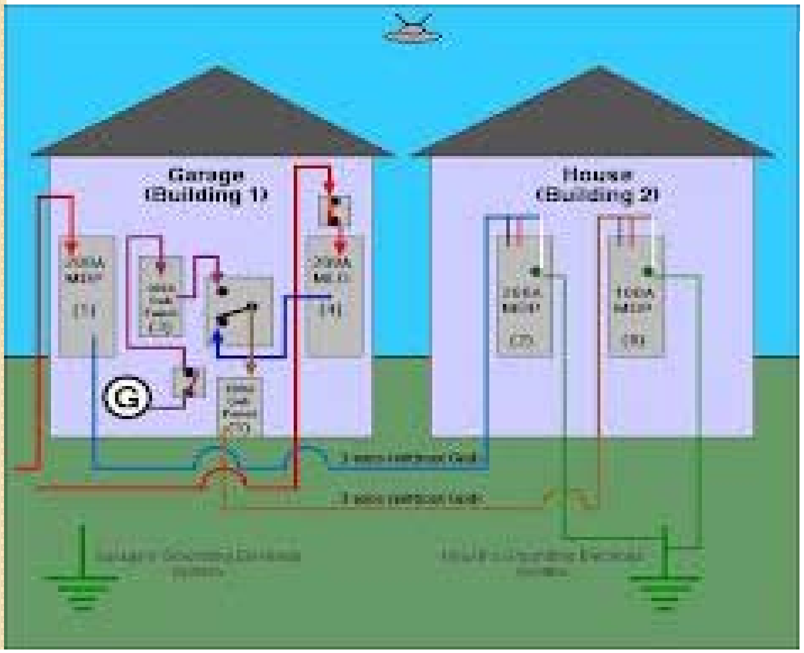
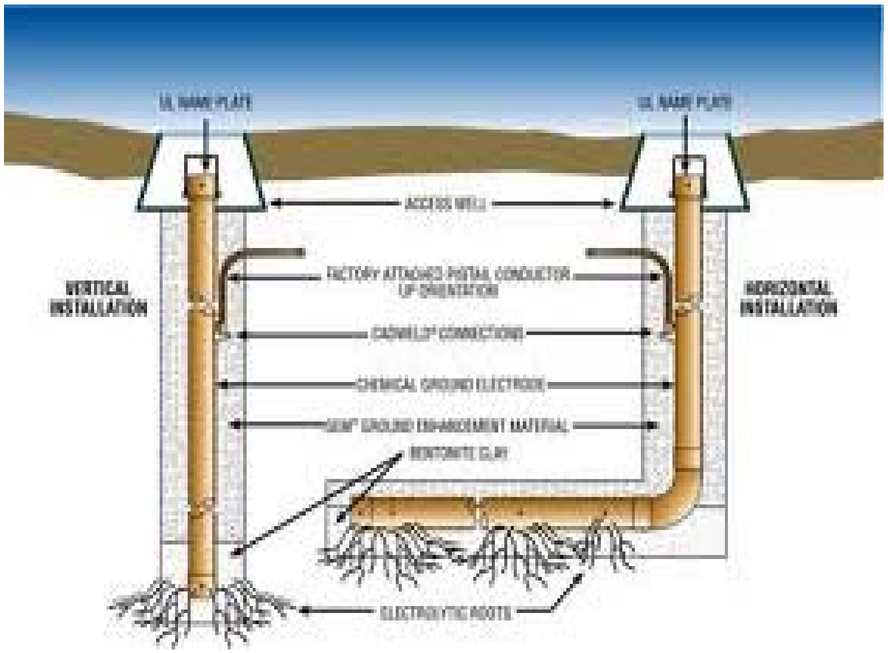
EARTHING SYSTEMS IN LOW VOLTAGE NETWORKS





INTRODUCTION

Electricity is very important in our life, but it also has dangerous problems that have bad effects on the electric power systems and human beings as well.

For the electric power systems

In case of fault conditions, the fault may lead to damage or failure in equipment of the system.

For human being

During these fault conditions, a high potential difference between the metal parts of the system - that should not be carrying current in the normal operation - and earth will be produced, if a man touches these parts, he will be exposed to an electric shock and it can be lethal.

All of these hazards urged the engineers to do something to limit these problems and protect man life. So earthing was introduced.

What is the difference between Neutral and Earth?

NEUTRAL

The neutral is the common point of three star-connected windings.

EARTH

Earth is the conductive mass of earth, whose electric potential at any point is conventionally taken as zero.

GROUND

National Electrical Code (NEC) define ground as: a conductive connection between any circuit/equipment and the earth.

System earthing

is a connection of the current-carrying conductors of a distribution system to the earth.

Safety earthing / Equipment earthing

is a connection of one or more of the non-current carrying metal parts (frames or enclosures) to the earth.

What are the different types of neutral point connection to earth?

The neutral may or may not be not be earthed.

The different types of neutral point connection to earth are:

1. Solidly (or directly) earthed neutral,
2. Unearthed or isolated neutral, or high impedance-earthed neutral,
3. Resistance earthed neutral,
4. reactance earthed neutral,

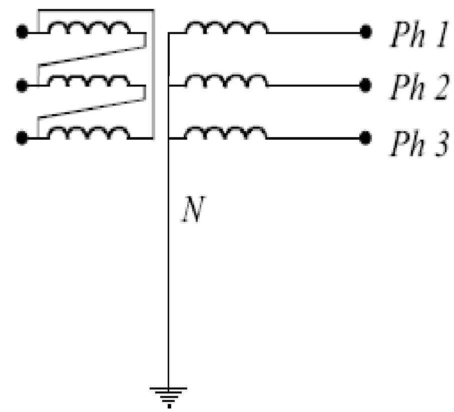
The neutral may be connected to earth either directly or via a resistor or reactor.

When there is no connection between the neutral point and earth, we say that the neutral is isolated or unearthed.

What are the different types of neutral point connection to earth?

Solidly earthed neutral

An electrical connection is intentionally made between the neutral point and earth.

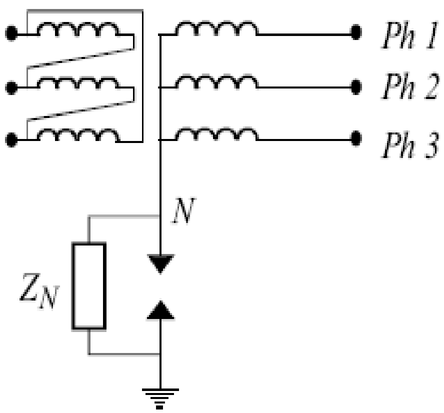


Unearthed neutral

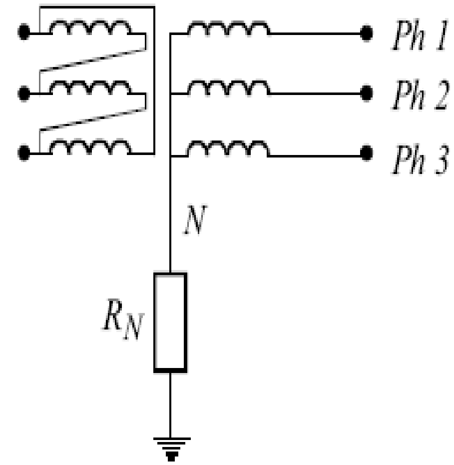
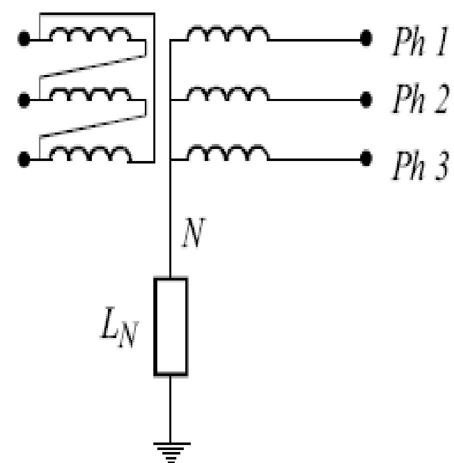
There is no electrical connection between the neutral point and earth, except for measuring and protective devices.

High impedance earthing

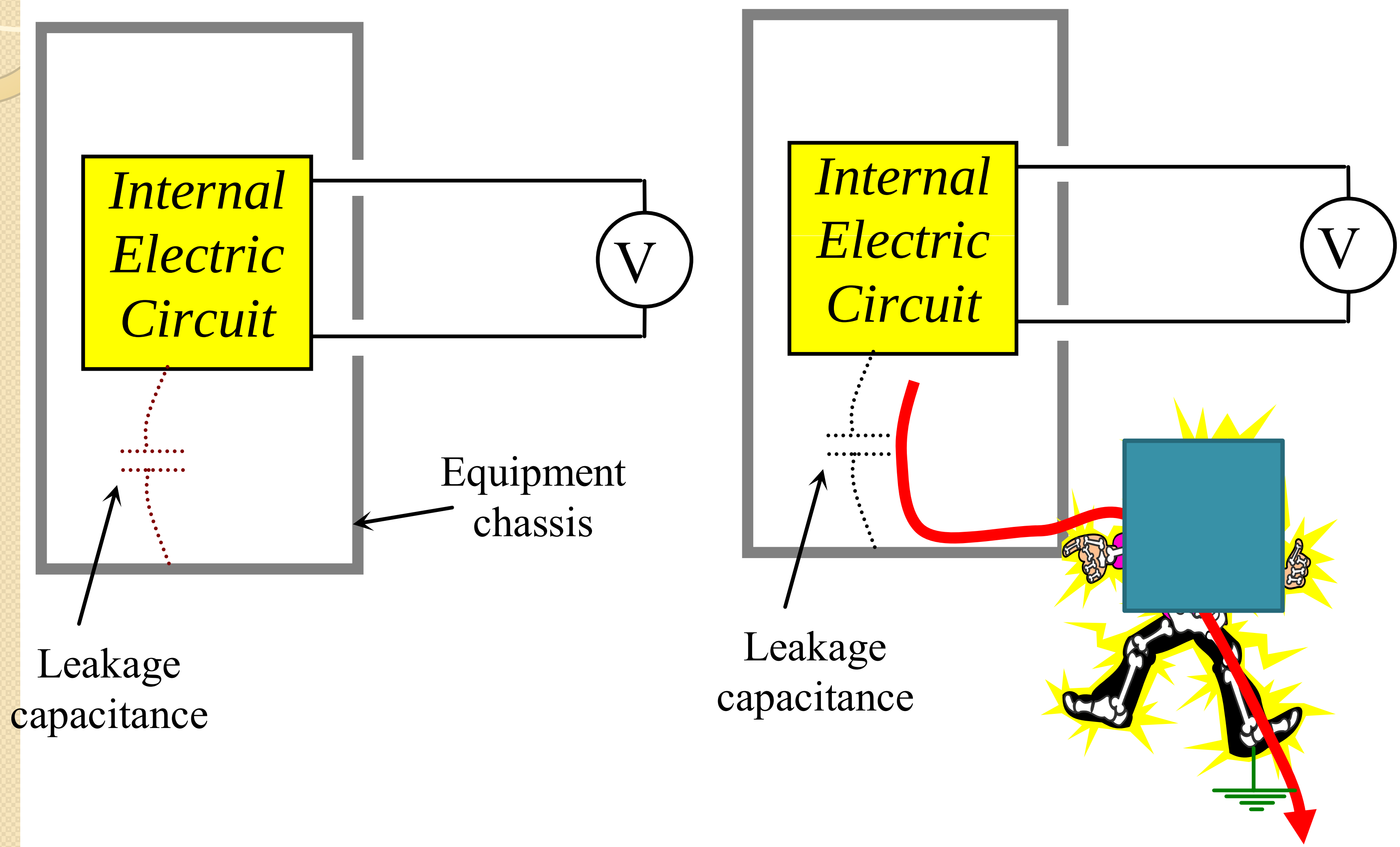
A high impedance is inserted between the neutral point and earth.



What are the different types of neutral point connection to earth?

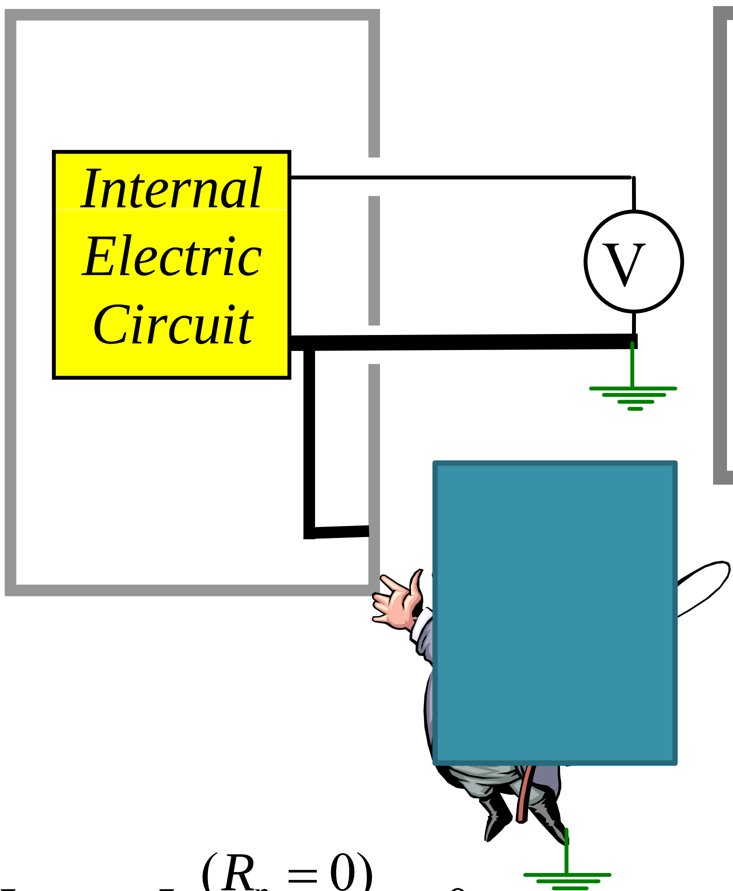
Resistance earthing A resistor is inserted between the neutral point and earth	
Reactance earthing A reactor is inserted between the neutral point and earth.	

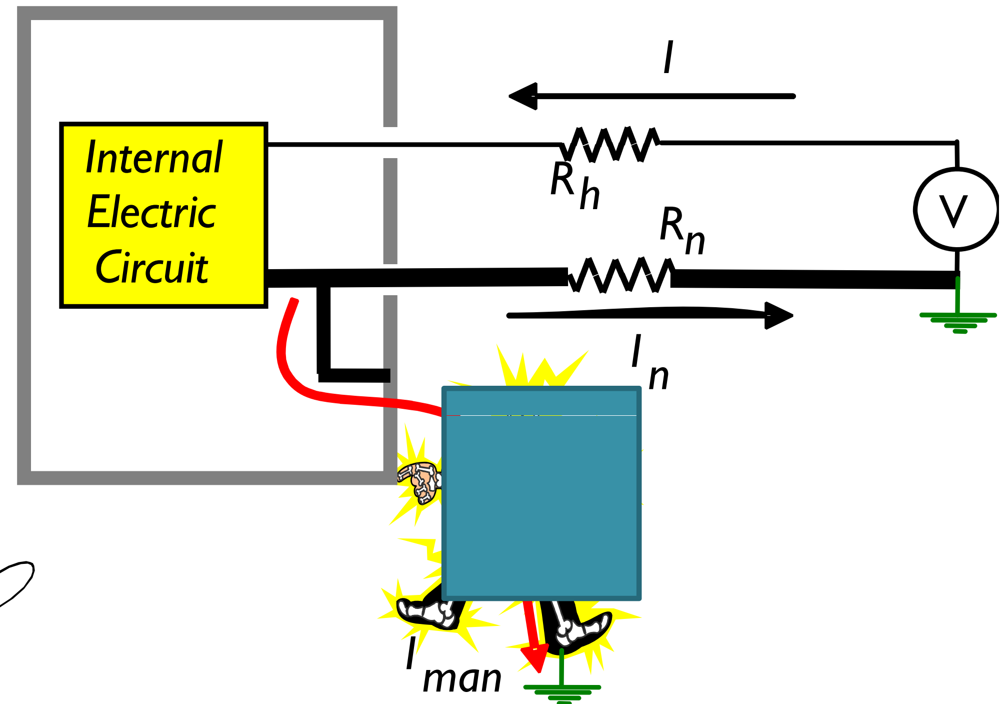
Neutral and Grounding



Neutral and Grounding

However!





$$I_{man} = I \frac{R_n}{R_n + R_{man}}$$

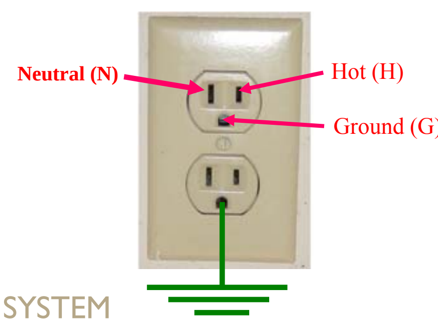
$$I_{man} = I \frac{(R_n = 0)}{R_n + R_{man}} = 0$$

What are the different types of neutral point connection to earth?

A solidly earthed neutral helps to limit overvoltages; however, it generates very high fault currents.

On the other hand, an isolated or unearthed neutral limits fault currents to very low values but encourages the occurrence of high overvoltages.

In an unearthed network or high impedance-earthed network, the damage is reduced, but the equipment must have an insulation level compatible with the level of overvoltages developed in this type of network.



State the importance of earthing / grounding?

1. To protect people from electric shock due to touching any metal part that should not be carrying current in the normal operation.
2. To make the high faulty current to go to earth through a low resistance, and hence to protect structures and equipments.
3. To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating limits or adversely affecting continuity of service.
4. Mainly to enable a system or equipment to be disconnected from the source of energy so as to avoid the effects of excessive currents produced under earth fault conditions.
5. To reduce the maintenance and operation expenses of ungrounded systems.

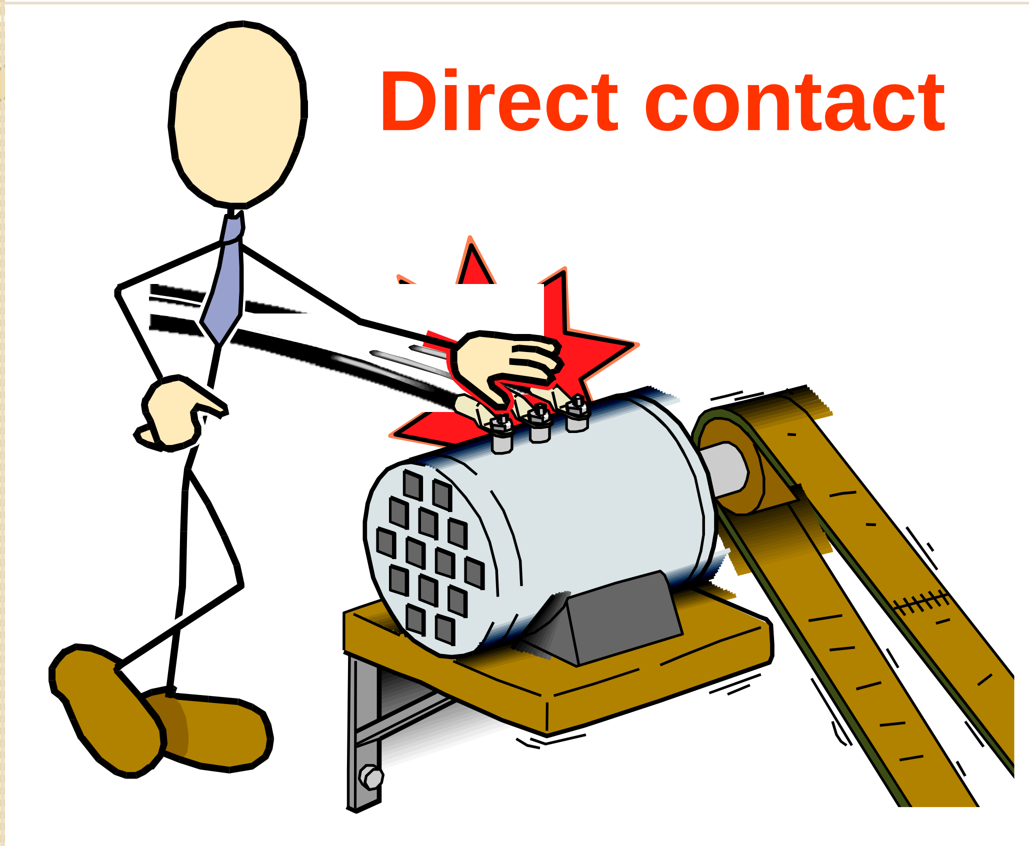
Therefore, The **PRIMARY** goal of the grounding system throughout any facilities is **SAFETY**.

Why ground at all?

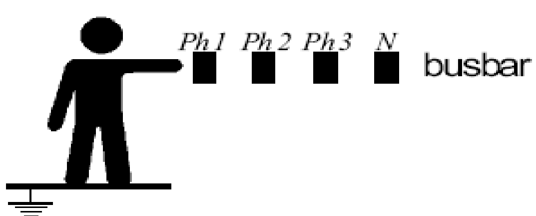
1- PERSONNEL SAFETY FIRST

2- EQUIPMENT PROTECTION SECOND

Direct and Indirect Contact



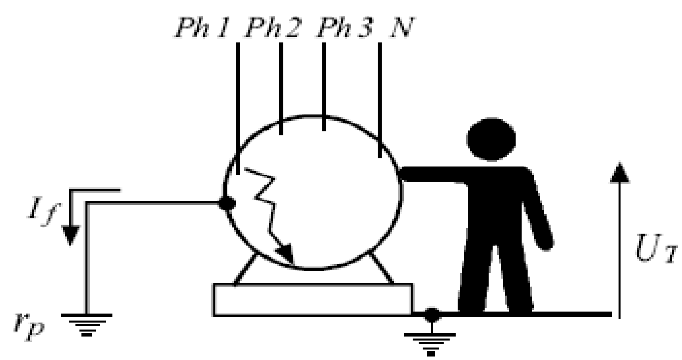
- "Contact of persons or livestock with live parts which may result in electric shock"
- This is the contact of a person with a live part of a piece of equipment that is energized.
- Contact may occur with a phase or with the neutral.



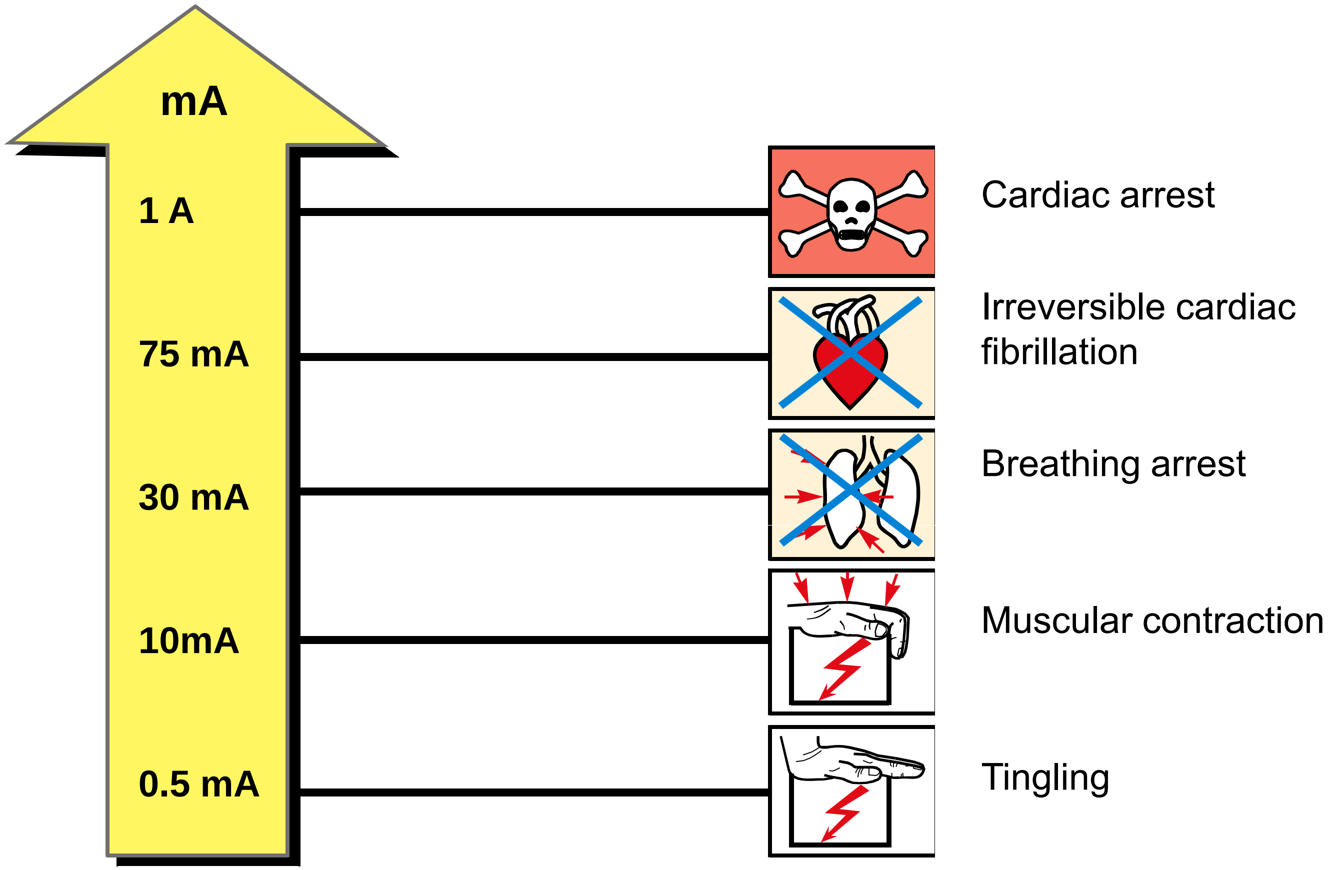
Direct and Indirect Contact

Indirect contact

- "Contact of persons or livestock with exposed conductive parts in case of the fault"
- This is the contact of a person with exposed conductive part of a load which is accidentally live following an insulation fault



Critical current thresholds



Standard IEC 60479-1

Earthing Systems

- **The Three Earthing Systems for low voltage systems are:**

1. T T
2. T N
3. I T

1st letter → first column; 2nd letter → second column

Situation of supply

T = Direct connection of Transformer Neutral (N) with the earth

I = Neutral unearthed or Impedance-earthed

Situation of installation frames

T = Exposed frames directly earthed

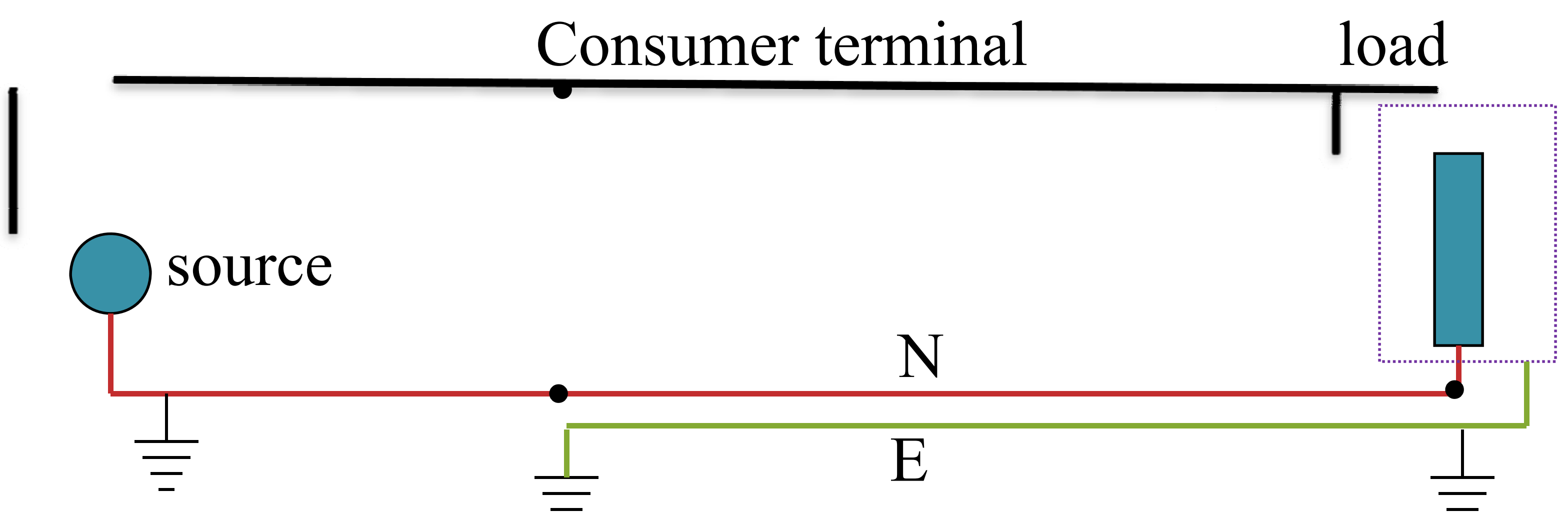
N = Frames connected to the supply point which is earthed,

- either by a separate Protective Earth conductor **(S).**
- Or combined with the Neutral **(C)**

Earthing Systems

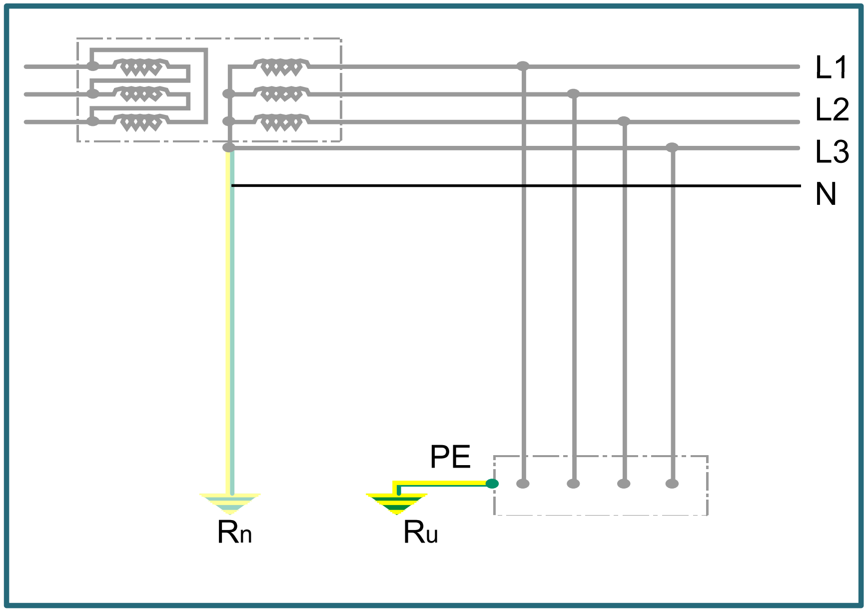
TT Earthing system technique

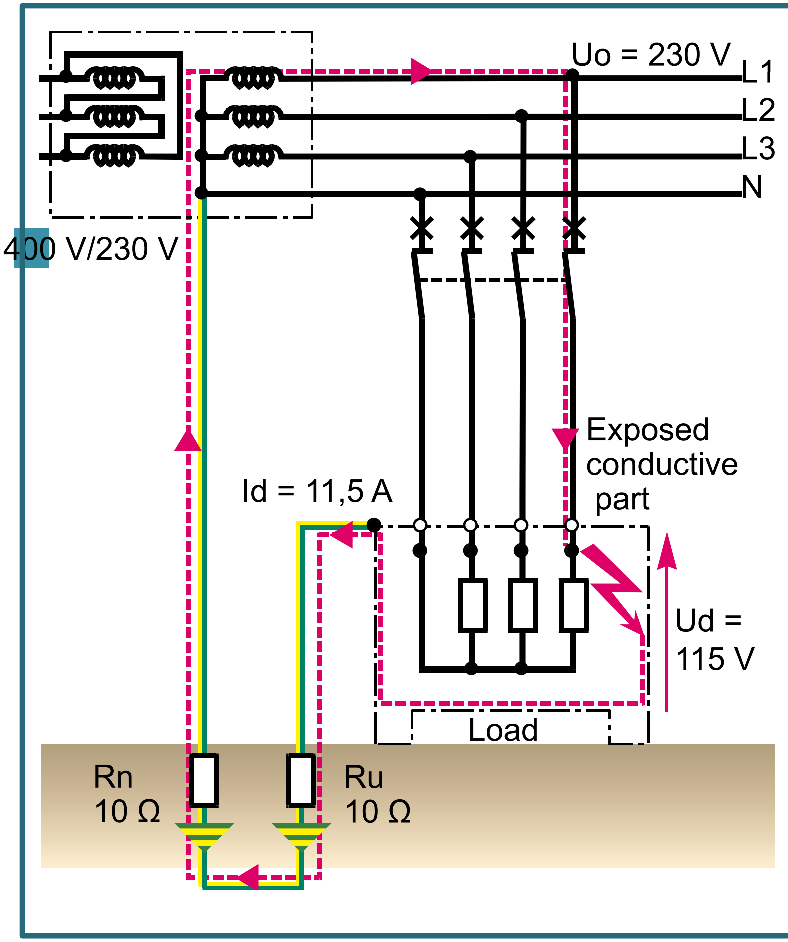
- The neutral point of the LV transformer is directly connected to an earth electrode.
- The exposed conductive parts of the installation are connected to an electrically separate earth electrode.



Earthing Systems

TT Earthing system technique





Value of fault current:

Id = Uo / (Rn + Ru) = 230 / (10 + 10)

= 11.5 A

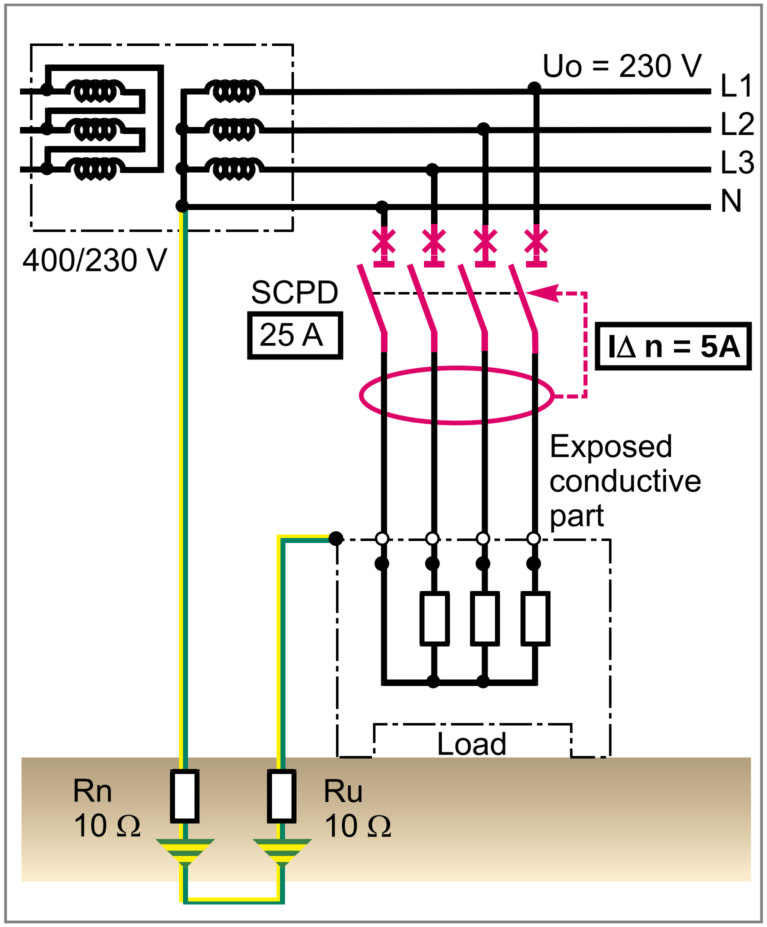
Ud = Ru x Id = 10 x 11.5 = 115 V

Ud > UL = 50 V

The fault current generates a dangerous touch voltage

Earthing Systems

TT Earthing system technique

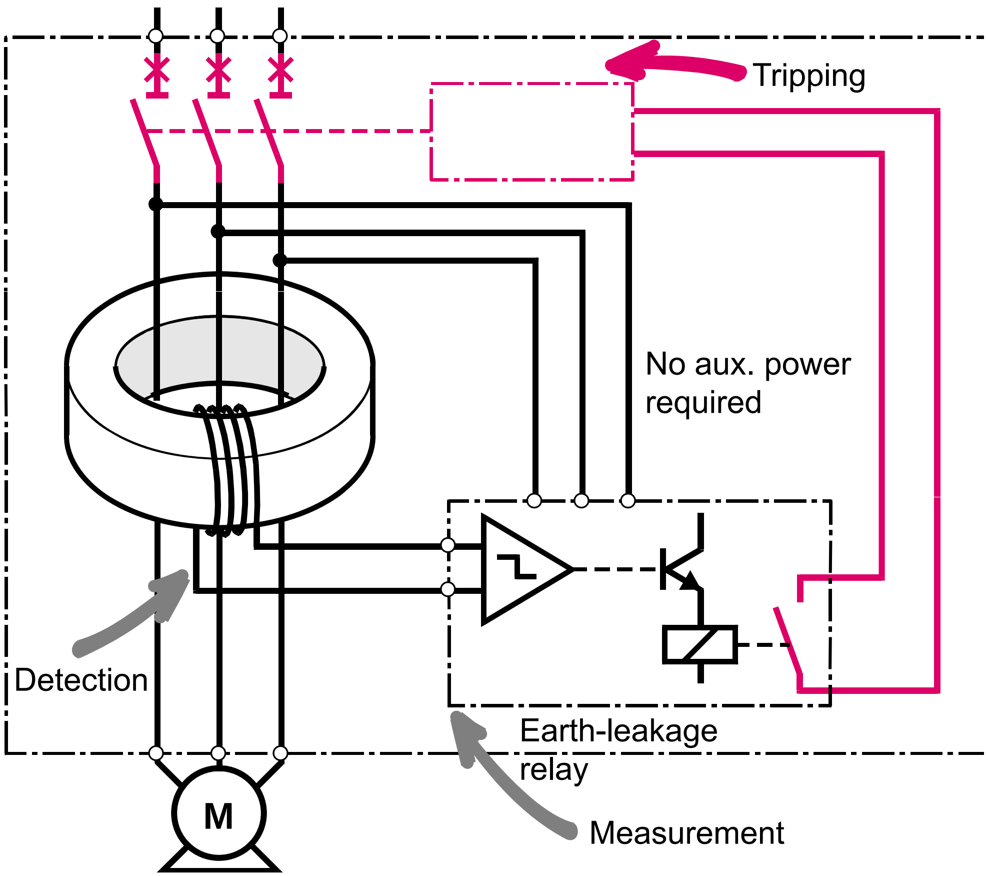


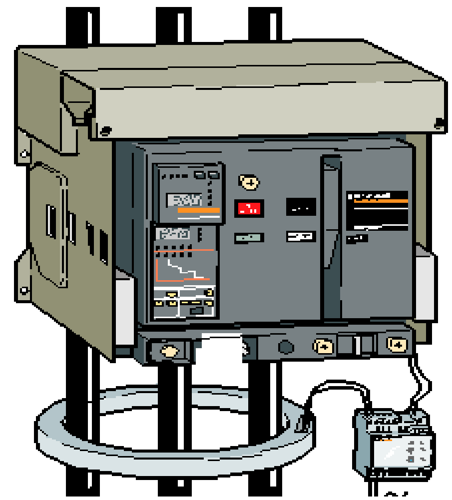
Solution

- The SCPD is usually not suitable for this type of fault (ST setting at **25 A**)
- A residual current device (RCD) specially designed for the protection of persons in TT system
- Tripping conditions:
  Max touch voltage < Safety value
  $Ru \times I\Delta n < U_L$
  ($I\Delta n$ is the setting of RCD)
- $I\Delta n = U_L / Ru$
  $= 50 / 10$
  $=$ **5 A**

Earthing Systems

TT Earthing system technique





Operating principle of RCD
requiring no auxiliary supply

1- Detection

2- Measurement

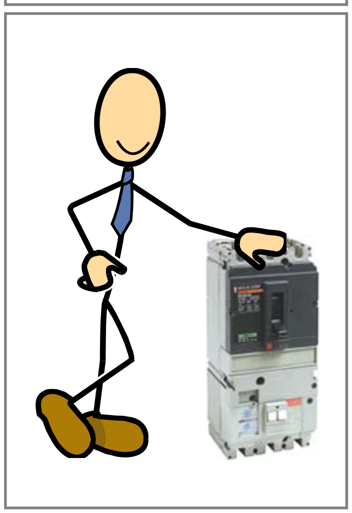
3- Tripping

Earthing Systems

TT Earthing system technique

Selection of solutions

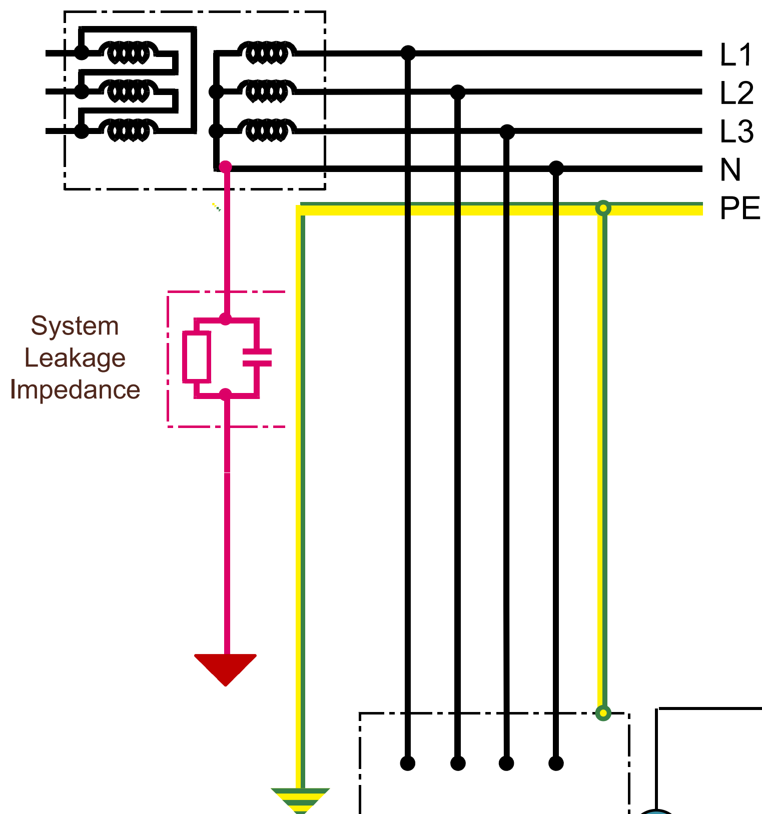
- For final distribution
- Application: protection of life and property in all sectors (industrial, commercial and residential)
- Main characteristics: continuity of service and safe if neutral conductor is cut



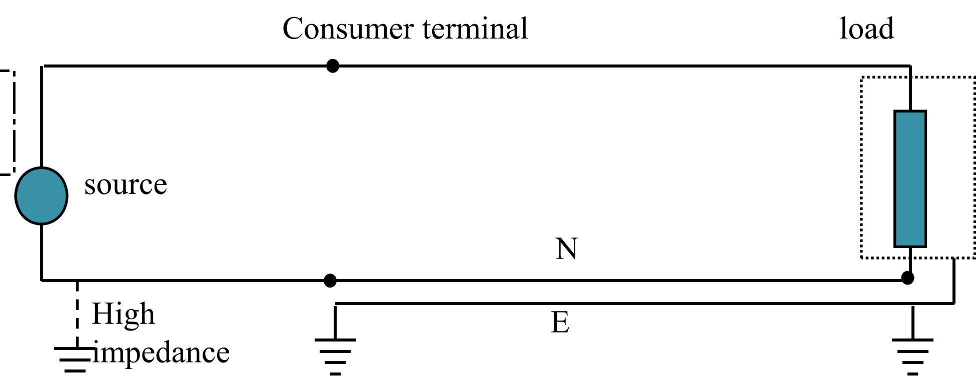
- For power distribution
- Application: general protection from the main low voltage switchboard to the secondary switchboard in industrial and large commercial buildings
- Main characteristics: high-performance solutions wide range of settings (discrimination)

Earthing Systems

IT Earthing system technique



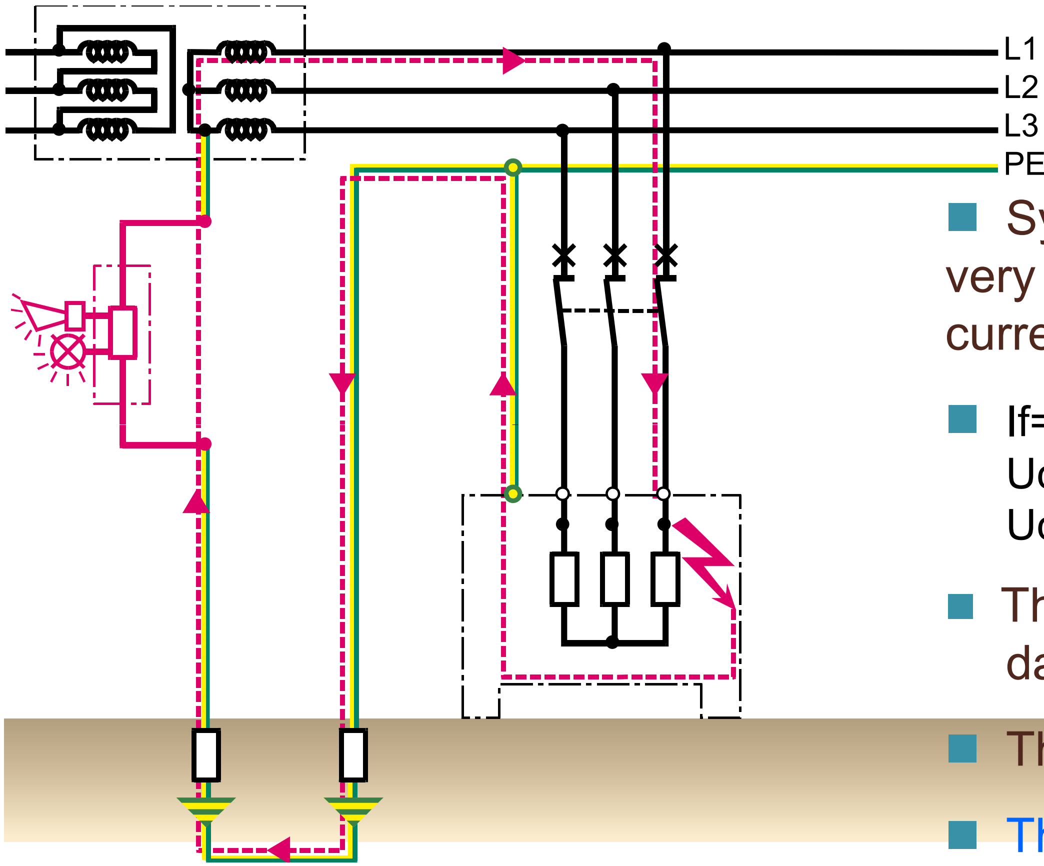
- The Neutral point of the LV transformer is Isolated, not connected to an earth electrode
- The exposed conductive parts of the loads are connected by the PE conductor to a common earth electrode or to separate earth electrodes
- Under Normal operation, the System is earthed by its System Leakage Impedance.



Earthing Systems

IT Earthing system technique

Earth-fault study (Signalling the first and the second fault)

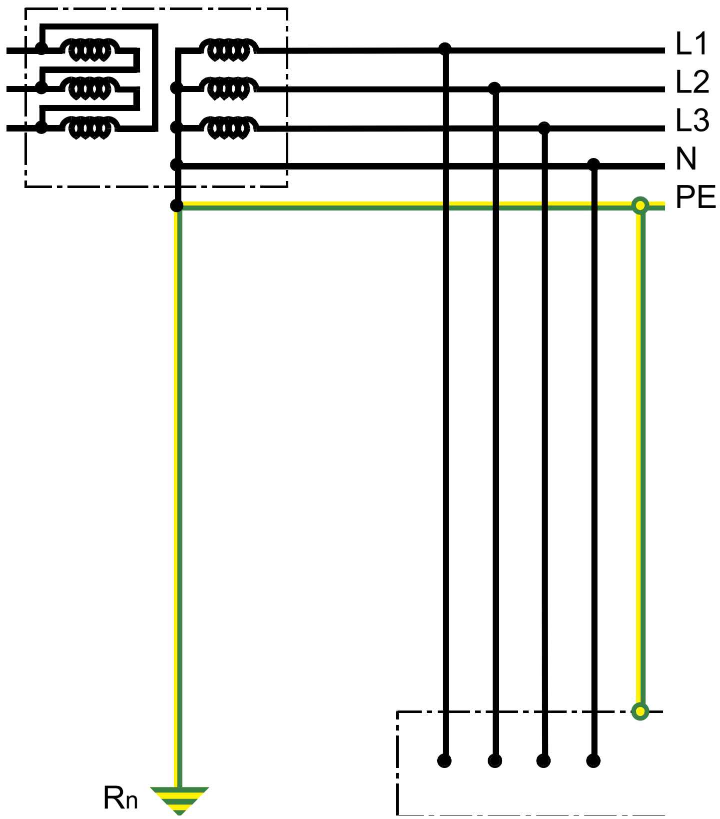


- System leakage impedance is very high and included in the fault current path
- If=U/Zt =230/3500 =0.065 A
  Uc=10 x0.065= 0.6V
  Uc< UL(50V)
- The touch voltage is not dangerous
- There is no risk of fire
- The fault does not cause tripping but it must be indicated

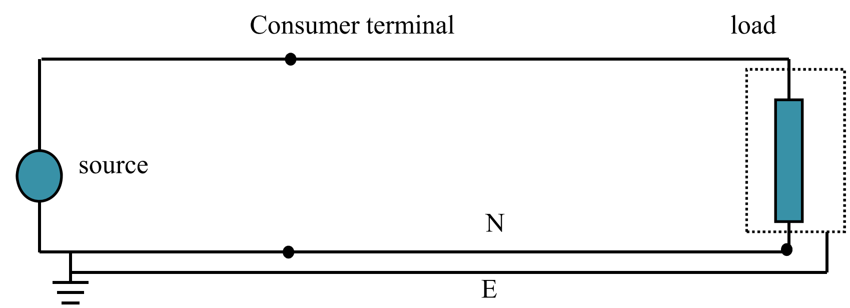
A second fault is dangerous and protection must be ensured by the SCPD 's or the RCDs (the same as in TT system)

Earthing Systems

TN Earthing system technique

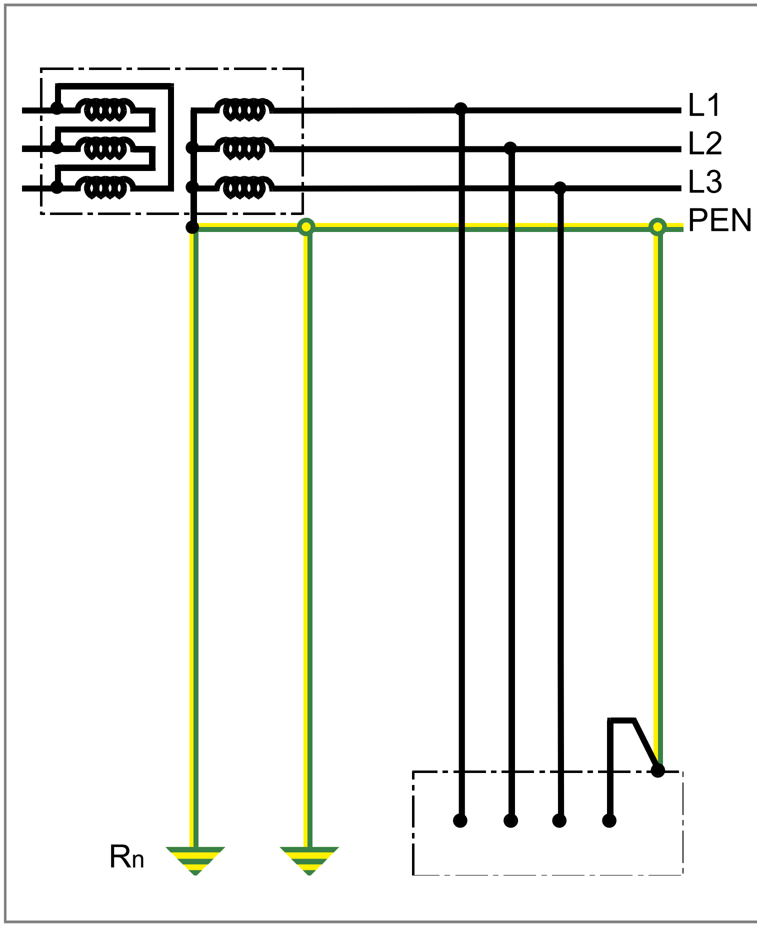


- The neutral point of the LV transformer is directly connected to an earth electrode
- The exposed conductive parts of the installation are connected by the PE to the same earth electrode
- For TN-S, The PE and neutral conductor are separated

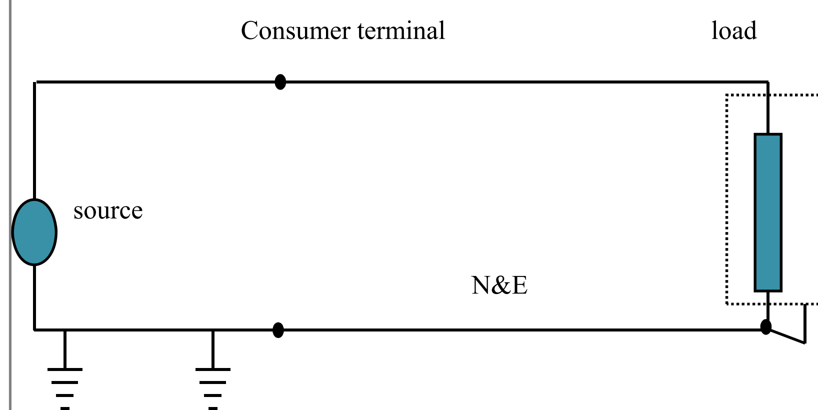


Earthing Systems

TN Earthing system technique

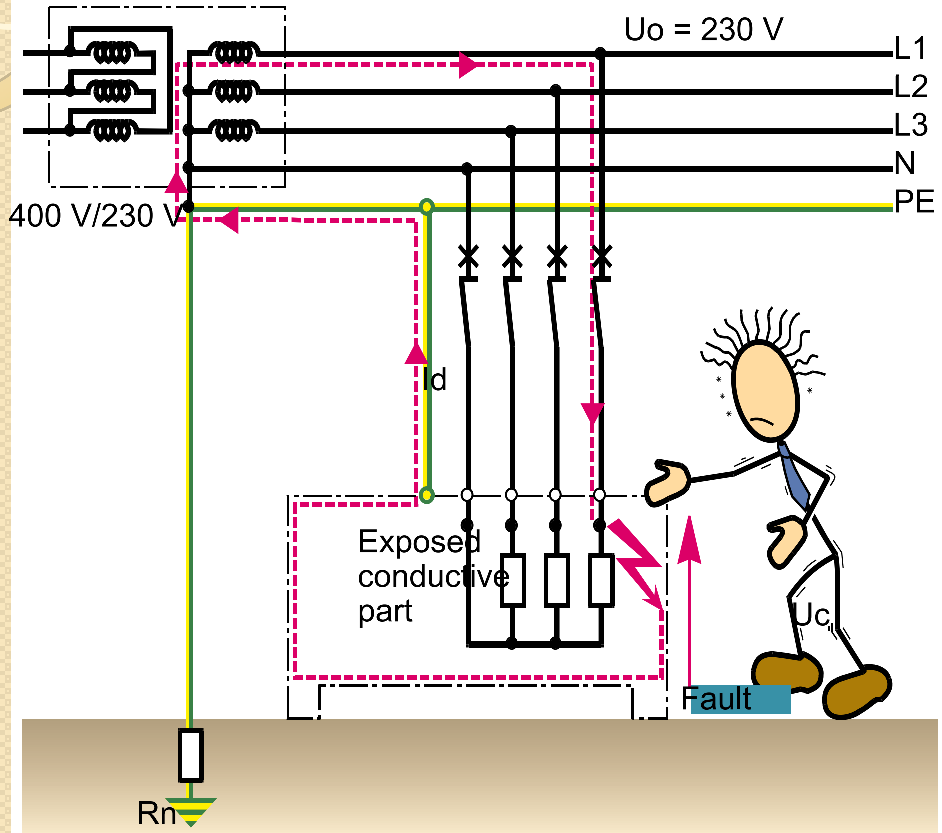


- for TN-C, A common conductor is used for both the PE and the neutral conductors (PEN)



Earthing Systems

TN Earthing system technique



- Consider the PH & PE Conductor are Copper, 50 m Long with a X-section of 35 mm2. The Fault Current

  $I_d = U_0/(R_{PE} + R_{PH})$

  $R_{PE} = R_{PH} = \rho. L/S$

  $\rho = 0.025$ Ω-mm2/m for Cu.

  $R_{PE} = R_{PH} = 0.025 \times 50/35 = 32.14$ mΩ

  $I_d = 230/(2 \times 0.3214) =$ **3578 A.**

- The fault current is equal to a Ph/N short-circuit

- This Fault Current will generate a Touch Voltage

  $U_c = R_{PE} \times I_d = 3578 \times 0.03214 = 115$ V.

- The fault current depends on the Length of the Lines

Comparison between three Earthing Systems

TT System	IT System	TN System
■ Fault current is dangerous ■ Fault current is too weak to trigger SCPDs ■ Fault current is limited by RCDs instantaneous ■ Dangerous touch voltage ■ First fault tripping ■ Human Protection ensured. ■ No Risk of Fire. ■ Continuity of Service ■ simple design ■ system easily extensible.	■ First-fault current is very weak and First-fault touch voltage is very weak ■ Dangerous touch voltage in the event of a double fault ■ Optimal safety when first fault occurs ■ Continuity of service when first fault occurs ■ 2nd fault is dangerous and protection must be ensured by SCPD 's or the RCDs (Tripping after the second fault)	■ High fault currents, enough to be tripped by the SCPDs ■ Dangerous touch voltage ■ Tripping after first fault instantaneous ■ TN-C not allowed where there is a risk of fire

Selection between three Earthing Systems

selection criteria

- Protection of persons
- Protection of equipment
- Continuity of the power supply
- Effects of disturbances
- Easy implementation
- Economic analysis

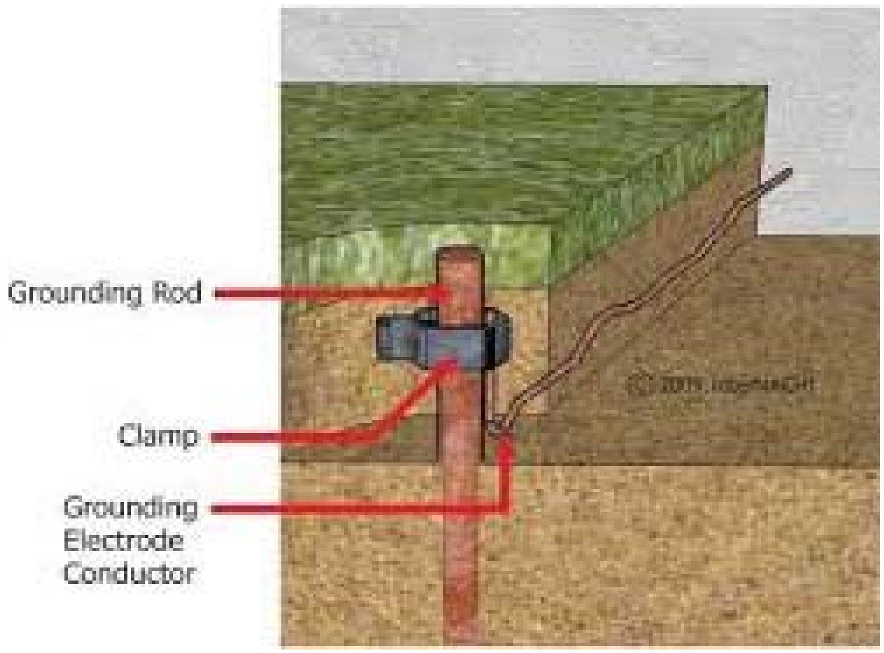
Criterion	TT	TN-S	TN-C	IT
Protection of people	**XXXX**	**XXX**	**XX**	**XXXX**
Protection against Fire	**XXXX**	**XXX**	**X**	**XX**
Ease of Implementation	**XXX**	**X**	**X**	**X**
Continuity of service	**XX**	**XX**	**XX**	**XXXX**
Upgradable installation	**XXXX**	**XX**	**XX**	**XX**
Cost Saving	**XX**	**XXX**	**XXXX**	**X**

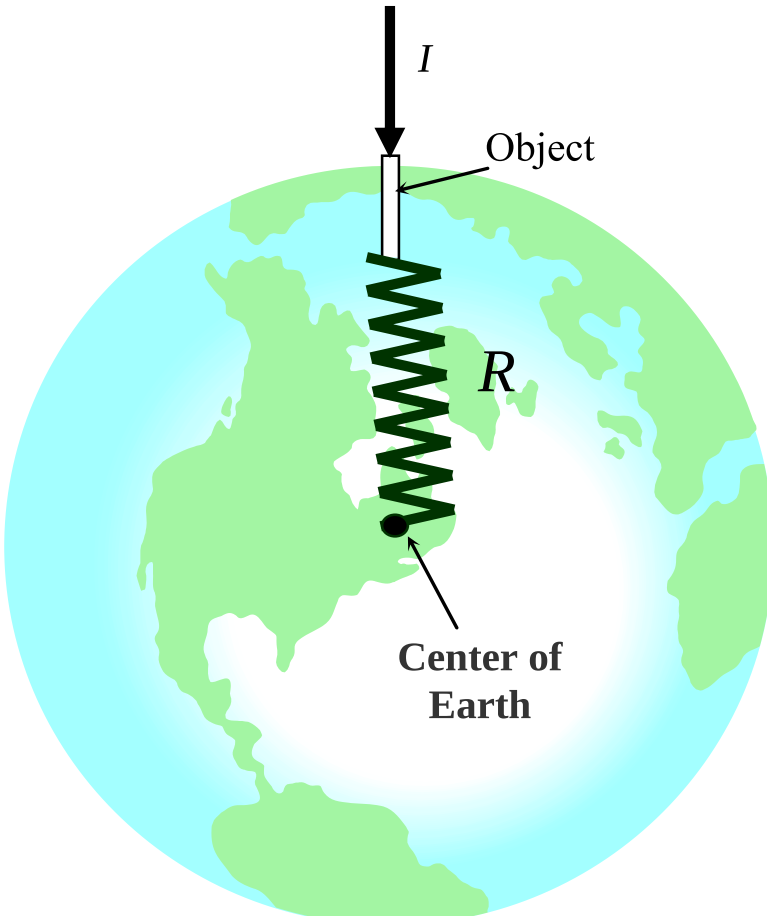
XXXX=Excellent **XXX=Good** **XX=Average** **X=Caution**

Ground Resistance

- **Ground Resistance:**

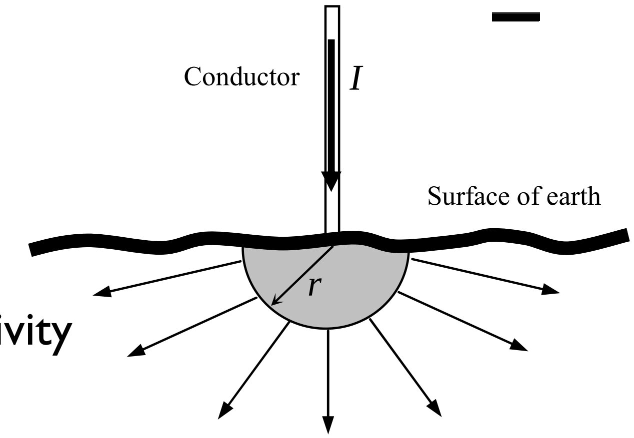
is the resistance which determines the amount of current flown through an object to earth.





Ground Resistance of Hemisphere

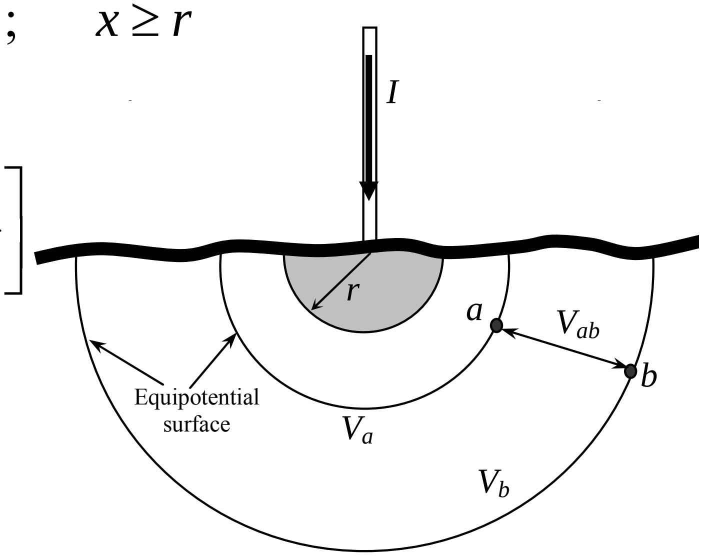
$$R_g = R_{ab} = \frac{V_{ab}}{I}; \qquad V_{ab} = \int_{x=a}^{x=b} E(x)\ dx$$



$$E(x) = \rho J(x); \qquad x \geq r$$; ρ is ground resistivity

$$J = \frac{I}{area\ of\ hemisphere} = \frac{I}{2\pi r^2} \qquad J(x) = \frac{I}{2\pi x^2}; \qquad x \geq r$$

$$V_{ab} = \int_{x=a}^{x=b} E(x)\ dx = \int_{x=a}^{x=b} \rho\ J(x)\ dx = \frac{\rho I}{2\pi}\left[\frac{1}{a} - \frac{1}{b}\right]$$



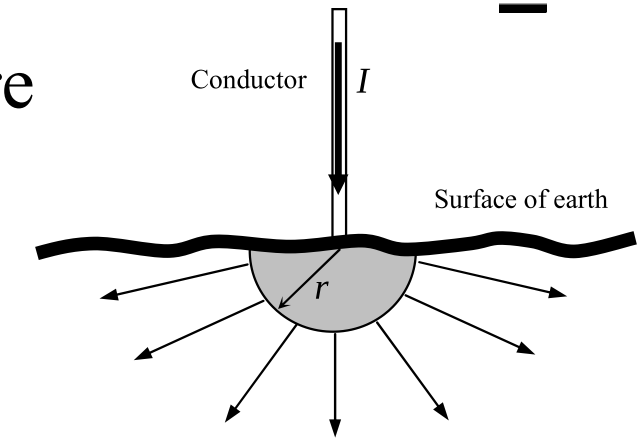
$$R_{ab} = \frac{V_{ab}}{I} = \frac{\rho}{2\pi}\left[\frac{1}{a} - \frac{1}{b}\right]$$

For a=r, b=∞

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

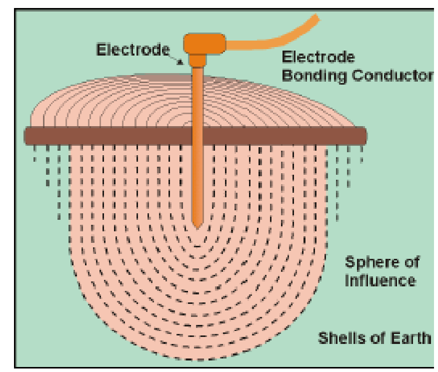
Ground Resistance of Hemisphere

Ground resistance of a hemisphere



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

Ground resistance at a distance of d m away from the center of the hemisphere



$$R_g = R_{rd} = \frac{V_{rd}}{I} = \frac{\rho}{2\pi}\left[\frac{1}{r} - \frac{1}{d}\right]$$

Ref: IEEE Standard 1048-1990 IEEE Standard 524a-1993	Soil Composition			
	Wet Organic	Moist	Dry	Bedrock
Resistivity ρ (Ohm- meter)	10	100	1000	10,000

Ground Resistance of Hemisphere

Example

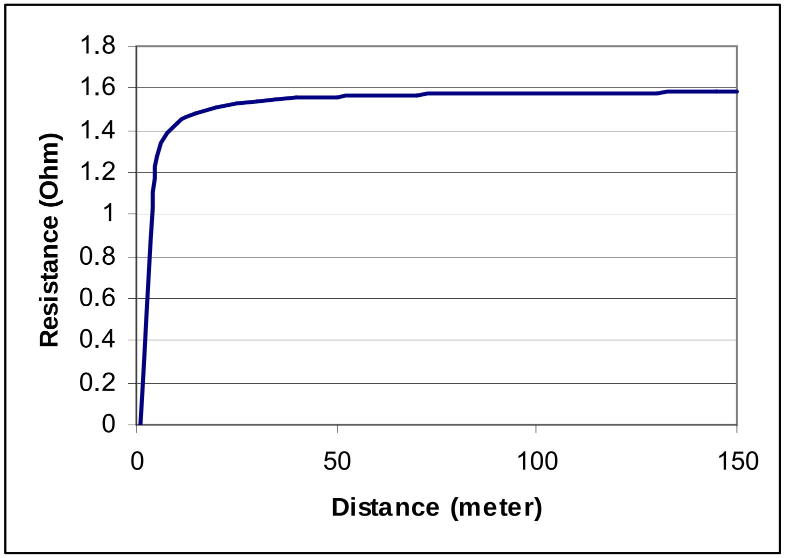
- Compute the ground resistance of a hemisphere with 2m diameter buried in a wet organic soil.
- Also compute the ground resistance at 2m, 10m and 100m away from the center of the hemisphere.

Solution

$$R_g = \frac{\rho}{2\pi\ r} = \frac{10}{2\pi 1} = 1.6\ \Omega$$

At 2m distance

$$R_{rd} = \frac{\rho}{2\pi}\left[\frac{1}{r} - \frac{1}{d}\right] = \frac{10}{2\pi}\left[\frac{1}{1} - \frac{1}{2}\right] = 0.8\ \Omega$$



Resistance of driven rods

The Ground Resistance (R_g) of a single rod, of diameter (d) and driven length (*L*) driven vertically into the soil of resistivity (ρ), can be calculated as follows:

$$R_{g_{equiv.}} = \frac{\rho}{2\pi L}\left[\ln\left(\frac{8L}{d}\right) - 1\right]$$

where:

	ρ	Soil Resistivity in Ω.m
	L	Buried Length of the electrode in m
	d	Diameter of the electrode in m

The rod is assumed as carrying current uniformly along its rod.

Examples

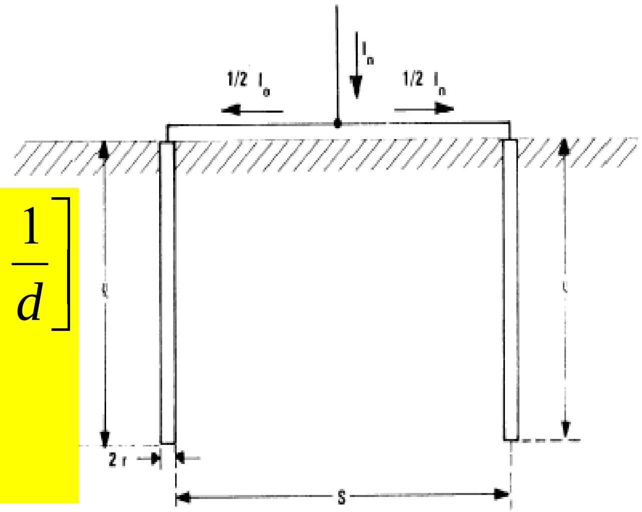
(a) 20mm rod of 3m length and Soil resistivity 50 Ω-m .....R=16.1 Ω

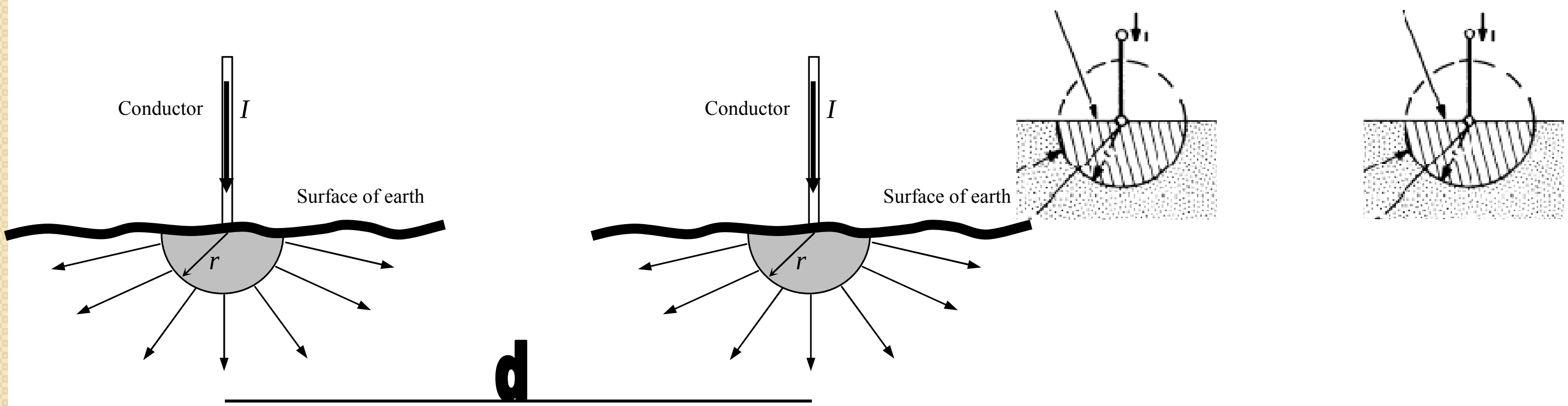
(b) 25mm rod of 2m length and Soil resistivity 30 Ω-m .....R=13.0 Ω

Ground Resistance of Two Hemisphere Electrodes

$$V = V_a + V_b = \frac{\rho(I/2)}{2\pi r} + \frac{\rho(I/2)}{2\pi d} = \frac{\rho(I/2)}{2\pi}\left[\frac{1}{r} + \frac{1}{d}\right]$$

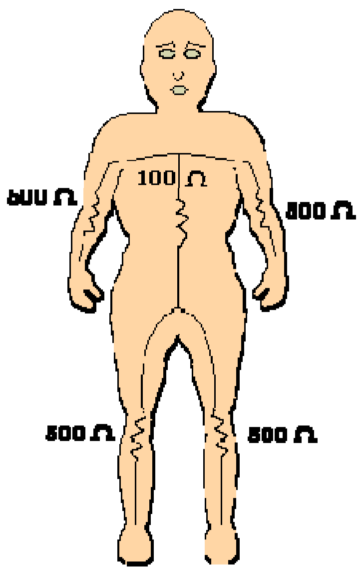
$$R_g = \frac{V}{I} = \frac{\rho}{2\pi}\left[\frac{1}{r} + \frac{1}{d}\right]$$



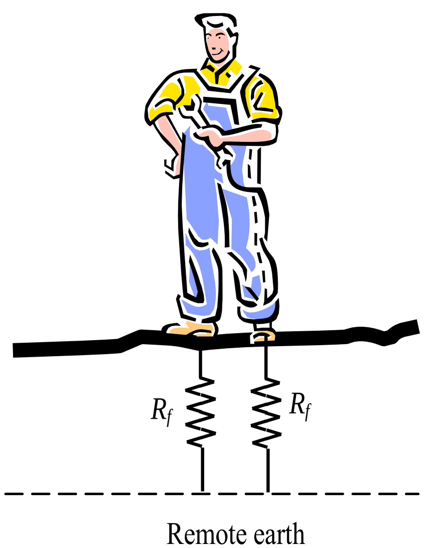


Touch and Step Potential

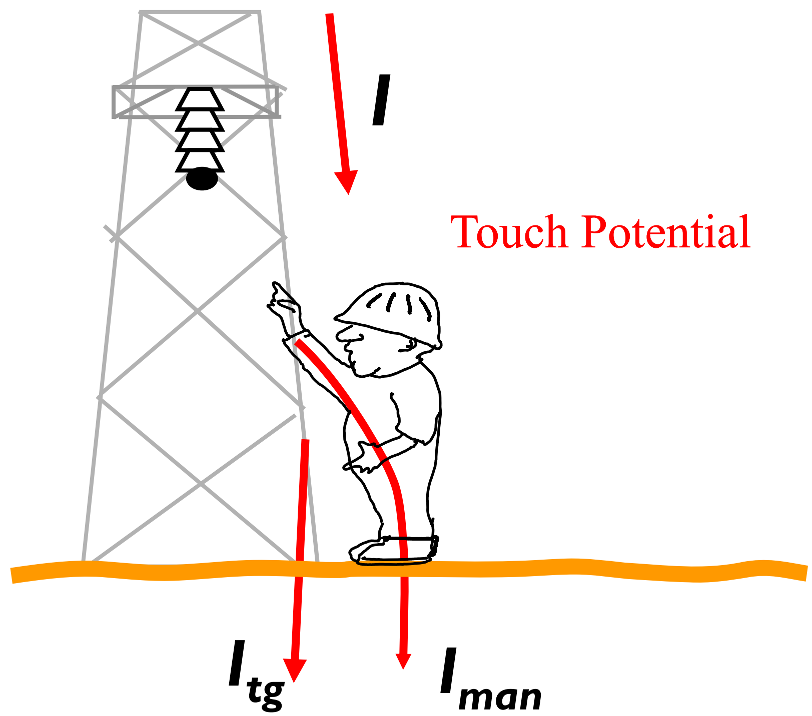
- Step Potential: Potential between the two feet.
- Touch Potential: Potential between two body parts at different potentials (Human and frame).



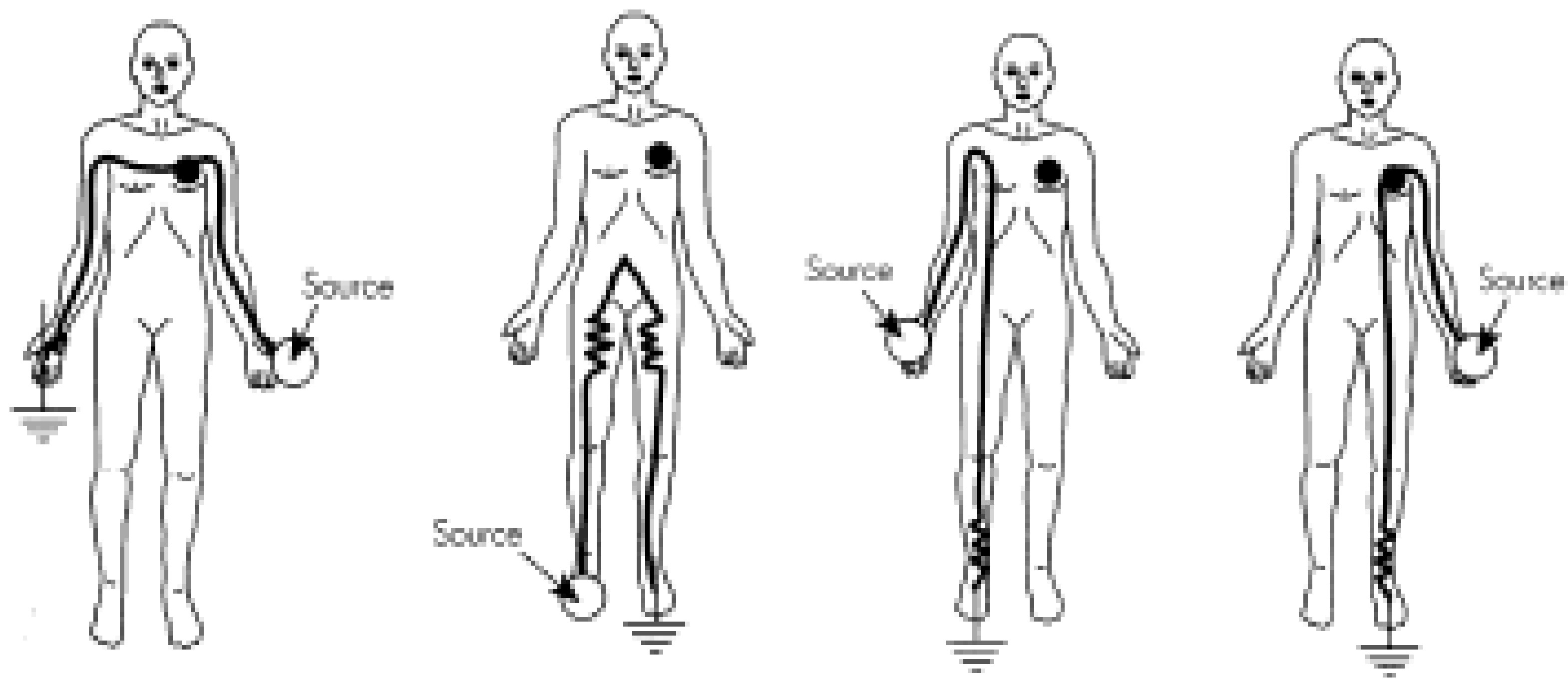
Body Resistance



Step Potential



Touch Current Pathways through the Body



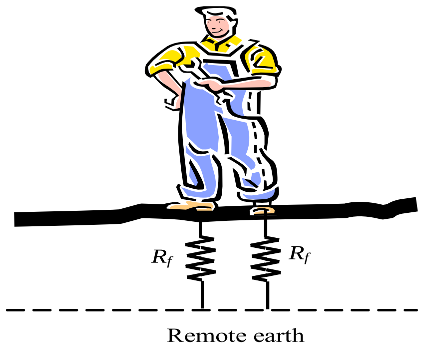
(A) Touch Potential

(B) Step Potential

(C and D) Touch/Step Potential

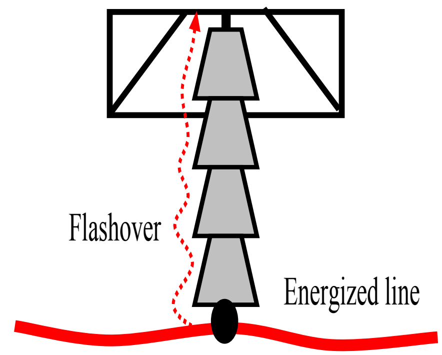
Ground Resistance of people

Assume the foot Resistance is $R_f = 3\rho$

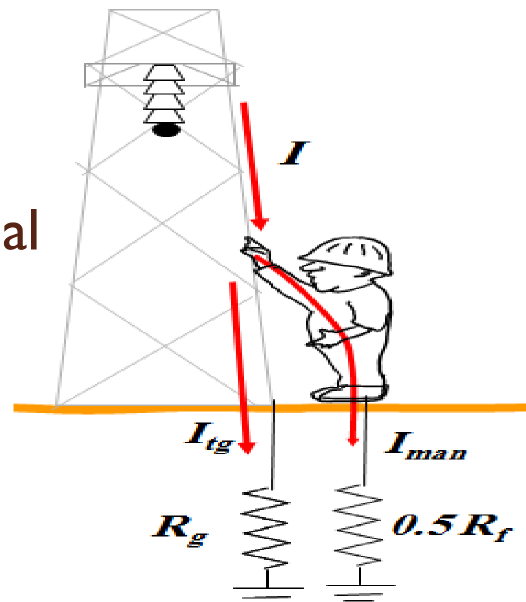


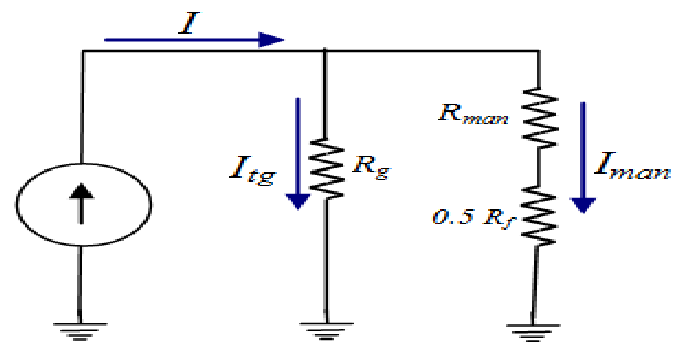
For standing person

$$R_g = \frac{R_f \times R_f}{R_f + R_f} = 0.5\ R_f = 1.5\rho$$



Touch Potential





$$I_{man} = I \frac{R_g}{R_g + R_{man} + 0.5 R_f}$$

Body Resistance in Ohms

R_{man} can be given as:

Resistance	Hand-to-hand		Hand-to-feet
	Dry condition	Wet condition	Wet condition
Maximum	13,500	1,260	1,950
Minimum	1,500	610	820
Average	4,838	865	1221

Ref: IEEE Standard 1048-1990

Ground Resistance of people

Example

- A power line insulator is partially failed and **<u>10A</u>** passes through the tower structure to the ground. Assume that the tower ground is a hemisphere with a radius of **<u>0.5</u>** meter, and the soil surrounding the hemisphere is **<u>moist</u>**.
  - Compute the voltage of the tower.
  - Assume that a man with a body resistance of **<u>3kΩ</u>** touches the tower while standing on the ground. Compute the current passing through the man.
  - Use Dalziel formula and compute the man's survival time.

Ground Resistance of people

Solution

The ground resistance of the hemisphere

$$R_g = \frac{\rho}{2\pi\ r} = \frac{100}{2\pi \times 0.5} = 32\ \Omega$$

The voltage of the tower

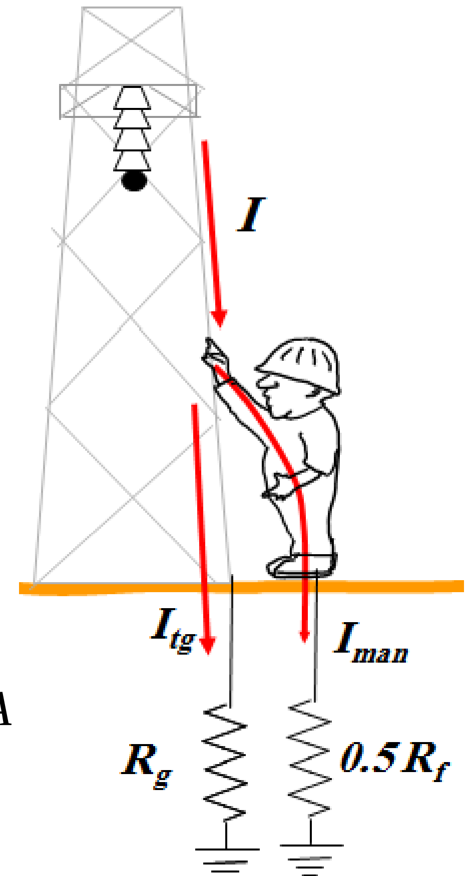
$$V = I\ R_g = 10 \times 32 = 320V$$

To compute the current through the man, first compute R_f

$$R_f = 3\rho = 3*100 = 300\ \Omega$$

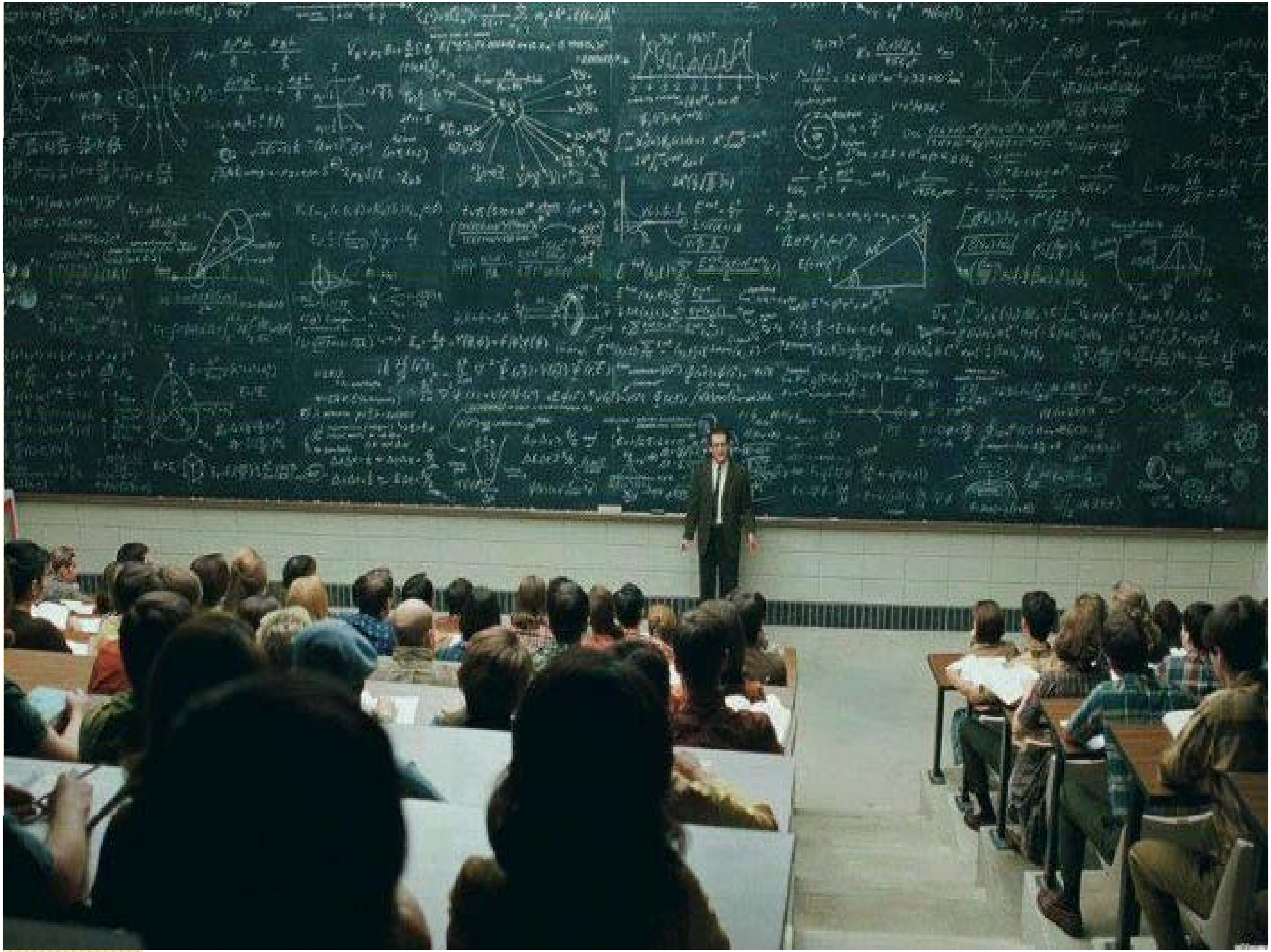
The current through the man is given as

$$I_{man} = I \frac{R_g}{R_g + R_{man} + 0.5 R_f} = 10 \frac{32}{32+3000+150} = 100\ mA$$



According to Dalziel formula, the man can survive for

$$t = \left(\frac{K}{I_{man}}\right)^2 = \left(\frac{157}{100}\right)^2 = 2.5\ s$$



Example

As shown, the following table gives the sets of observations obtained while studying the Townsend phenomenon in a gas. Compute the values of the Townsend's primary and secondary ionization coefficients from the data given.

Set 1:									
Gap distance (mm)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
Applied voltage V (volts)	1000	2000	3000	4000	5000	6000	7000	8000	10000
Observed current I (A)	10^{-13}	3×10^{-13}	6×10^{-13}	10^{-12}	4×10^{-12}	10^{-11}	10^{-10}	10^{-9}	5×10^{-7}
Set 2:									
V (volts)	500	1000	1500	2000	2500	3000	3500	4000	4500
I (A)	5×10^{-14}	1.5×10^{-13}	3×10^{-13}	6×10^{-13}	10^{-12}	5×10^{-12}	5×10^{-11}	3×10^{-10}	10^{-8}

The minimum current observed when 150 V was applied was 5×10^{-14} A.

Solution

The current at minimum applied voltage, I_0, is taken as 5×10^{-14} A, and

The values of log I/I_0 versus d for two values of electric field, $E_1 = 20$ kV/cm and $E_2 = 10$ kV/cm are given in Table **below**

Table given

Set 1:									
Gap distance (mm)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
Applied voltage V (volts)	1000	2000	3000	4000	5000	6000	7000	8000	10000
Observed current I (A)	10^{-13}	3×10^{-13}	6×10^{-13}	10^{-12}	4×10^{-12}	10^{-11}	10^{-10}	10^{-9}	5×10^{-7}
Set 2:									
V (volts)	500	1000	1500	2000	2500	3000	3500	4000	4500
I (A)	5×10^{-14}	1.5×10^{-13}	3×10^{-13}	6×10^{-13}	10^{-12}	5×10^{-12}	5×10^{-11}	3×10^{-10}	10^{-8}

Table calculated

	Gap (mm)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
Set 1:	I/I_0 for $E_1 = 20$ k V/cm	2	6	12	20	80	200	2×10^3	2×10^4	5×10^7
	log I/I_0	0.3010	0.7181	1.0792	1.3010	1.9031	2.3010	3.3010	4.3010	7.6990
Set 2:	I/I_0 for $E_2 = 10$ k V/cm	1	3	6	12	20	100	1000	6000	2×10^5
	log I/I_0	0	0.4771	0.7781	1.0792	1.3010	2.0	3.0	3.7781	5.3010

Solution

the graph of d versus $\log I/I_0$ is plotted as shown in Fig. below

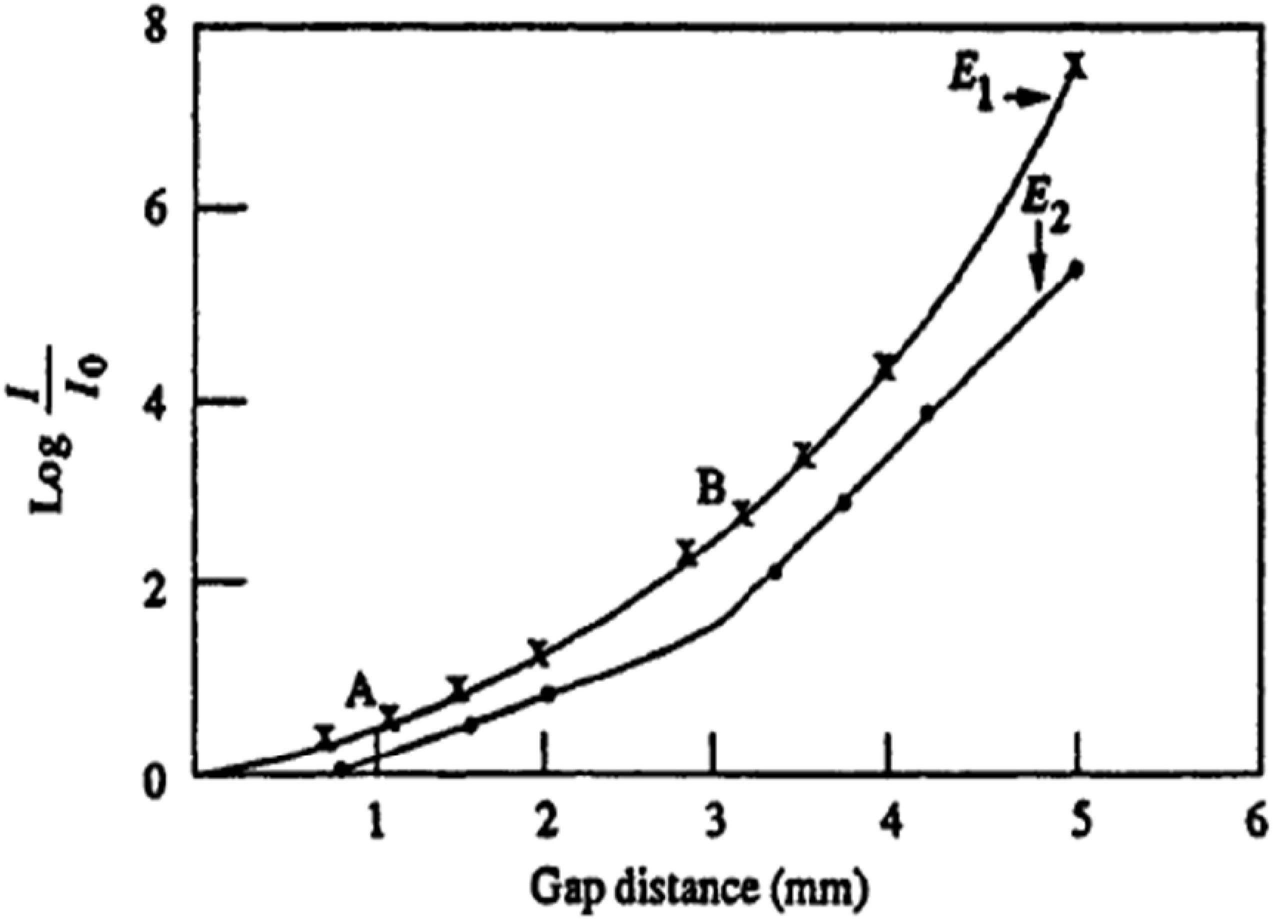
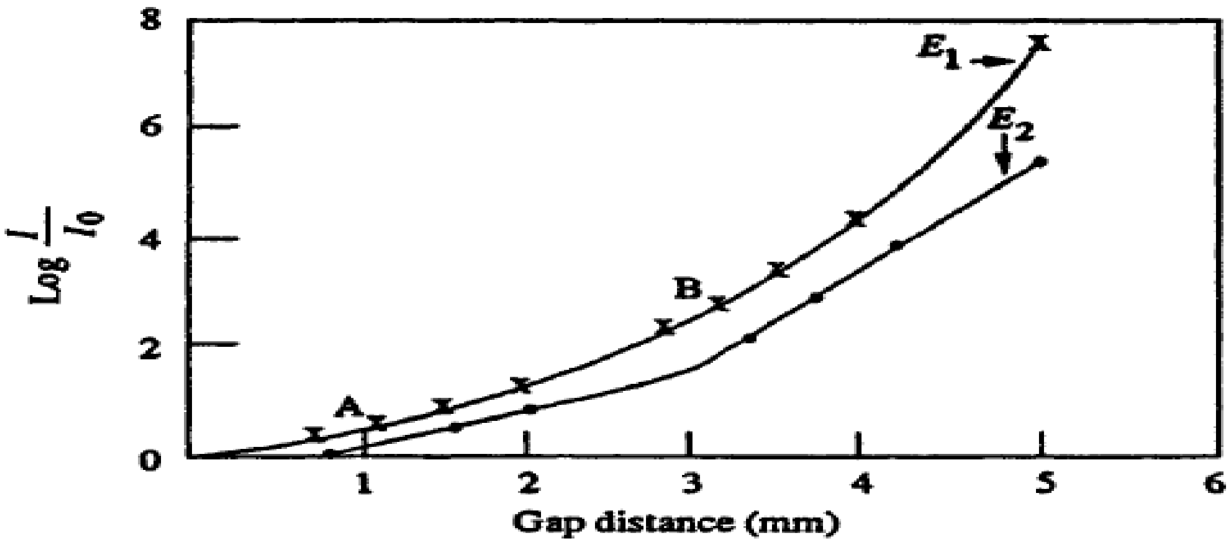


Fig. Log I/I_0 as a function of gap distance

Solution



Value of α at E_1 (= 20 kV/cm) i.e. α_2 = slope of curve E_1

$$= \frac{2.9}{2.5 \times 10^{-1}}$$

$$= 11.6\ \text{cm}^{-1}\ \text{torr}^{-1}$$

Value of α at E_2 (= 10 kV/cm) i.e. α_1 = slope of curve E_2

$$= \frac{13}{2 \times 10^{-1}}$$

$$= 6.5\ \text{cm}^{-1}\ \text{torr}^{-1}$$

Solution

As the sparking potential and the critical gap distance are not known, the last observations will be made use in determining the values of γ.

For a gap distance of 5 mm, at $E_1 = 20$ kV/cm,

$$I = \frac{I_0 \exp(\alpha d)}{1 - \gamma[\exp(\alpha d) - 1]}$$

$$\frac{I}{I_0} = \frac{\exp(\alpha d)}{1 - \gamma[\exp(\alpha d) - 1]}$$

Substituting $\alpha_1 = 11.6$, $d = 0.5$ cm, and $I/I_0 = 5 \times 10^7$

$$5 \times 10^7 = \frac{\exp(5.8)}{1 - \gamma[\exp(5.8) - 1]}$$

$$= \frac{330.3}{1 - \gamma(330.3 - 1)}$$

or $$\gamma = 3.0367 \quad 10^{-3}/\text{cm. torr, at } E_1 = 20 \text{ kV/cm}$$

(Check this value with other observations also.)

Solution

For $E_2 = 10\ \text{kV/cm}$

$\alpha_2 = 6.5/\text{cm . torr}$

$d = 0.5\ \text{cm}$

and $I/I_0 = 2 \times 10^5$

Substituting these values in the same equation,

$$2 \times 10^5 = \frac{\exp(3.25}{1\gamma\,[\exp\,(3.25) - 1]}$$

$$= \frac{25.79}{1 - \gamma\,(25.79 - 1)}$$

or, $\gamma = 4.03 \times 10^{-2}/\text{cm . torr, at } E_2 = 10\ \text{kV/cm}$

Matching dielectric constants

When composite insulation has components with different dielectric constants, utilisation of the materials may be impaired. This is especially true in the oil/transformerboard dielectric. This is because the oil has a lower dielectric constant and lower dielectric strength compared to that of transformerboard. Since dielectrics are in series

$$\frac{V_1}{V_2} = \frac{C_2}{C_1} = \frac{A\varepsilon_2}{d_2}\cdot\frac{d_1}{A\varepsilon_1} = \frac{\varepsilon_2 d_1}{\varepsilon_1 d_2}$$

$$V = V_1 + V_2$$

$$\frac{V_1}{V} = \frac{V_1}{V_1 + V_2} = \frac{\varepsilon_2 d_1}{\varepsilon_1 d_2 + \varepsilon_2 d_1}$$

$$\xi_1 = \frac{V_1}{d_1} = \frac{\varepsilon_2}{\varepsilon_1 d_2 + \varepsilon_2 d_1}.V$$

$$\xi_2 = \frac{V_2}{d_2} = \frac{\varepsilon_1}{\varepsilon_1 d_2 + \varepsilon_2 d_1}.V$$

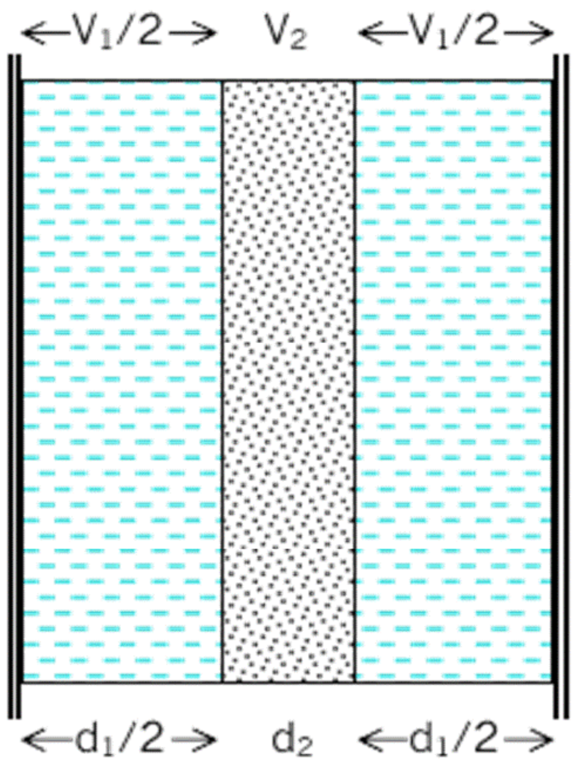


Figure 6 - Composite Dielectric