Kg)	I_B(70 Kg)
0.2 SEC	259 mA	351 mA
0.5 SEC	164 mA	222 mA
1 SEC	116 mA	157 mA

FIG_EA_32


V2
V1
V3
V4
STATION
REMOTE POINT
a
b
d
c
TRUE EARTH
PILOT CABLE HAVING CONTINUOUS METALLIC SHEATH INSULATED THROUGHOUT BUT WITH BOTH ENDS EXPOSED. SHEATH BONDED TO MAIN EARTH GRID AT SUBSTATION END ONLY
EQUIPOTENTIAL LINES DURING FLOW OF EARTH FAULT CURRENT
BURIED ELECTRODE


Ve
POTENTIAL AT GROUND SURFACE
WITH RESPECT TO REMOTE EARTH
V_1
LOWER STEP POTENTIAL
WITH GUARD RING
V_1
STEP POTENTIAL
WITHOUT GUARD RING
EARTH
ELECTRODE
GUARD RINGS BONDED
TO EARTH ELECTRODE


WITHOUT GUARD RING
WITH GUARD RING
GUARD RINGS BURIED
AT INCREASING DEPTHS
TO CONTROL GROUND
POTENTIAL GRADIENT

SWITCHYARD GROUNDING DESIGN

1. GPR, SV AND TV

- GPR : GROUND POTENTIAL RISE
- MAXIMUM VOLTAGE THAT STATION GROUNDING GRID MAY ATTAIN RELATIVE TO DISTANCE GROUNDING POINT ASSUMED TO BE AT THE POTENTIAL OF REMOTE EARTH
- GPR PROPORTIONAL TO I_{GRID} & R_{GRID}
- $I_{GRID} = S_F \times I_{FAULT}$

  S_F: PERCENTAGE OF FAULT CURRENT DISCHARGED BY GROUNDING GRID TO EARTH
- GPR = $I_{GRID} \times R_{GRID}$

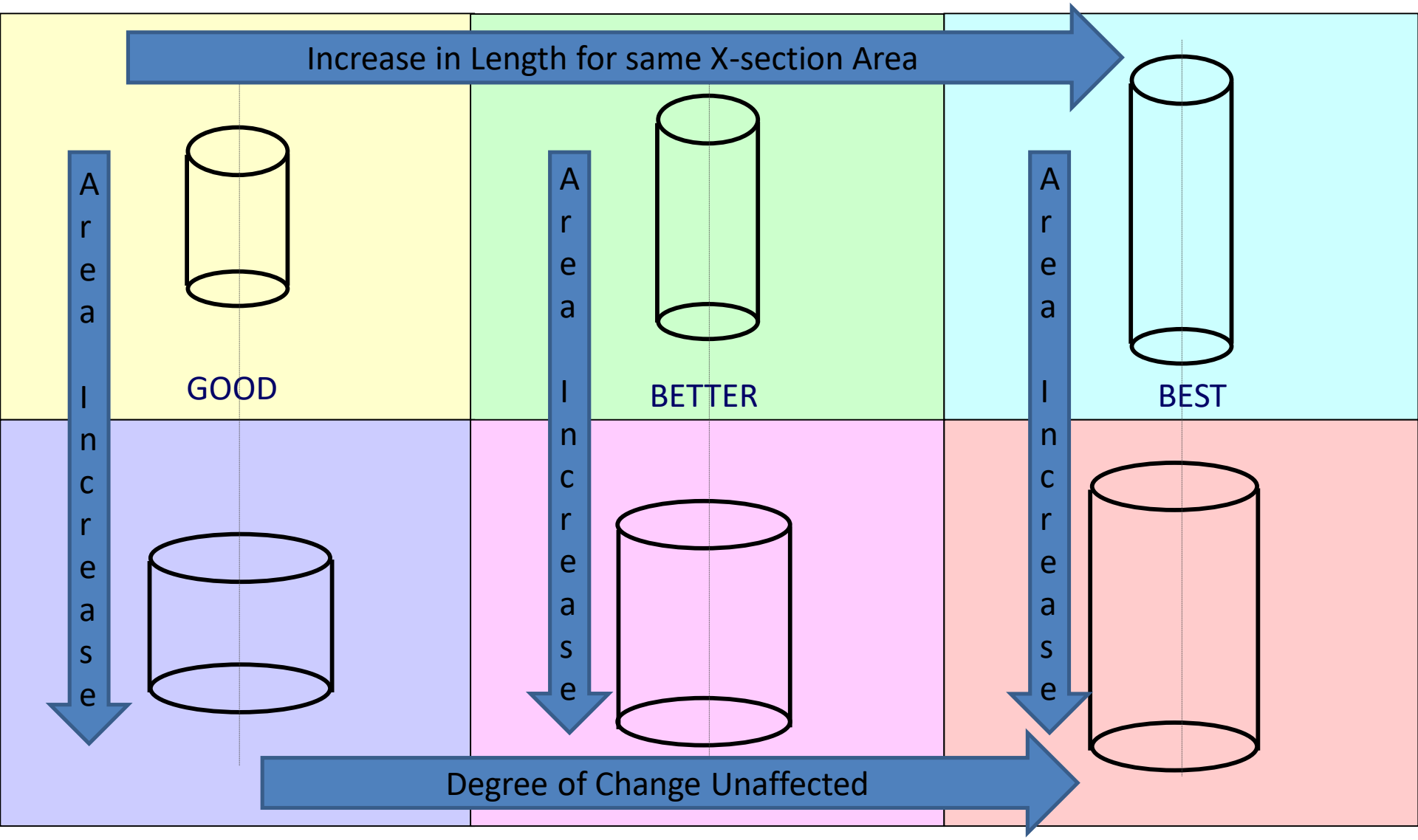
- CONCLUSION
  - EFFECT OF ELECTRODE DIAMETER ON

    GRID RESISTANCE
    STEP POTENTIAL
    TOUCH POTENTIAL

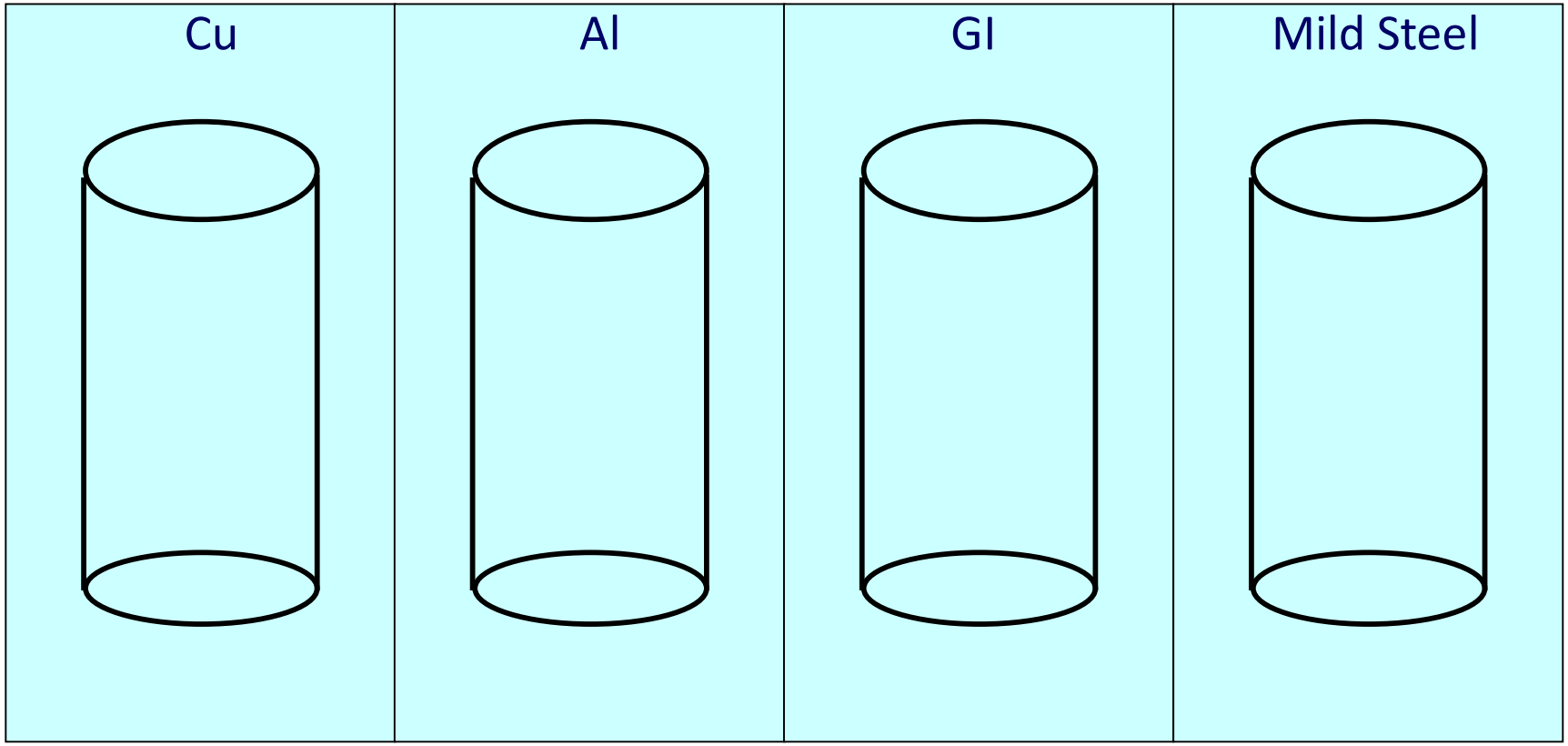
    } VERY MARGINAL

  - EXCEPT FOR CARRYING THE FAULT CURRENT FOR SPECIFIED TIME, CONDUCTOR CROSS SECTION PLAYS VERY MINOR PART IN GROUND GRID DESIGN.

Effect of Dimensions of Electrode on Earth Resistance

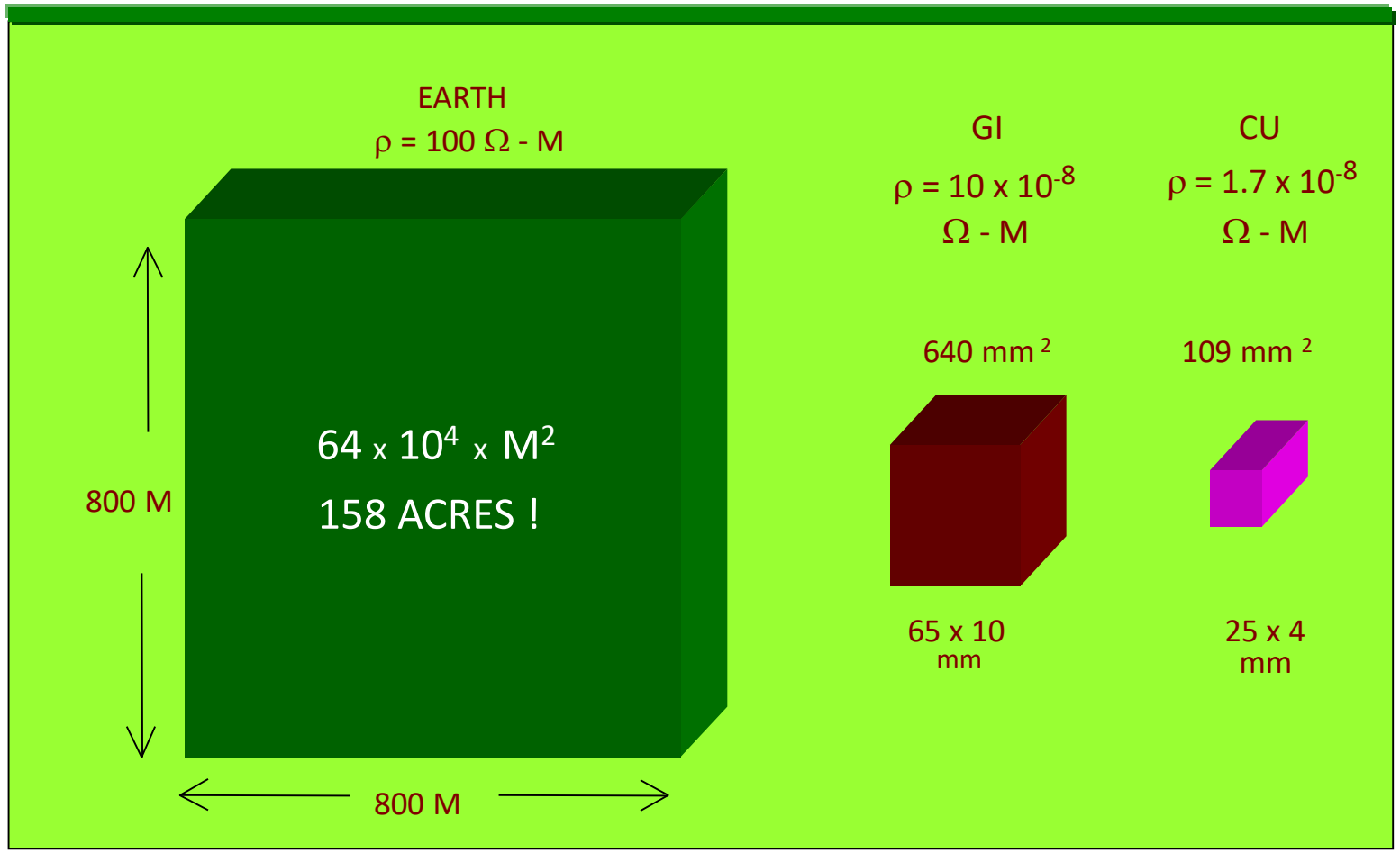


Effect of Material on Electrode Resistance
(Same Dimensions of Electrode)



$R_{electrode}$: Unaffected

Comparison X-Sectional Area vis-à-vis Resistivity Amongst Commonly used Substance in Earthing System



CURRENT RATING IN AMPS / mm^2 (IS 3043)

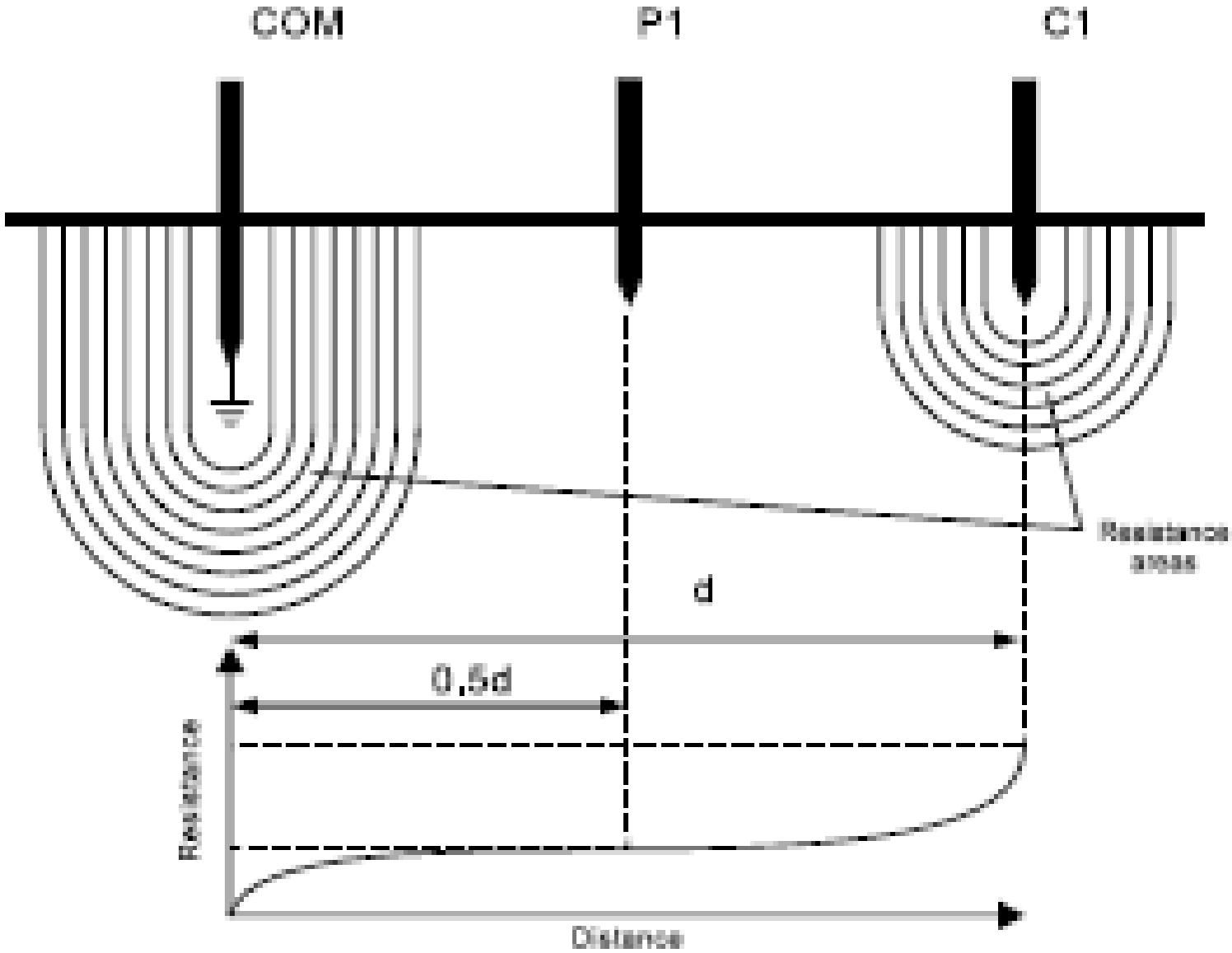
MATERIAL	GI	COPPER	ALUMINUM
0.5 SEC RATING	113	290	178
1 SEC RATING {K}	80	205	126
3 SEC RATING	46	118	73

FAULT CURRENT: 40 kA

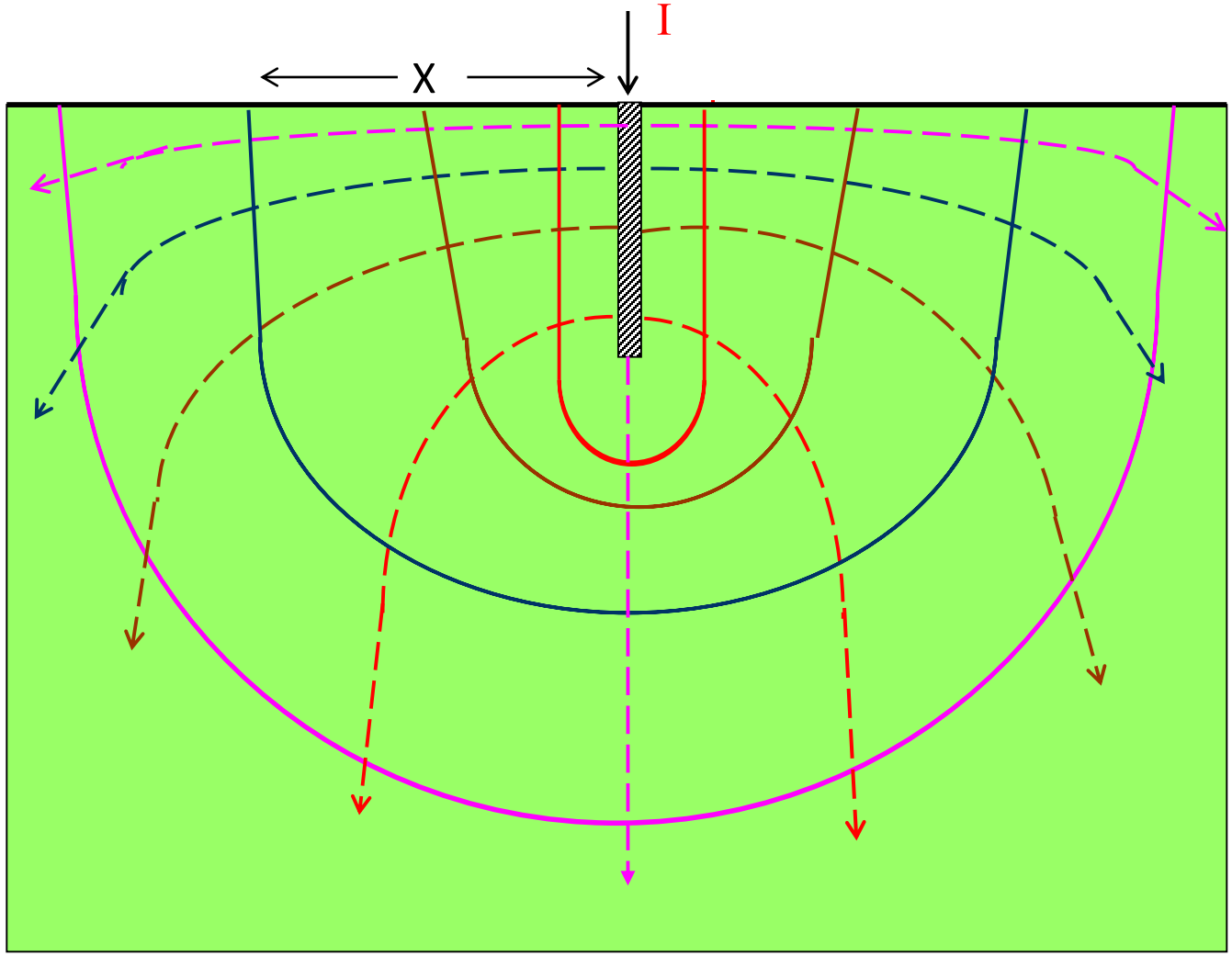
FAULT DURATION: 0.5 SEC

MATERIAL: GI

ESTIMATE MINIMUM SIZE?

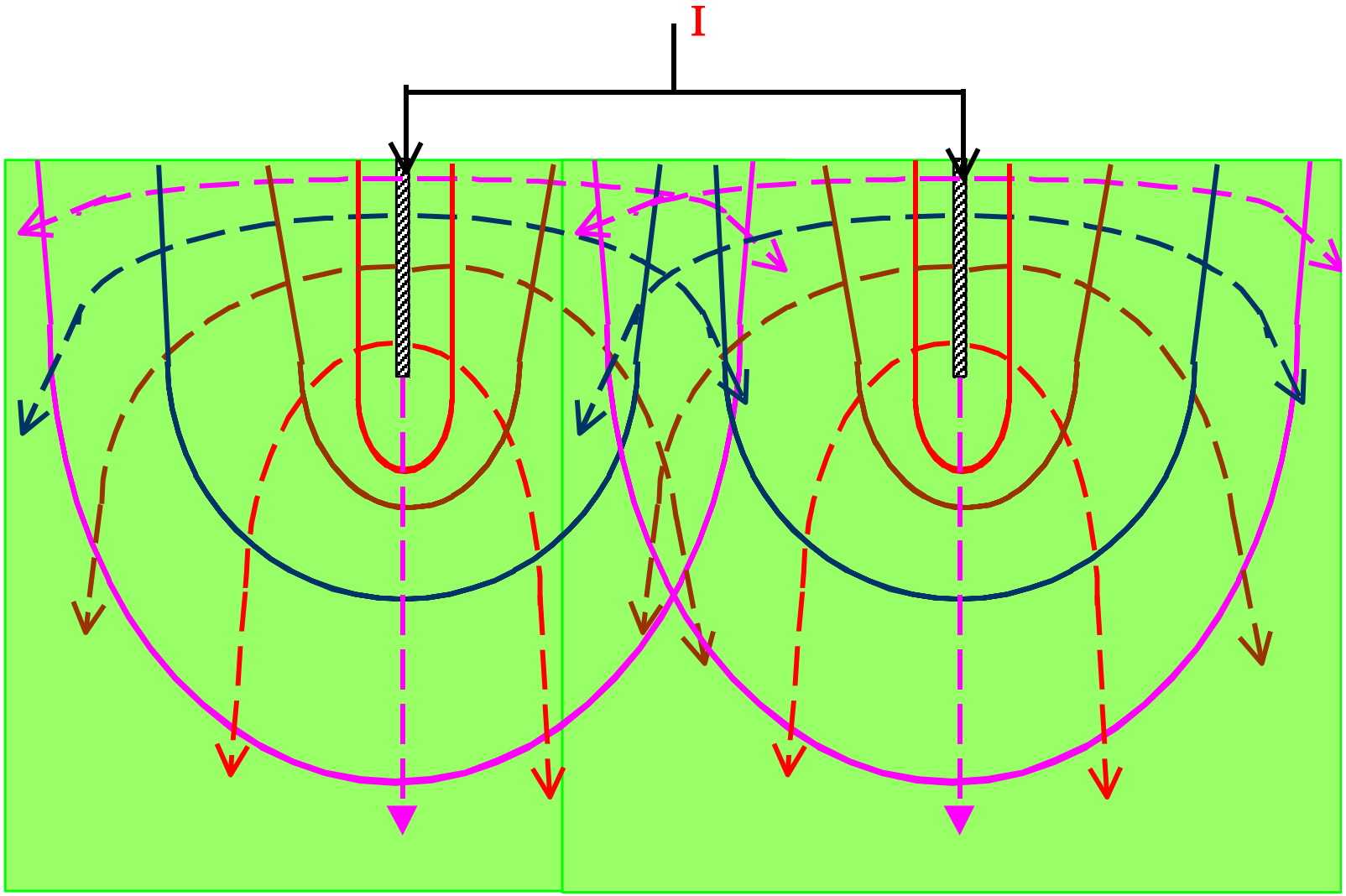

COM
P1
C1
Resistance
d
0,5d
Resistance
Distance

RESISTANCE AREA OF DRIVEN EARTH ROD

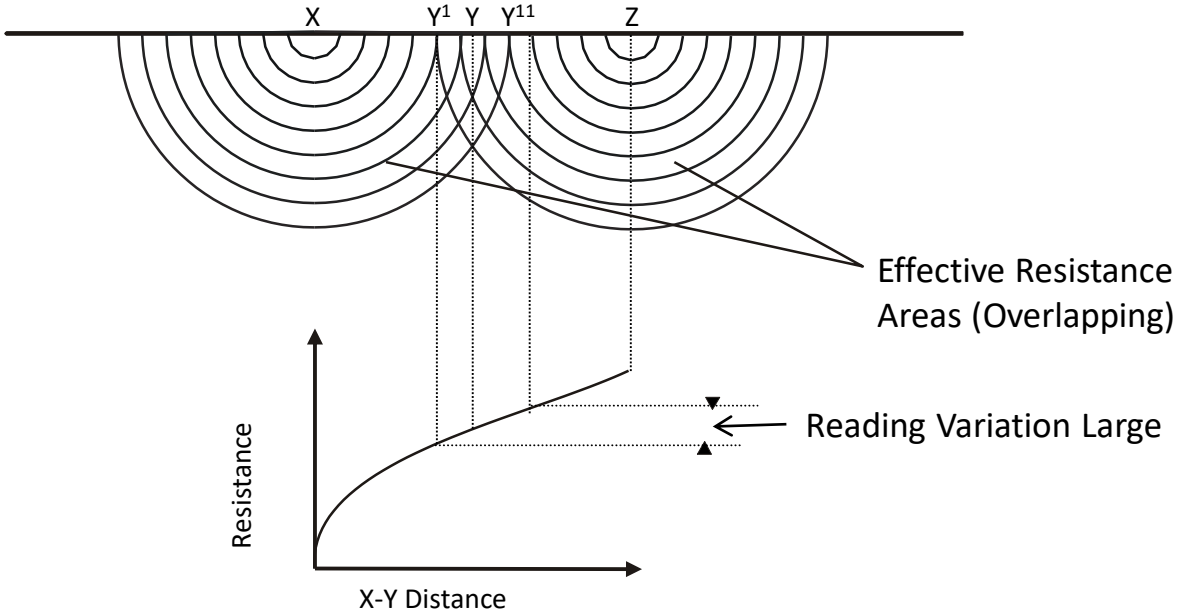


AS X ⇒ VERY HIGH, SHELL ⇒ HEMI SPHERE

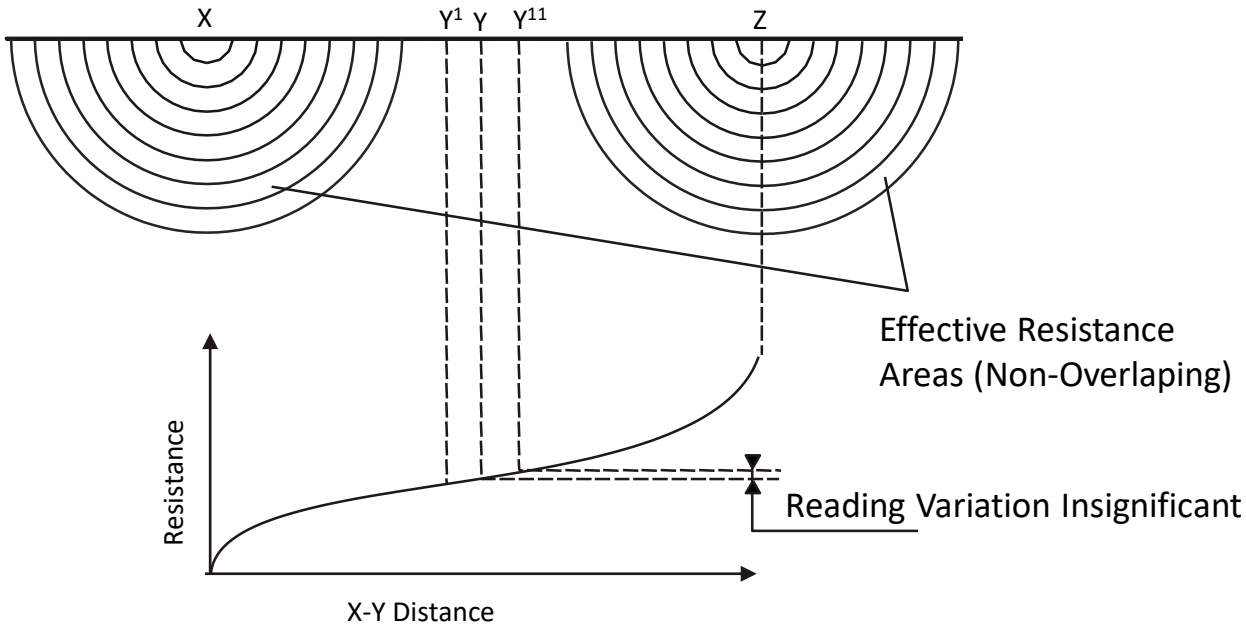
OVER LAPPING RESISTANCE AREAS OF TWO EARTH RODS



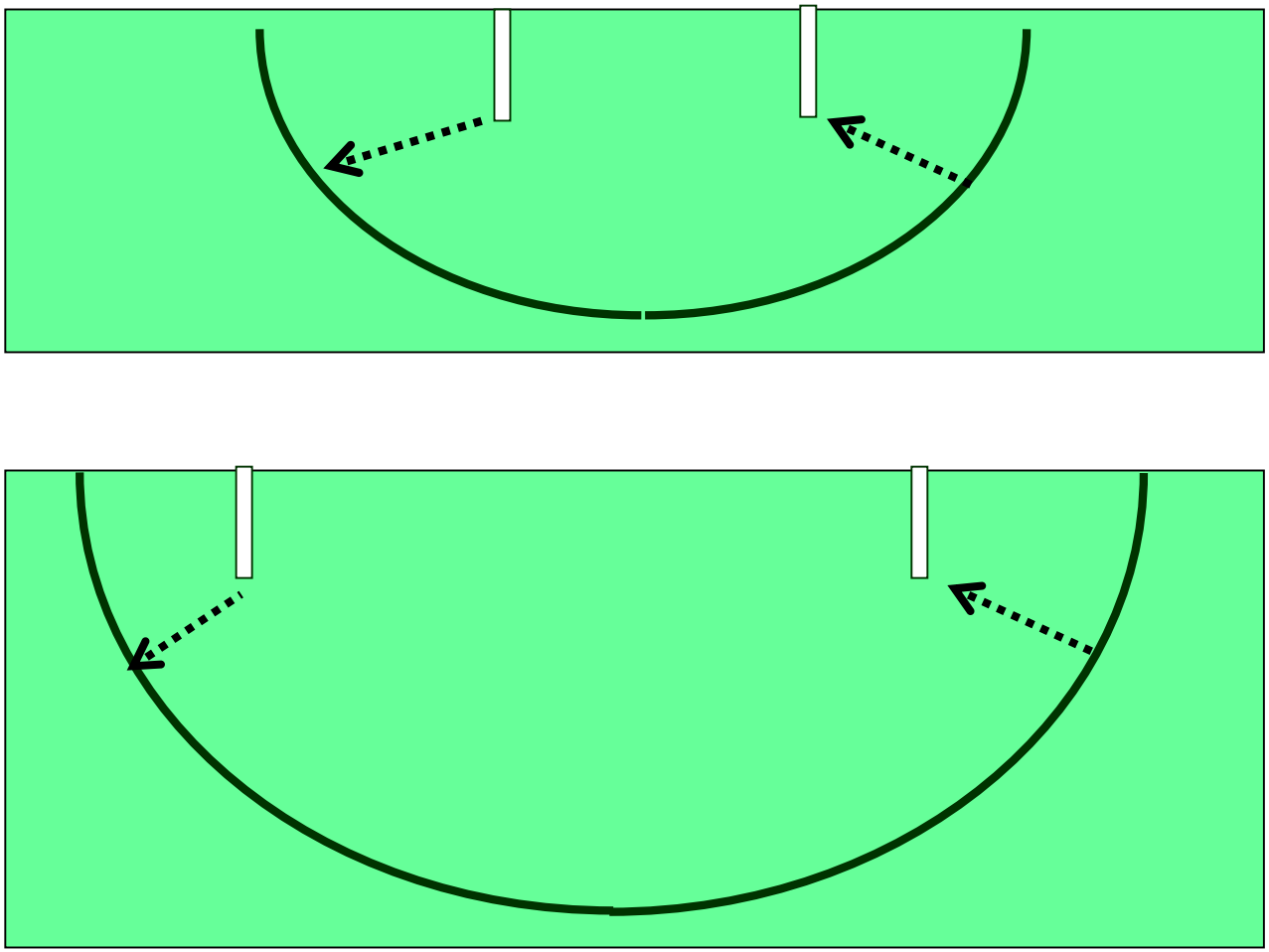
Variation of Resistance (Concentric Shells of earth overlapping)



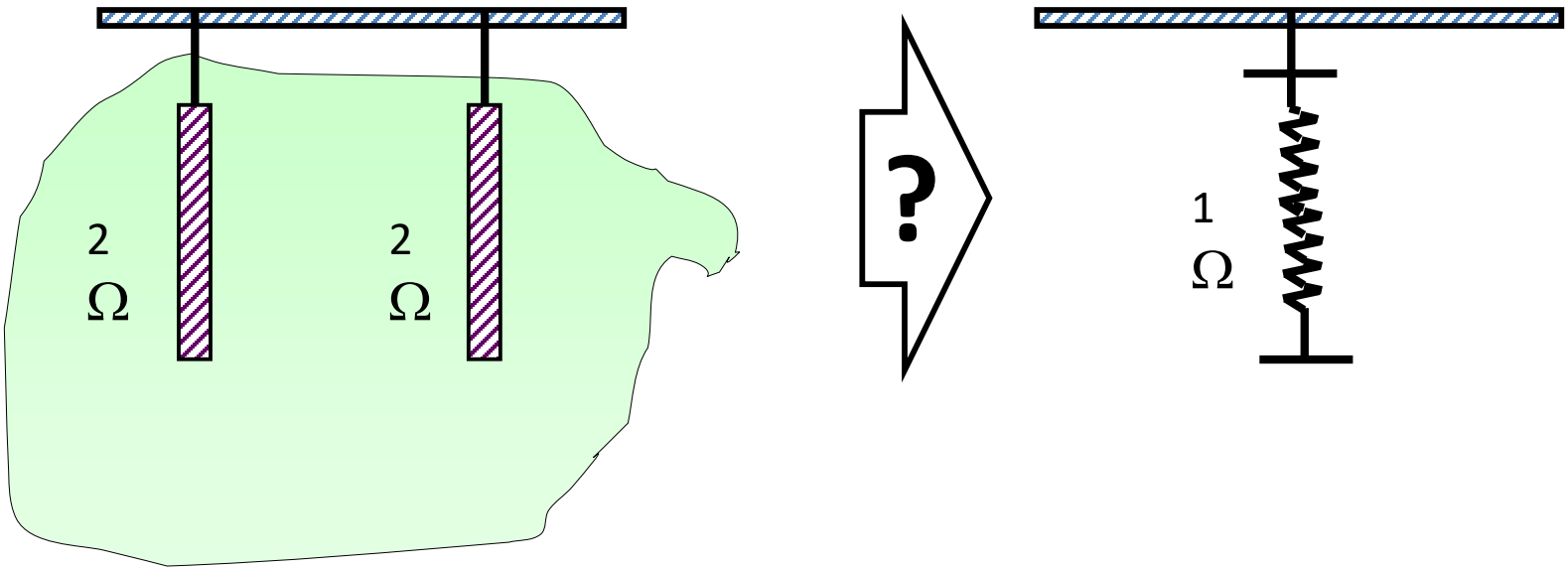
Variation of Resistance (Concentric Shells Non-Overlapping)



SPACING vs DEPTH

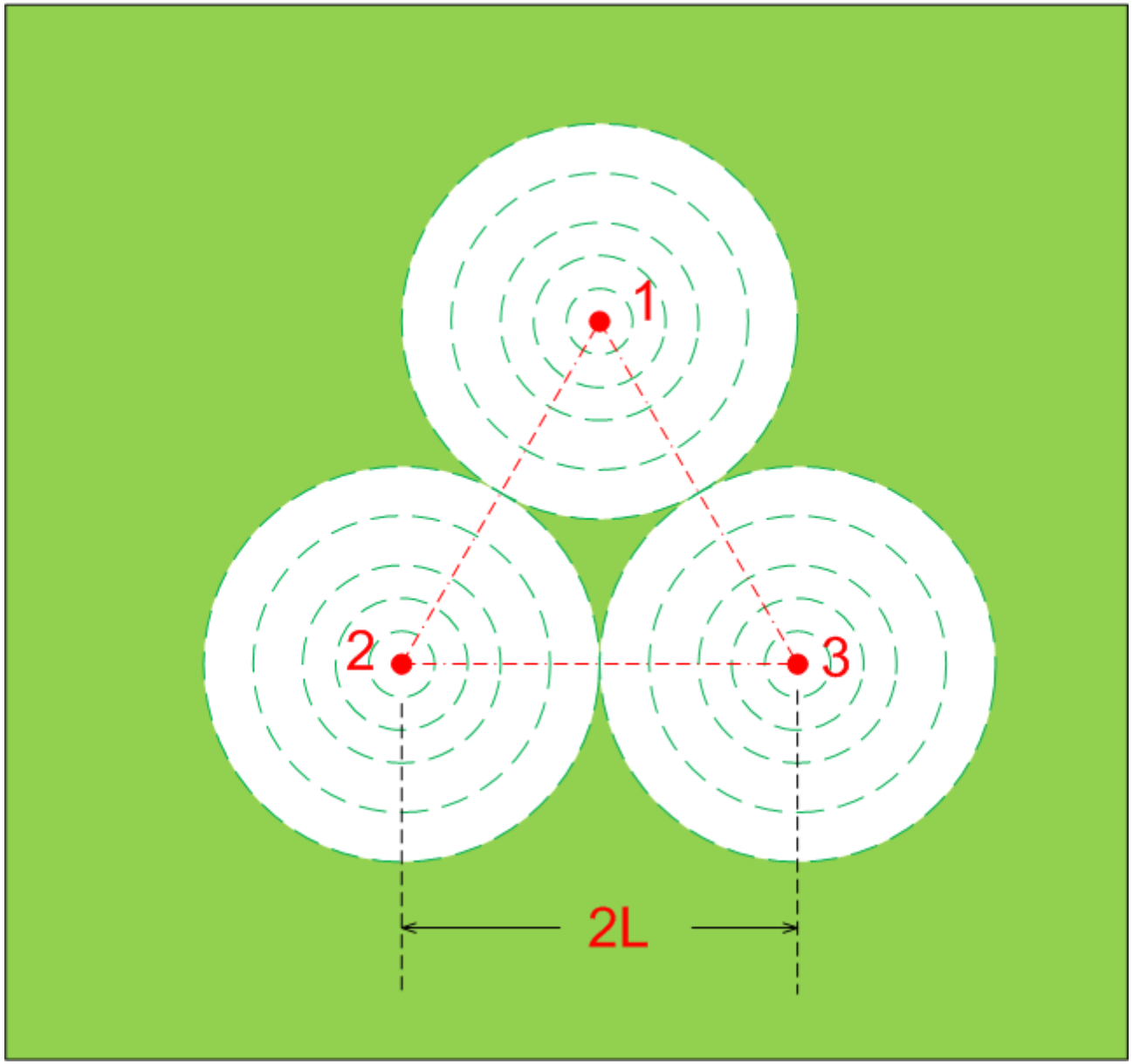


DRIVEN RODS OR PIPE ELECTRODES - Two Parallel



Incremental gain in Earth Resistance with Parallel Electrodes is Not Linear

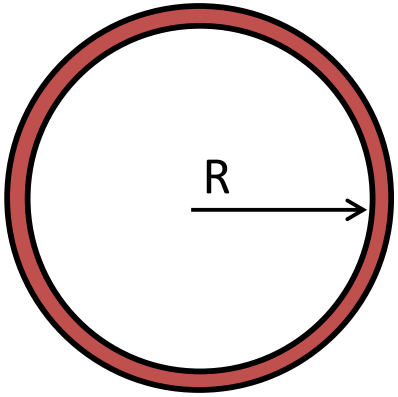
Mutual Resistance has a role to play


1
2
3
2L

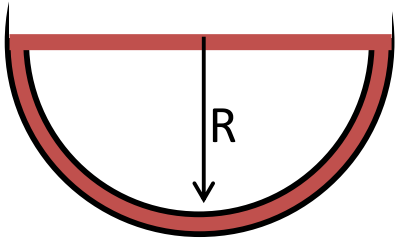
Effect of Length and Diameter of Rod/pipe on its Earth Resistance

- Diameter
  - Minor Influence On Earth Resistance
  - Affects Current Carrying Capability
- Length
  - Major Influence
  - Affects Current Dissipation in Earth
  - Length >3 Meter incremental gain is of diameter increase is insignificant

RESISTANCE TO EARTH OF HEMI- SPHERICAL ELECTRODE

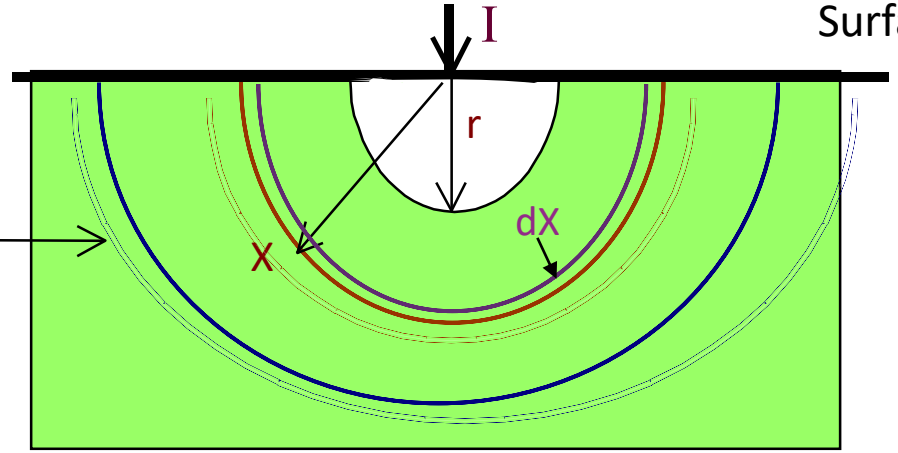


Surface Area 'A' = 4 π R^2



Surface Area 'A' = 2π R^2

HEMI-SPHERICAL SHELLS



$$R = \int_r^\infty \frac{\rho dx}{2\pi x^2} = \frac{\rho}{2\pi}\left[-\frac{1}{x}\right]_r^\infty$$

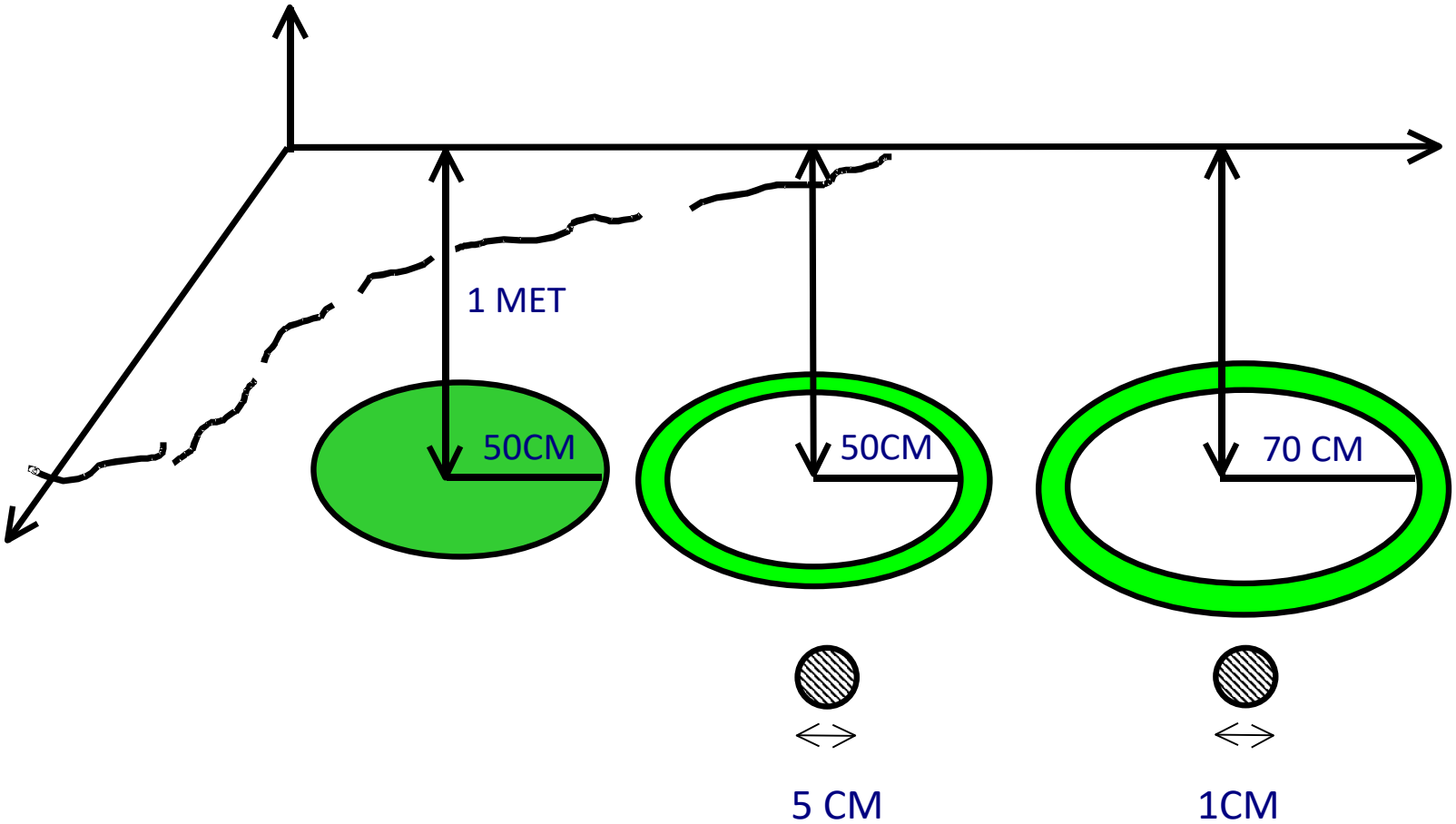
$$= \frac{\rho}{2\pi r}$$

- Approximation of Resistance at distance 'L'

$$R_L = \frac{\rho L}{A}$$

- Variation of Resistance, experimental, validates this formulation
- Within 5 meters 90% of R_∞

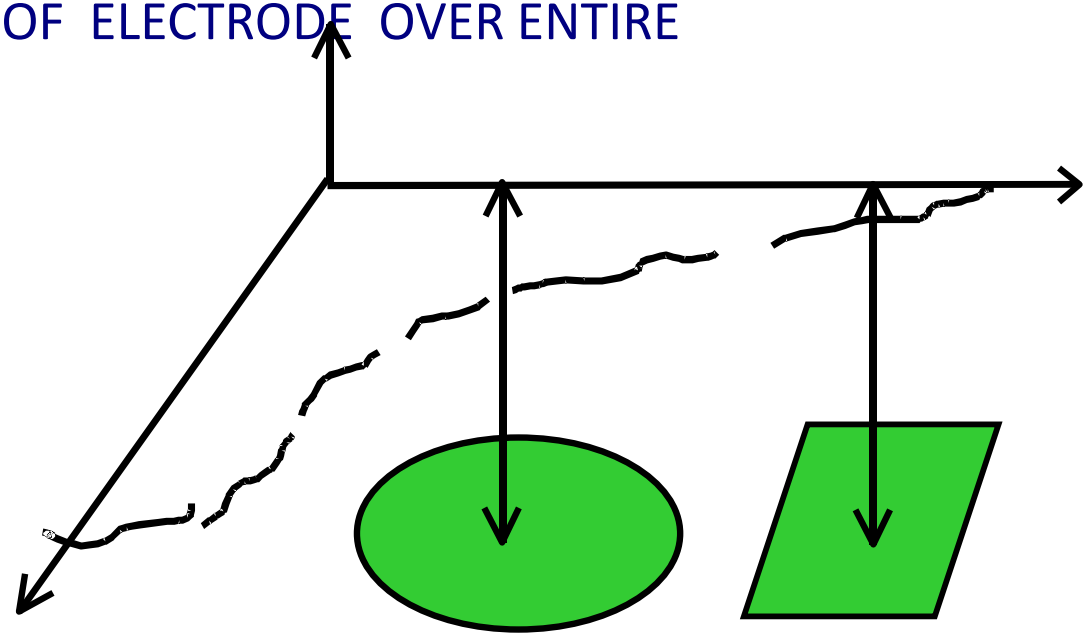
RESISTANCE TO EARTH OF PLATE ELECTRODES



R = 29.2 Ω IN ALL THREE CASES

PLATE ELECTRODES

- FIRST TYPE OF ELECTRODES USED IN EARLY DAYS
- IT WAS ASSUMED THAT TO GET LOW RESISTANCE, SURFACE AREA OF ELECTRODE BE INCREASED
- THIS FALLACY HAS PERSISTED FOR A VERY LONG TIME
- IN SOME CASES, EFFORTS WERE MADE TO EXTEND THE SURFACE AREA OF ELECTRODE OVER ENTIRE BUILDING SITE!



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- Length
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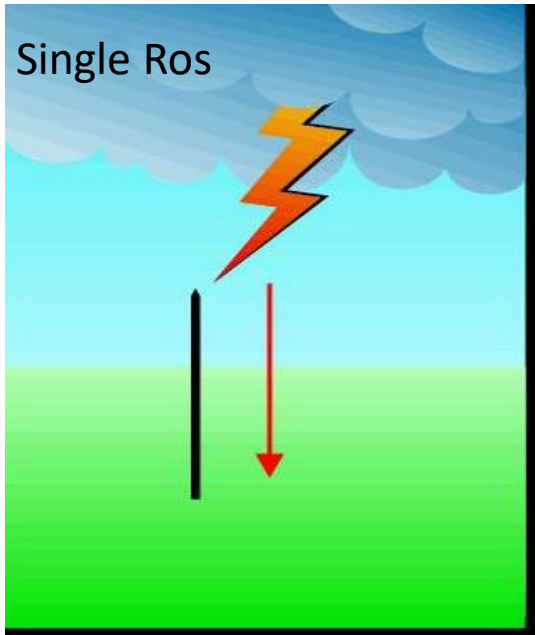
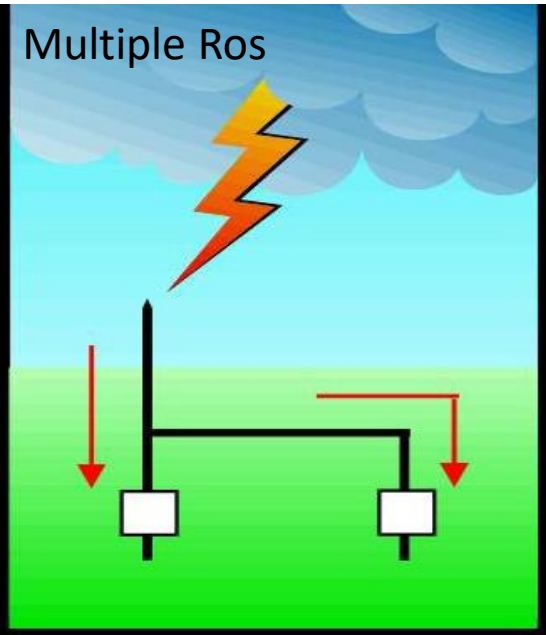
  - Length >3 Meter incremental gain of diameter increase is insignificant

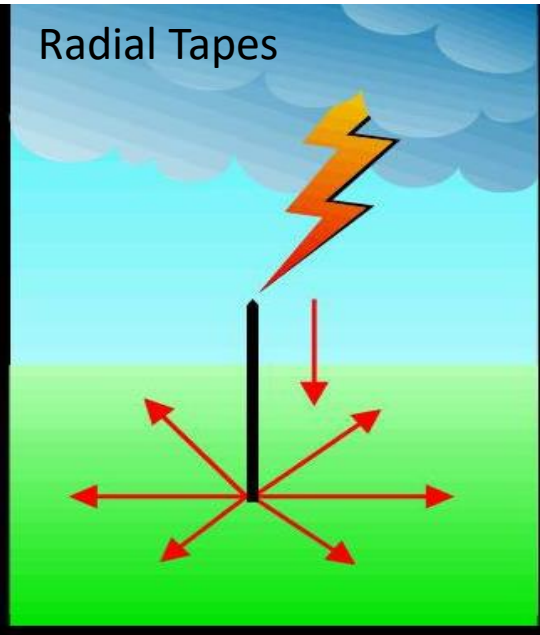
$$R = \rho \frac{L}{A}$$

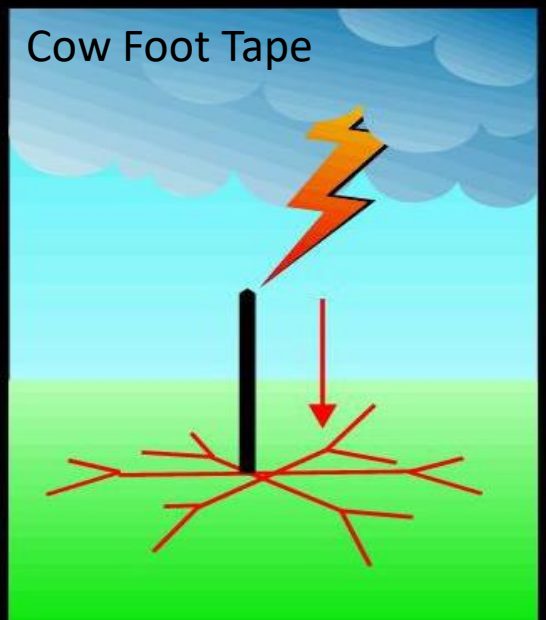
- R- Resistance for a straight conductor, in Ω
- L – Length of conductor, in m
- A- Area of conductor, in m^2
- Soil Resistivity 'ρ '- specific resistivity in Ω/m

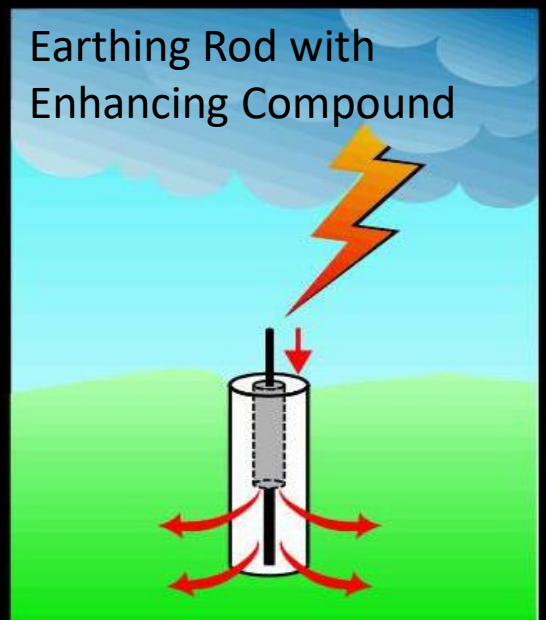
Methods of Earthing for Lightning Protection [Earthing.pdf]







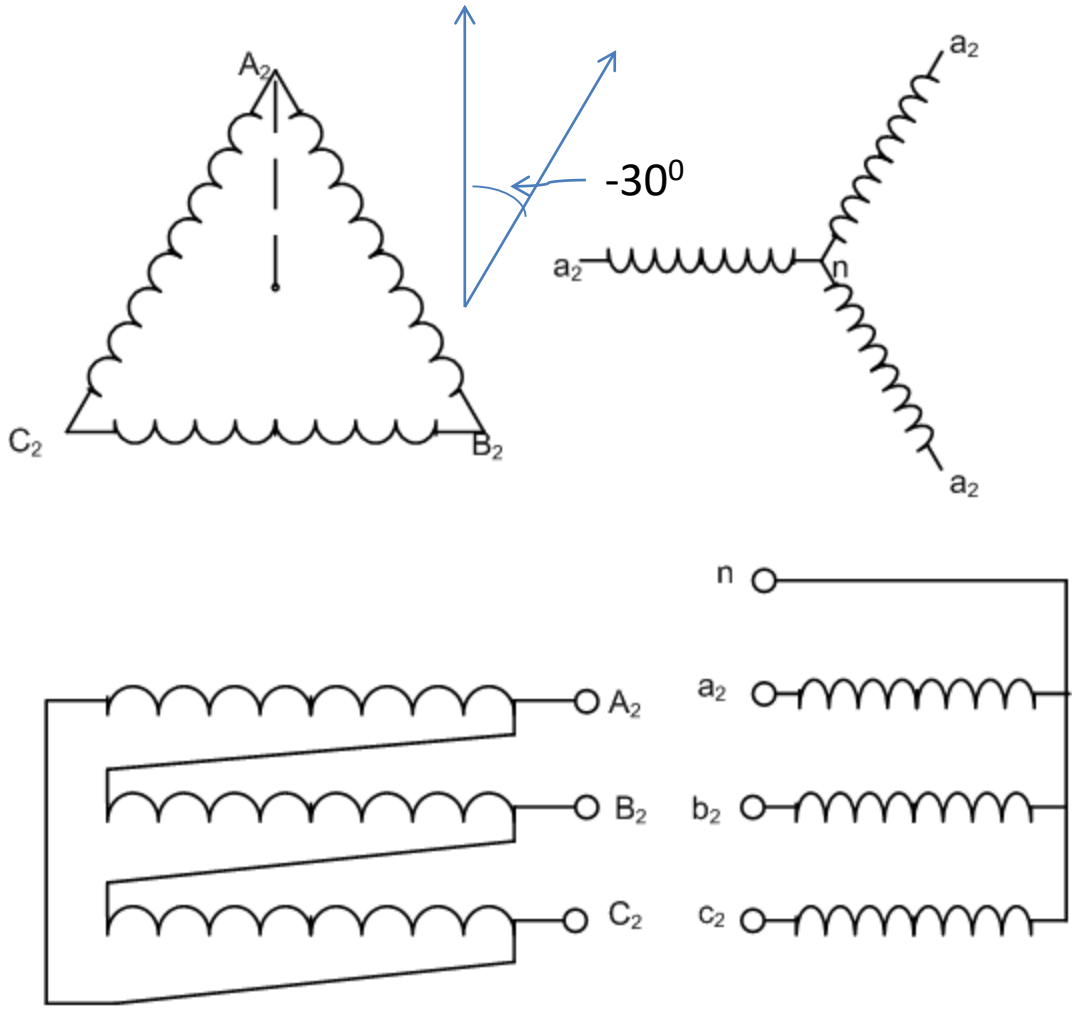




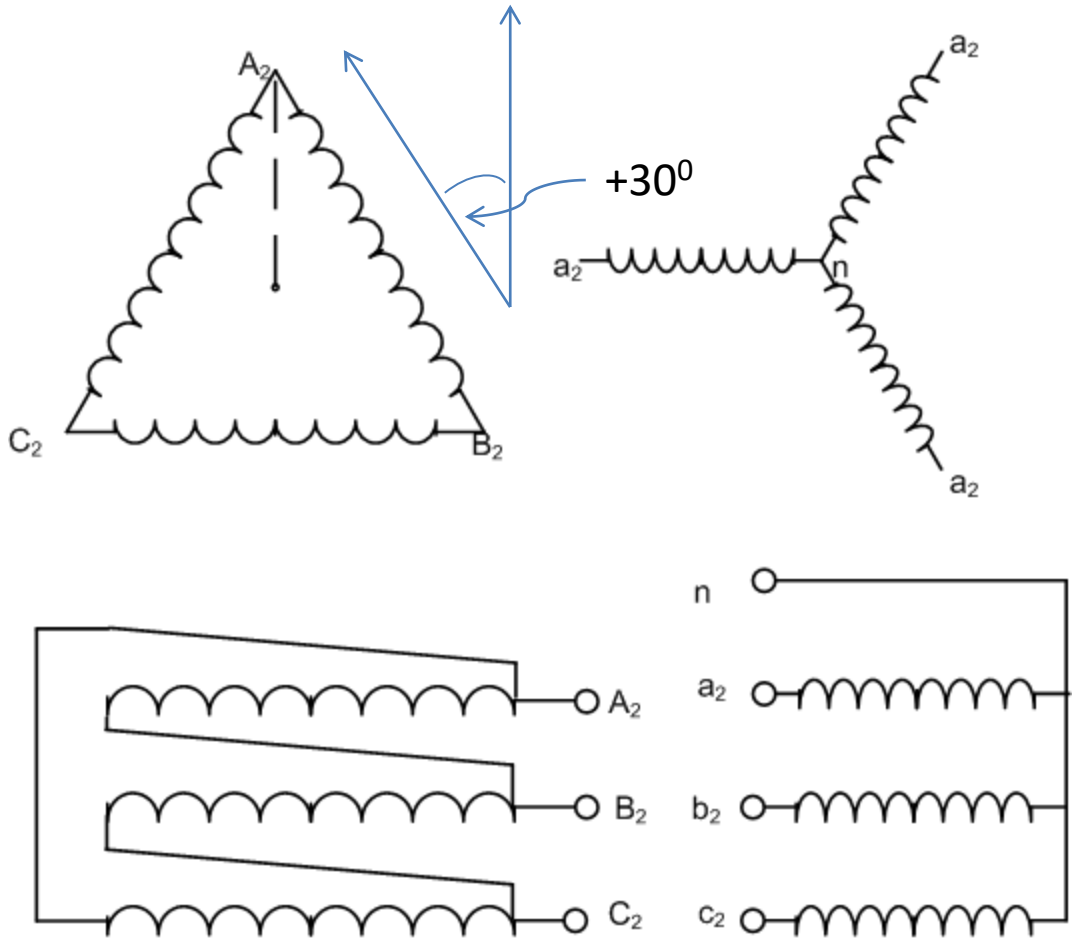
- Earth Resistance
  - Resistivity
  - Moisture
  - Chemical Composition of soil
  - Geometry

Different Equipment and Grounding Connection

Apparatus	Connection to Earthing System
Power Transformer	1. Earthing bolt of transformer 2. Neutral
HV Circuit Breaker	1. Operating mechanism 2. Earthing bolt on frame
Surge Arrester	Directly
Support of bushing and lightning arrester	Earthing bolt on device flange or base plate
Potential Transformer	1. Earthing bolt on tank 2. LV Neutral of phase leads terminated through flexible copper conductor to case of transformer
Isolator	1. Welded Base frame 2. Bolt on operating mechanism 3. Base plate
Current Transformer	1. Earthing Bolt 2. Secondary Winding terminated through flexible copper conductor top case of transformer

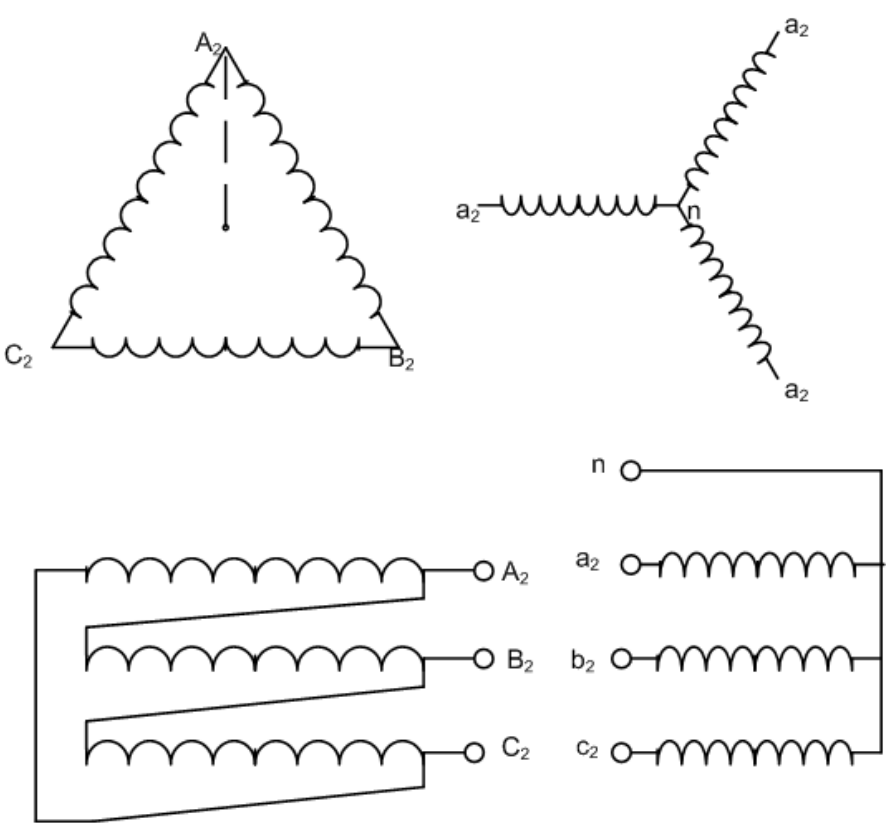


DY1 (-30⁰) Vector Group

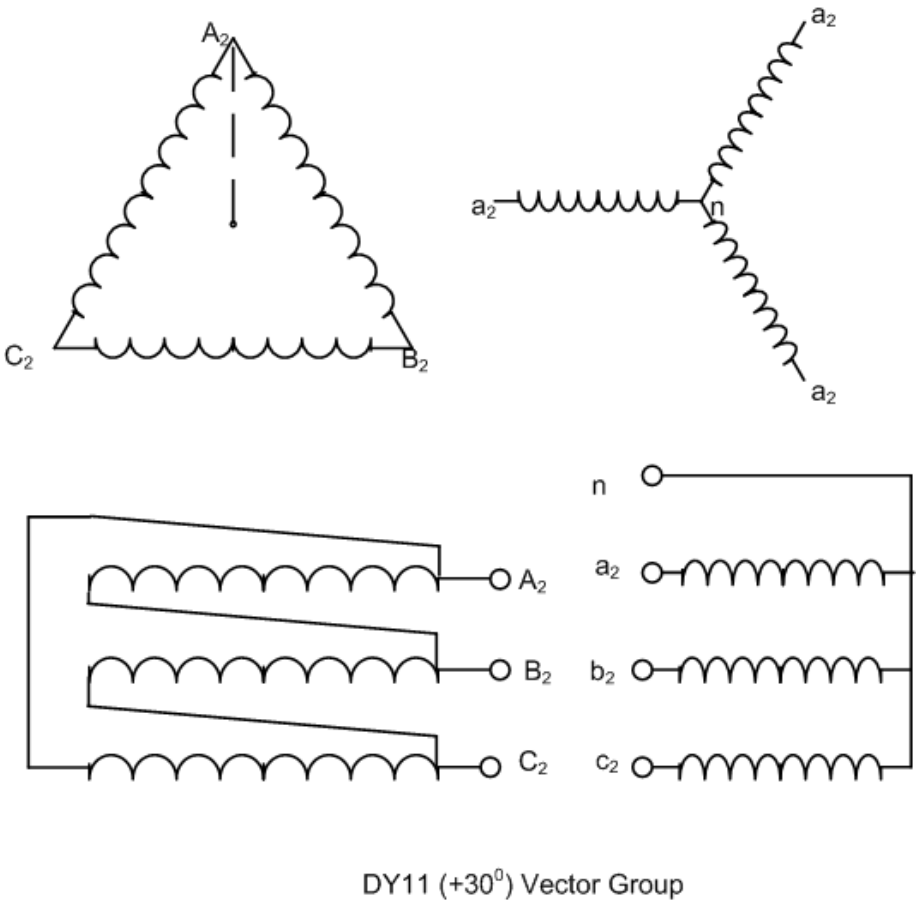


DY11 (+30⁰) Vector Group

What Changes DY1 into DY11 Vector Group??



DY1 (-30^0) Vector Group



DY11 (+30^0) Vector Group