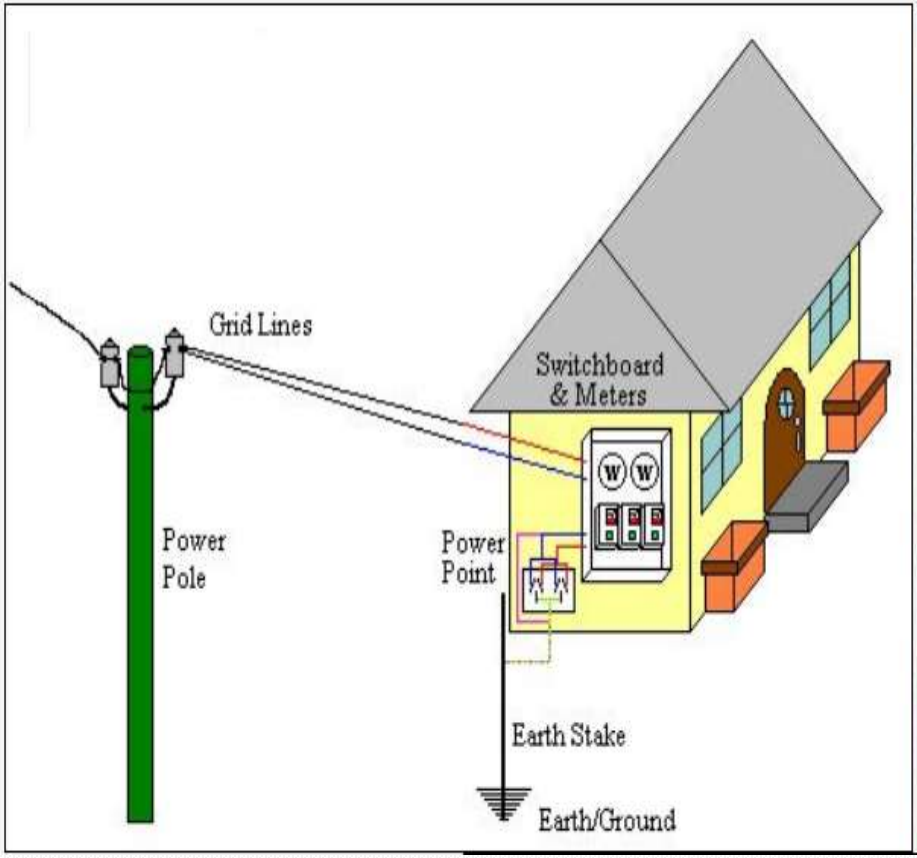
UNIT – IV

POWER SYSTEM EARTHING

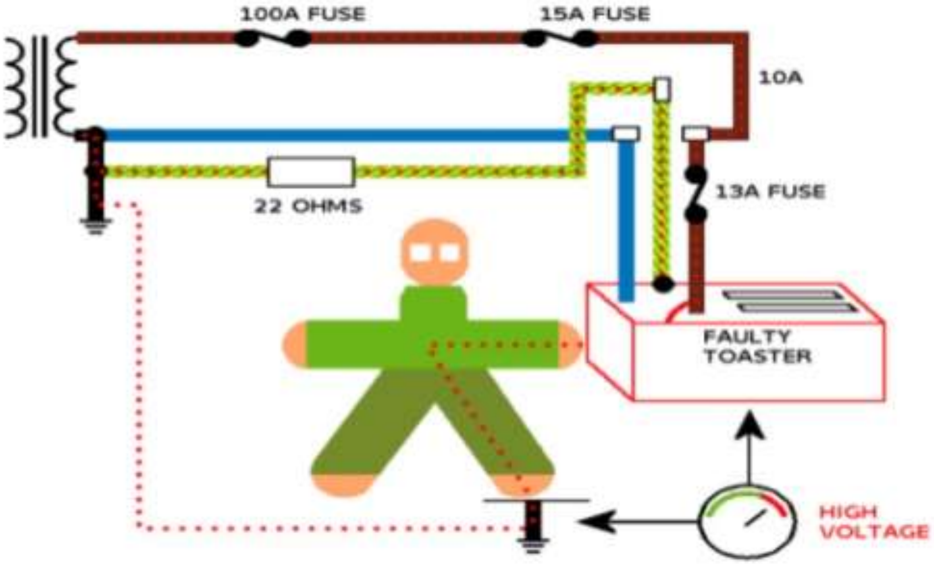


POWER SYSTEM EARTHING

- Objectives-definitions-Tolerable limits of body currents-Soil resistivity-Earth resistance-Tolerable Step and touch voltages-design of earthing grid-Tower footing resistance-Neutral earthing-Ungrounded and effectively earthed system-Resistance, Reactance, Arc suppression coil earthing and grounding transformers. Arcing grounds-protection against arcing grounds.

POWER SYSTEM EARTHING

- The process of connecting metallic bodies of all the electrical apparatus and equipment to huge mass of earth by a wire having negligible resistance is called Earthing.
- The term earthing means connecting the neutral point of supply system or the non current carrying parts of the electrical apparatus to the general mass of earth in such a manner that all times an immediate discharge of electrical energy takes place without danger.



Importance of Earthing, in Power System

50 % Failure of equipments attributed to Earthing.

40,000 Lightening storms/day or

100 Lightening storms/second

98 % of the faults in the system are due to SLG Faults

1.5 % of the faults are due to Line to Line Faults

0.5 % of the faults are due to 3 Phase Faults

The objective of earthing are:

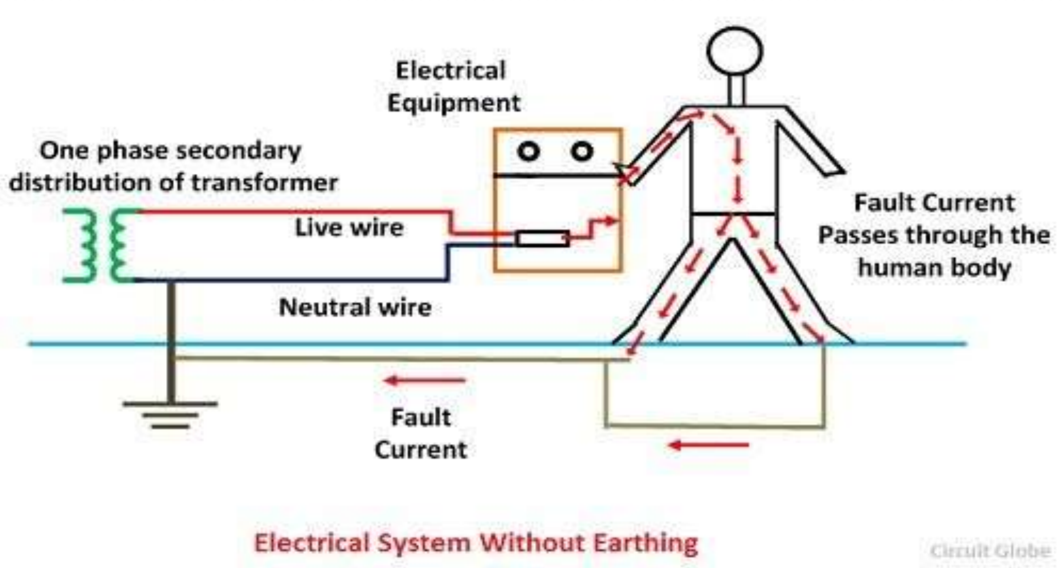
1. To ensure that no part of equipments, other than live parts should assume a potential which is dangerously different from surroundings.
2. To allow sufficient current to flow safely for proper operation of protective devices.
3. To limit over voltages between neutral and ground and between line and ground.
4. To suppress dangerous high potential gradients.

Earthing can be divided into two ways

- 1.Neutral earthing
- 2.Equipment earthing.

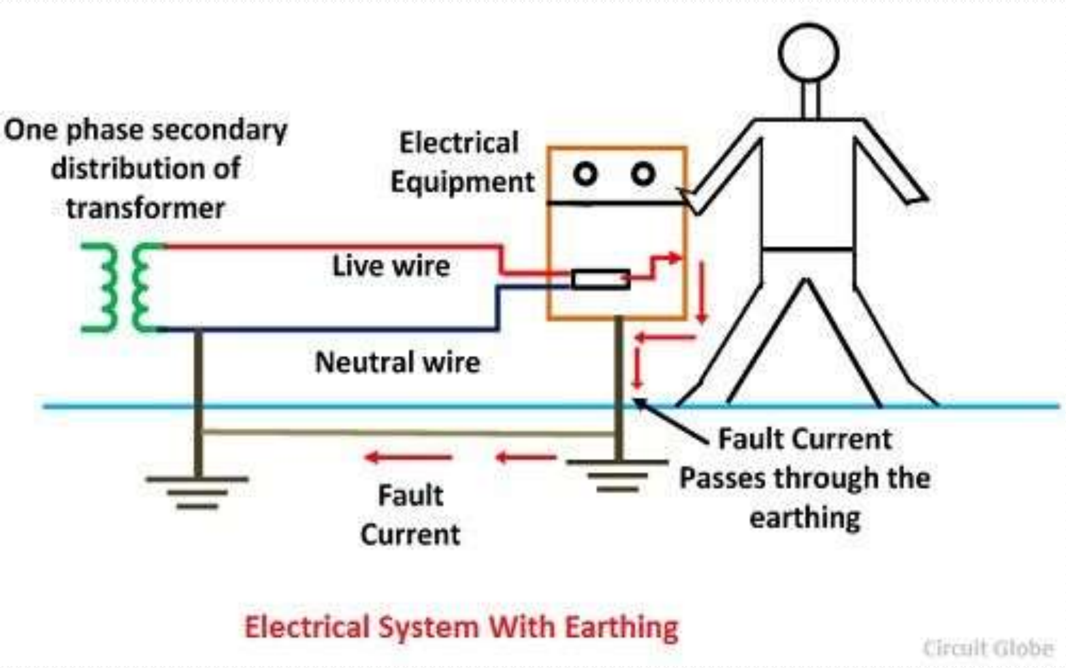
- Neutral earthing deals with earthing of system neutral to ensure safety of personnel and protection against lighting.
- Equipment earthing deals with earthing of non-current carrying parts of equipment to ensure safety of personnel and protection against lighting.

- Earthing can be done by electrically connecting the respective parts in the installation to some system of electrical conductors or electrodes placed near the soil or below the ground level.
- The earthing mat or electrode under the ground level have flat iron riser through which all the non-current-carrying metallic parts of the equipment are connected.



Electrical System Without Earthing

- When the fault occurs the fault current from the equipment flows through the earthing system to the earth and thereby protect the equipment from the fault current.
- At the time of the fault, the earth mat conductors rise to the voltage which is equal to the resistance of the earth mat multiplied by a ground fault.



Electrical System With Earthing

- The contacting assembly is called earthing. The metallic conductors connecting the parts of the installation with the earthing are called electrical connection.
- The earthing and the earthing connection together called the earthing system

DEFINITIONS:

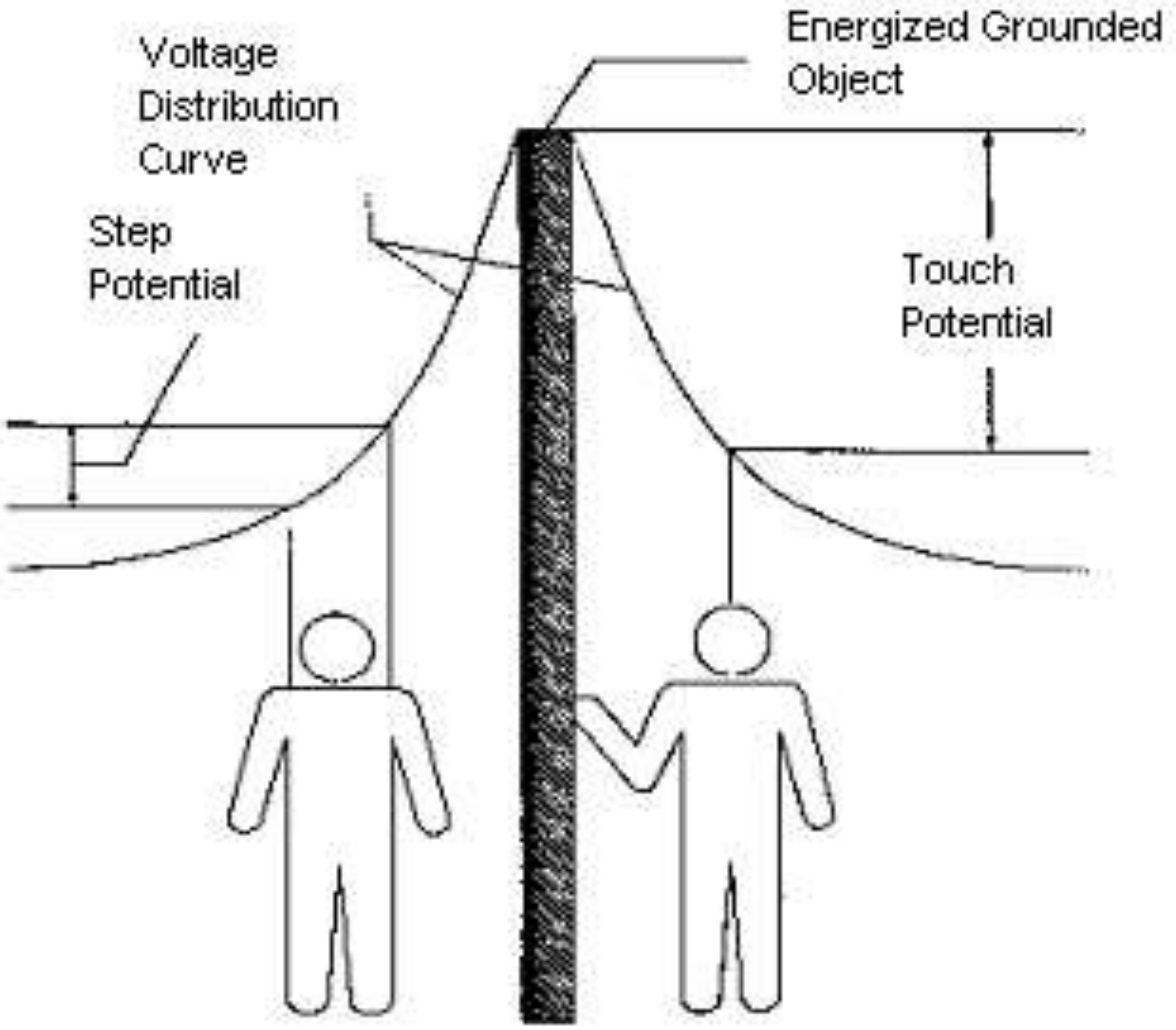
- **EARTH ELECTRODE**: A rod , pipe, plate or an array of conductors, embedded in earth horizontally or vertically.
- In distribution system the earth electrode consists of a rod about 1m long , driven vertically into ground.
- For substations an elaborate earthing system known as earth grid or earth mat is used.
- **EARTH CURRENT**: The current dissipated by earth electrode into the ground.

- **RESISTANCE OF EARTH ELECTRODE:** The resistance offered by the earth electrode to the flow of current into the ground.
- The resistance is not the ohmic resistance of the electrode but represents the resistance of the mass of earth surrounding the earth electrode.
- Numerically it is equal to the ratio of potential of earth electrode with respect to remote point, to the current dissipated by it.

- **STEP POTENTIAL**: The potential difference shunted by a human body between two accessible points on the ground separated by the distance of one pace assumed to be equal to 1m.

- **TOUCH POTENTIAL**: The potential difference between a point on the ground and a point on an object likely to carry fault current (e.g Frame of equipment) and which can be touched by a person.

Step and touch voltages



STEP & TOUCH POTENTIALS

- **MESH POTENTIAL**: The maximum potential within a mesh of the grid**.**
- **TRANSFERRED POTENTIAL**: A special case of touch potential where a potential is transferred into or out of the substation.

TOLERABLE LIMITS OF BODY CURRENTS:

- The effect of electric current passing through vital organs of the body depends on magnitude, duration and frequency of current.
- The most dangerous consequences is a heart condition known as ventricular fibrillation which results in stoppage of blood circulation.

(a)Effect of magnitude of current :

- The threshold of perception is a current of 1mA.
- Current in the range of 1-6 mA are known as "Let to go current" because these currents, though unpleasant, do not impair the ability of a person, holding an energised object, to release it.
- Currents in the range 9-25 mA may be painful and impair the ability to release energised object. Still higher current makes breathing difficult.

- However , if the current is less than about 60 mA, the effect are not permanent and disappear when current is interrupted.
- Currents higher than 60 mA ,the effects are not permanent and disappear when current is interrupted. Currents higher than 60 mA may lead to ventricular fibrillation, injury and death.

(b)Effect of duration of current :

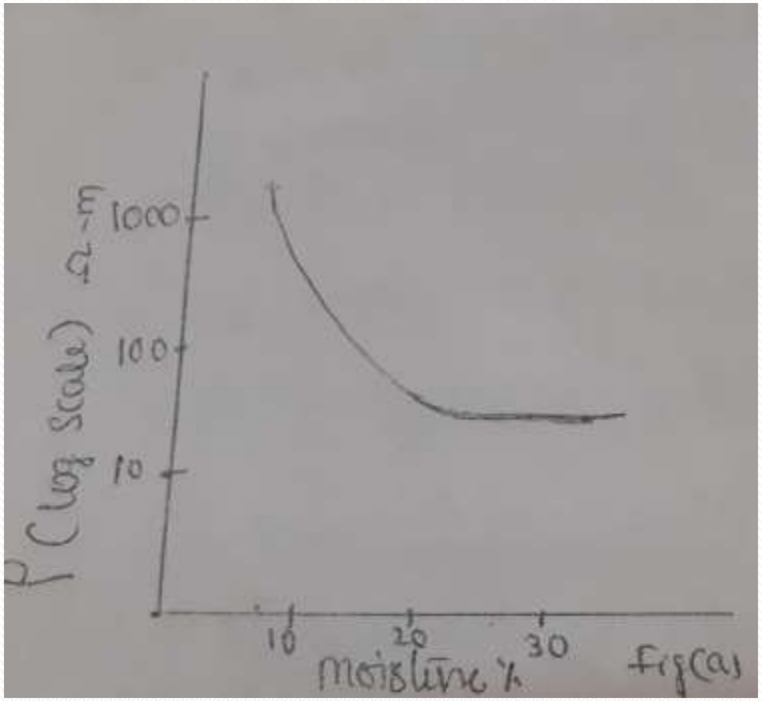
- The magnitude of 50Hz tolerable current is related to duration. According to tests reported by Dalziel, 99.5% of persons of 50Kg weight can safety withstand the current given by equation.
- $I_B = 0.116/\sqrt{t}$ -------- 1 where I_B is RMS value of body current in amperes and t is the time in seconds. If the weight of body is 70Kgs.
- $I_B = 0.157/\sqrt{t}$ -------- 2 are valid for $0.03<t<3$ sec.

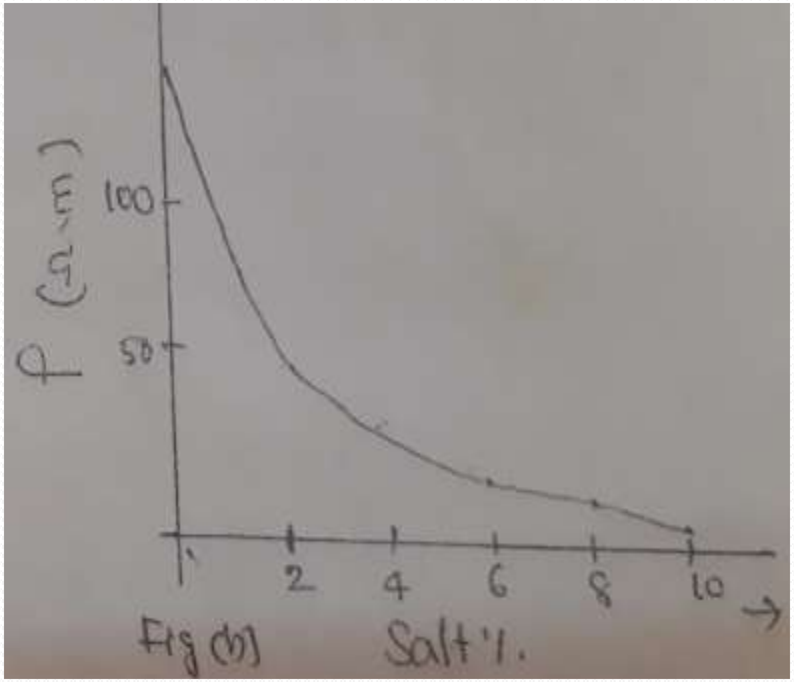
(c)Effect of frequency:

- The tolerable currents mentioned above for 50-60 Hz. It has been found that human body can tolerance about 5times higher direct current.
- At high frequencies (3000-10kHz) still higher currents can be tolerated.

SOIL RESISTIVITY:

- The resistivity of soil depends on the following factors
- **SOIL TYPE**: The type of soil governs the resistivity to large extent. Some typical values are Sea water 2.5 Ω -m, Tap water 20 Ω -m, Clay 50 Ω -m, Sand 2000 Ω -m, dry concrete 10000 Ω -m, rock 10000 Ω -m.
- **MOISTURE CONTENT**: Electrical conduction in soil is electrolytic. Soil resistivity decreases with increase in moisture content as shown in Fig 1.
- However when the moisture is more than 20% the change in resistivity is negligible. The amount of water which a soil can absorb depends on soil type, grain size and compactness.

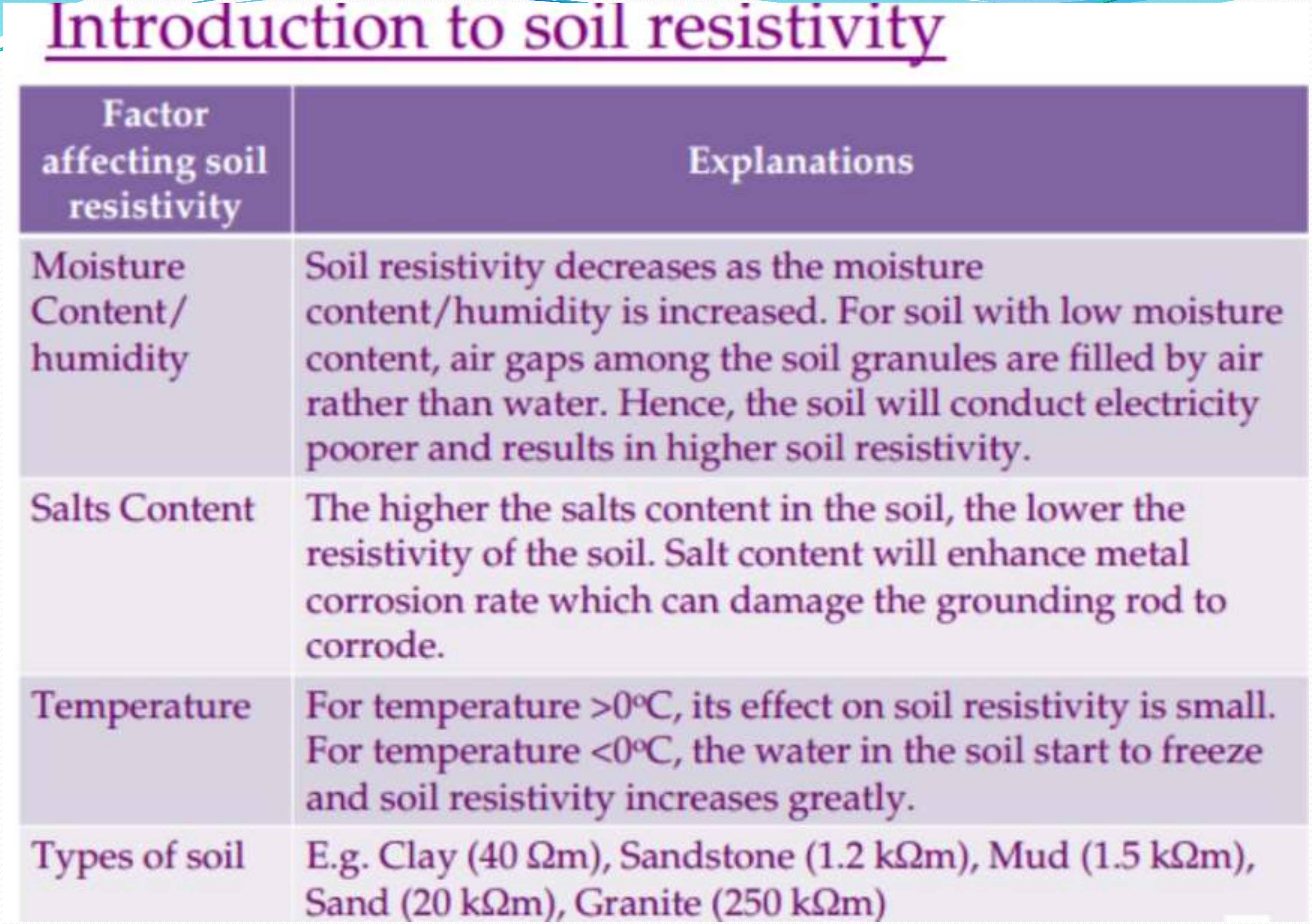

ρ (log scale) Ω-m
1000
100
10
10
20
30
moisture %
Fig(a)


ρ (Ω-m)
100
50
2
4
6
8
10
Fig (b)
Salt %

- **TEMPERATURE**: When temperature is more than zero degrees , its effect on soil resistivity is negligible. At zero degrees , water in the soil starts freezing and resistivity increases.
- **SALT CONTENT**: The composition and amount of soluble salts also affect resistivity considerably as shown in Fig2.

- **MAGNITUDE OF CURRENT**: If the value of current being dissipated by the soil is high, it may cause significant drying of soil and increase in its resistivity.

  The soil resistivity at a particular location also changes with depth. Generally the lower layers of soil have greater moisture content and lower resistivity. However , if the lower layer contains hard , rocky soil resistivity may increase with depth.



Introduction to soil resistivity

Factor affecting soil resistivity	Explanations
Moisture Content/ humidity	Soil resistivity decreases as the moisture content/humidity is increased. For soil with low moisture content, air gaps among the soil granules are filled by air rather than water. Hence, the soil will conduct electricity poorer and results in higher soil resistivity.
Salts Content	The higher the salts content in the soil, the lower the resistivity of the soil. Salt content will enhance metal corrosion rate which can damage the grounding rod to corrode.
Temperature	For temperature >0°C, its effect on soil resistivity is small. For temperature <0°C, the water in the soil start to freeze and soil resistivity increases greatly.
Types of soil	E.g. Clay (40 Ωm), Sandstone (1.2 kΩm), Mud (1.5 kΩm), Sand (20 kΩm), Granite (250 kΩm)

Max. Value of Earth Resistance to be achieved

Equipment to be Earthed	Max. Value of Earth Resistance to be achieved in Ohms
Large Power Stations	0.5
Major Substations	1.0
Small Substations	2.0
Factories Substations	1.0
Lattice Steel Tower	3.0
Industrial Machine and Equipment	0.5

* The Earth Resistance depends upon the moisture content in the soil.

Design of earthing grid

- The following steps should be followed for the design of earthing grid
- **(a) Data needed for the design**
- 1.Substation ground area
- 2.soil resistivity at the site
- 3.Fault clearing time
- 4.Maximum grid current
- 5.Resistivity of soil at surface

(b) Design of earthing system

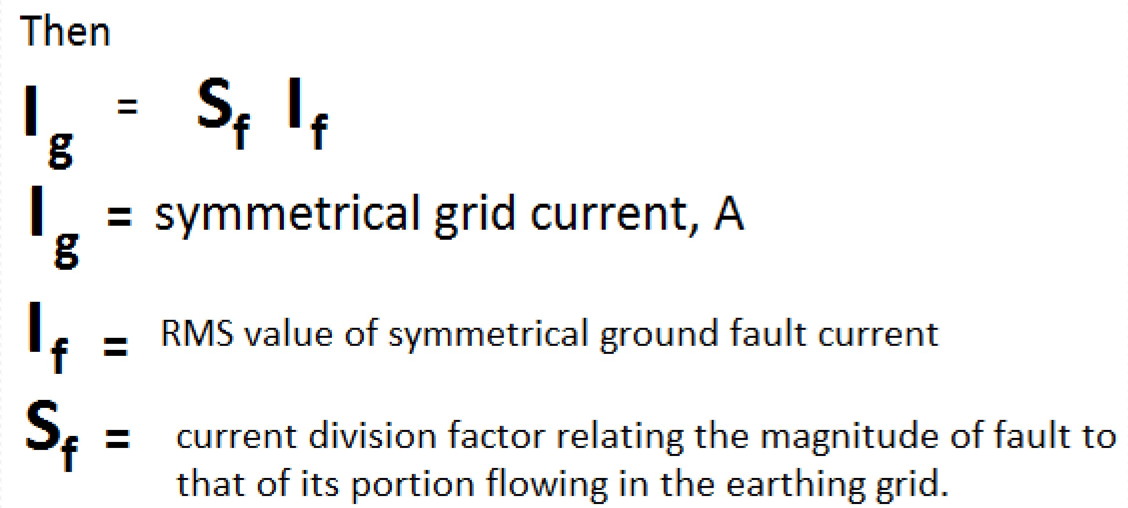
- 1.selection of electrode material
- 2.Determination of conductor size
- 3.Preliminary design
- 4.Determination of conductor length required for control of voltage gradient.
- 5.calculation of resistance and ground potential rise.
- 6.checking of step potential and version of design, if necessary

Design of earthing grid ..

- **Substation ground area and soil resistivity :**
- Generally the Substation plan is prepared before the grid design.
- The earthing grid should cover as much ground area as possible.
- Soil resistivity should be determined.
- A thin surface layer of crushed rock helps in limiting the body current.
- **Fault clearing time:**
- Fault clearing time is governed by system stability considerations and depends on protection and switchgear equipment.

Determination of maximum grid current

- A SLG fault is more common and causes more fault current as compared to DLG fault.
- Therefore ,the design is based on SLG fault current.
- For calculation of this current grid resistance and fault resistance assumed zero



Then

$$I_g = S_f \, I_f$$

I_g = symmetrical grid current, A

I_f = RMS value of symmetrical ground fault current

S_f = current division factor relating the magnitude of fault to that of its portion flowing in the earthing grid.

From the value of I_g the design value of grid current is found as

$$I = G_f D_f I_g$$

I = Maximum grid current

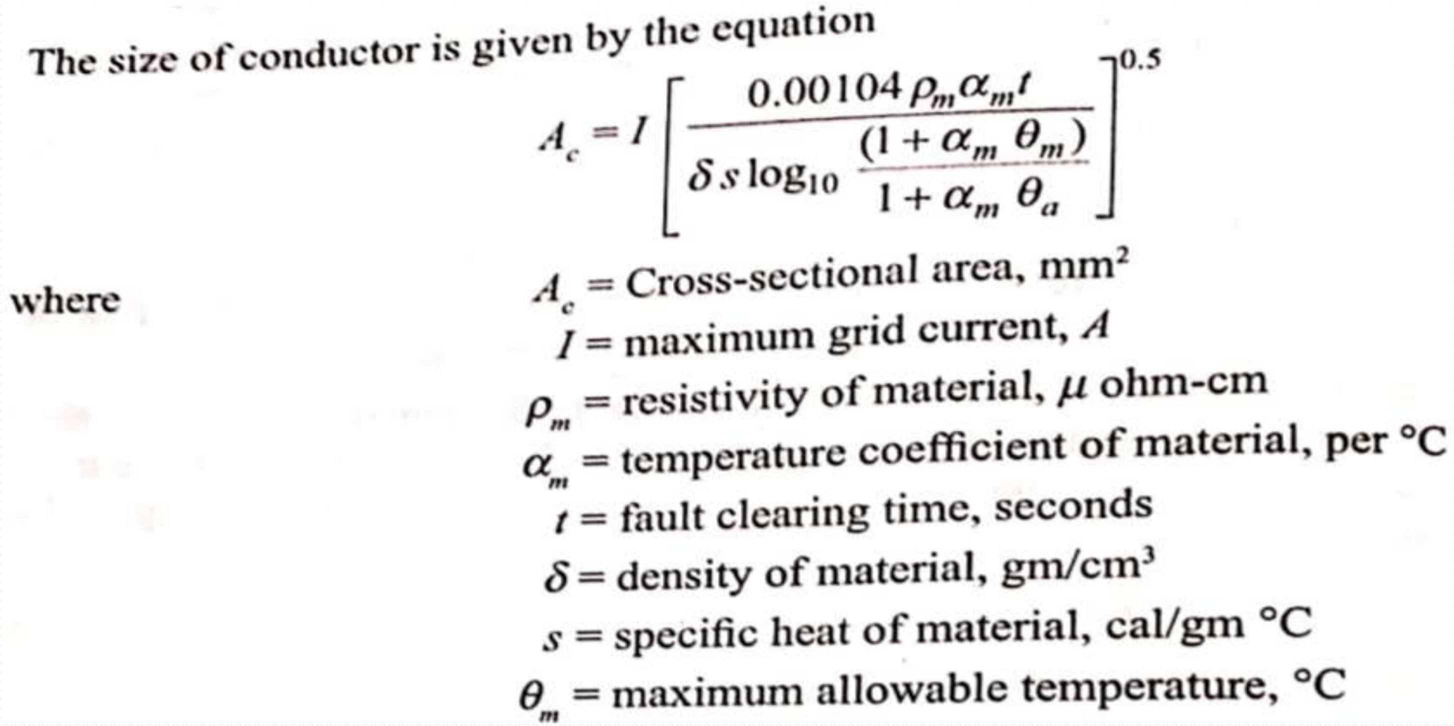
G_f = A factor to account for increase in fault current due to growth during life span of grid

D_f = Decreament factor to account for asymmetry of the fault current (Lie in the range 1.2 to 1.5)

Selection of electrode material:

- The material for grounding grid should have good conductivity, be mechanically rugged and resist fusing and deterioration of joints.
- However , a grid of copper forms a galvanic cell with other buried structures and pipes, likely to corrosion.
- Aluminum is not used due to corrosion problem.
- The material most commonly used presently is galvanized steel.

Determination of conductor size:



The size of conductor is given by the equation

$$A_c = I\left[\frac{0.00104\,\rho_m\alpha_m t}{\delta\, s \log_{10}\frac{(1+\alpha_m\,\theta_m)}{1+\alpha_m\,\theta_a}}\right]^{0.5}$$

where

A_c = Cross-sectional area, mm^2

I = maximum grid current, A

ρ_m = resistivity of material, μ ohm-cm

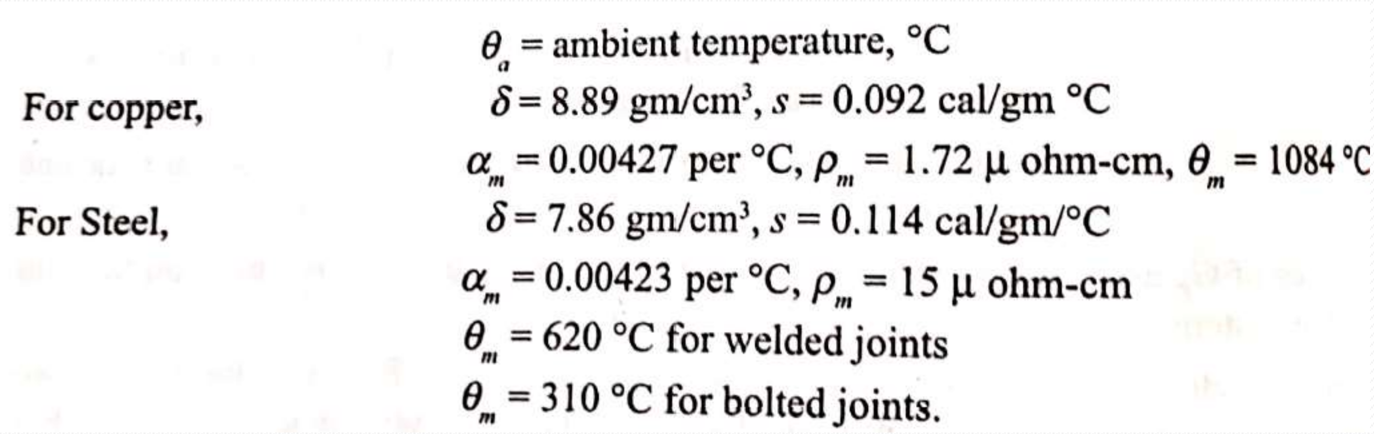
α_m = temperature coefficient of material, per °C

t = fault clearing time, seconds

δ = density of material, gm/cm^3

s = specific heat of material, cal/gm °C

θ_m = maximum allowable temperature, °C



θ_a = ambient temperature, °C

For copper, $\delta = 8.89$ gm/cm^3, $s = 0.092$ cal/gm °C

$\alpha_m = 0.00427$ per °C, $\rho_m = 1.72\ \mu$ ohm-cm, $\theta_m = 1084$ °C

For Steel, $\delta = 7.86$ gm/cm^3, $s = 0.114$ cal/gm/°C

$\alpha_m = 0.00423$ per °C, $\rho_m = 15\ \mu$ ohm-cm

$\theta_m = 620$ °C for welded joints

$\theta_m = 310$ °C for bolted joints.

Tower footing resistance

- Tower footing resistance is the resistance offered by tower footing to the dissipation of current.
- The effective wire depends to a large extended on the tower footing resistance.
- The tower top potential depends on this resistance to a large extent.
- A low value of tower footing resistance results in less voltage stresses across line insulation.
- A tower footing resistance of 20 Ohms for EHV lines and 10 Ohms for HV lines provides sufficient lightning protection.

EARTH RESISTANCE

Hemispherical Electrode

Fig. 1 (a) shows a buried hemisphere. The total resistance can be divided into three parts (i resistance of conductor (ii) contact resistance between the surface of electrode and main body of earth (iii) resistance of body of earth surrounding the electrode.

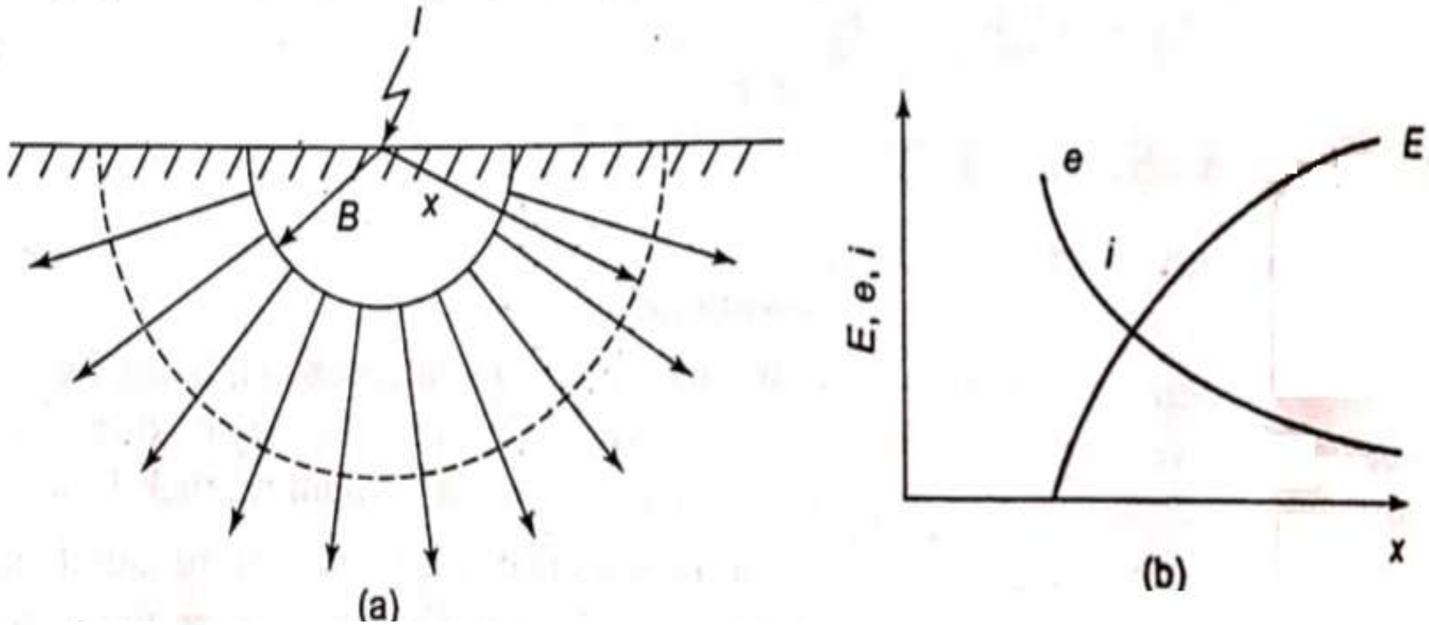
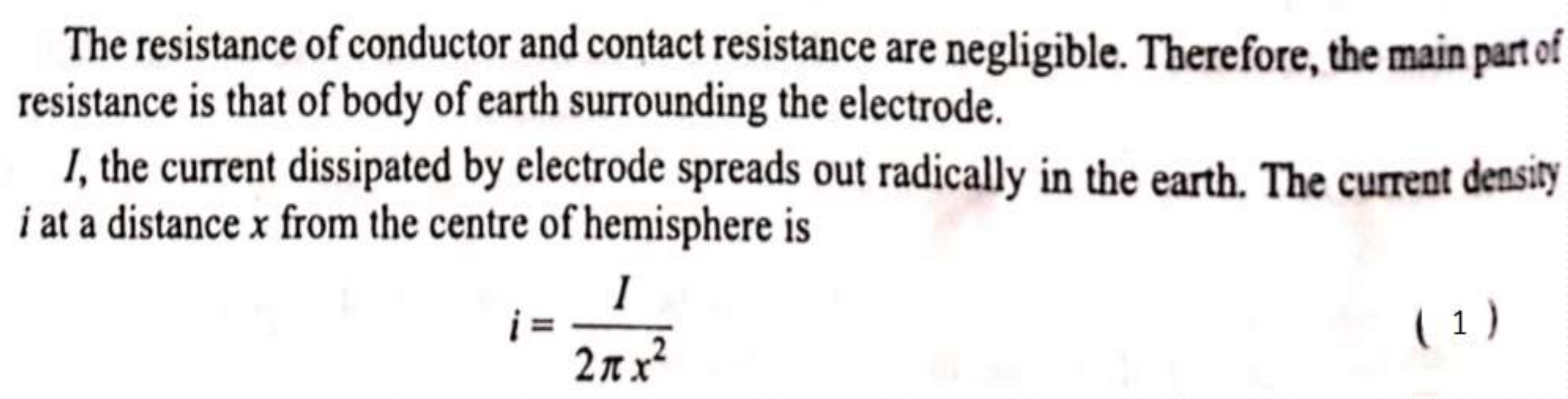


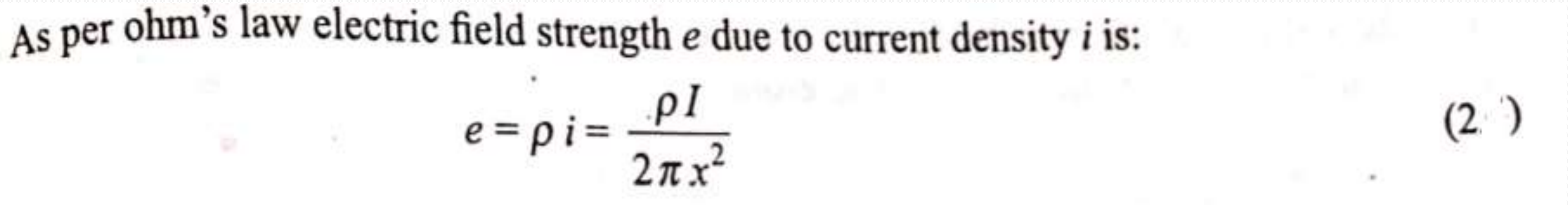
Fig. 1 (a) Hemispherical electrode (b) Variation of e, i, E, with x



The resistance of conductor and contact resistance are negligible. Therefore, the main part of resistance is that of body of earth surrounding the electrode.

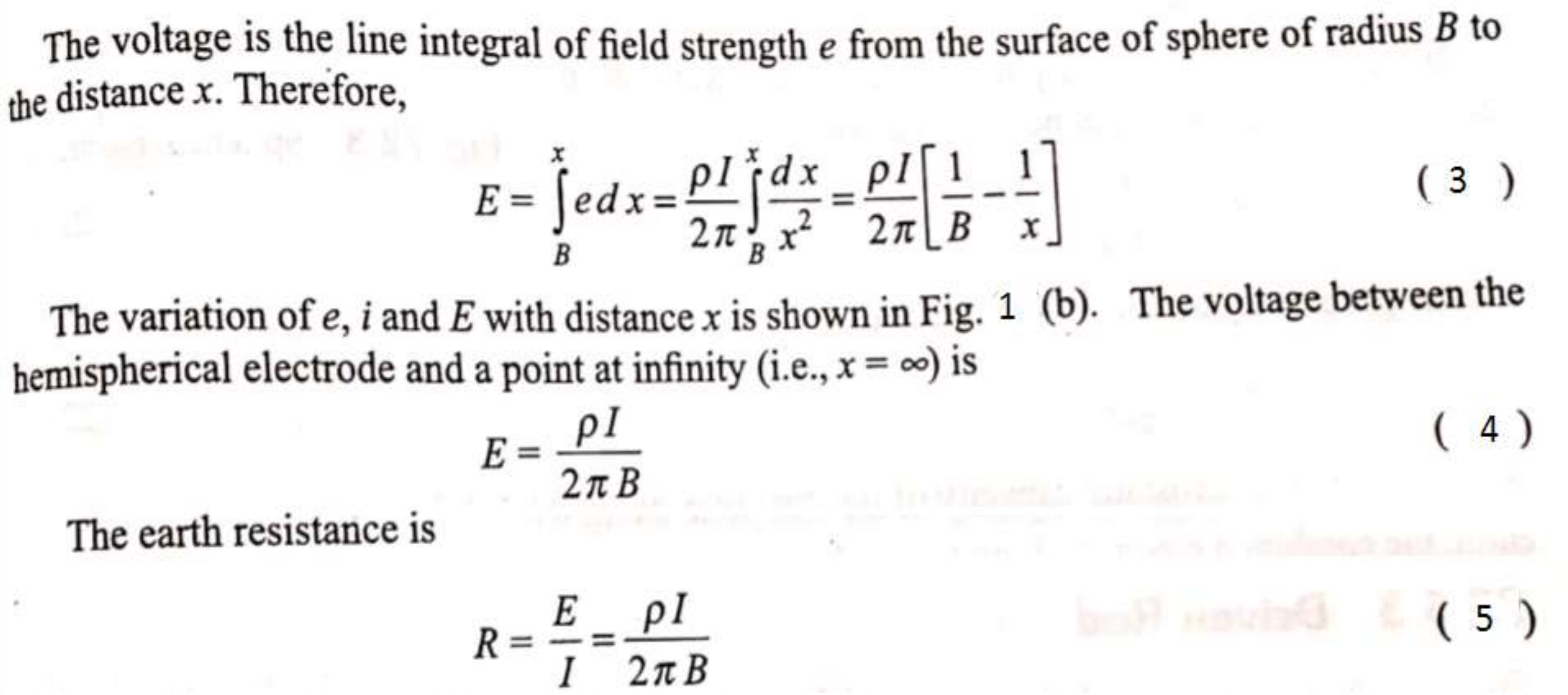
I, the current dissipated by electrode spreads out radically in the earth. The current density *i* at a distance *x* from the centre of hemisphere is

$$i = \frac{I}{2\pi x^2} \qquad (1)$$



As per ohm's law electric field strength *e* due to current density *i* is:

$$e = \rho i = \frac{\rho I}{2\pi x^2} \qquad (2)$$



The voltage is the line integral of field strength *e* from the surface of sphere of radius *B* to the distance *x*. Therefore,

$$E=\int_B^x e\,dx=\frac{\rho I}{2\pi}\int_B^x\frac{dx}{x^2}=\frac{\rho I}{2\pi}\left[\frac{1}{B}-\frac{1}{x}\right] \qquad (3)$$

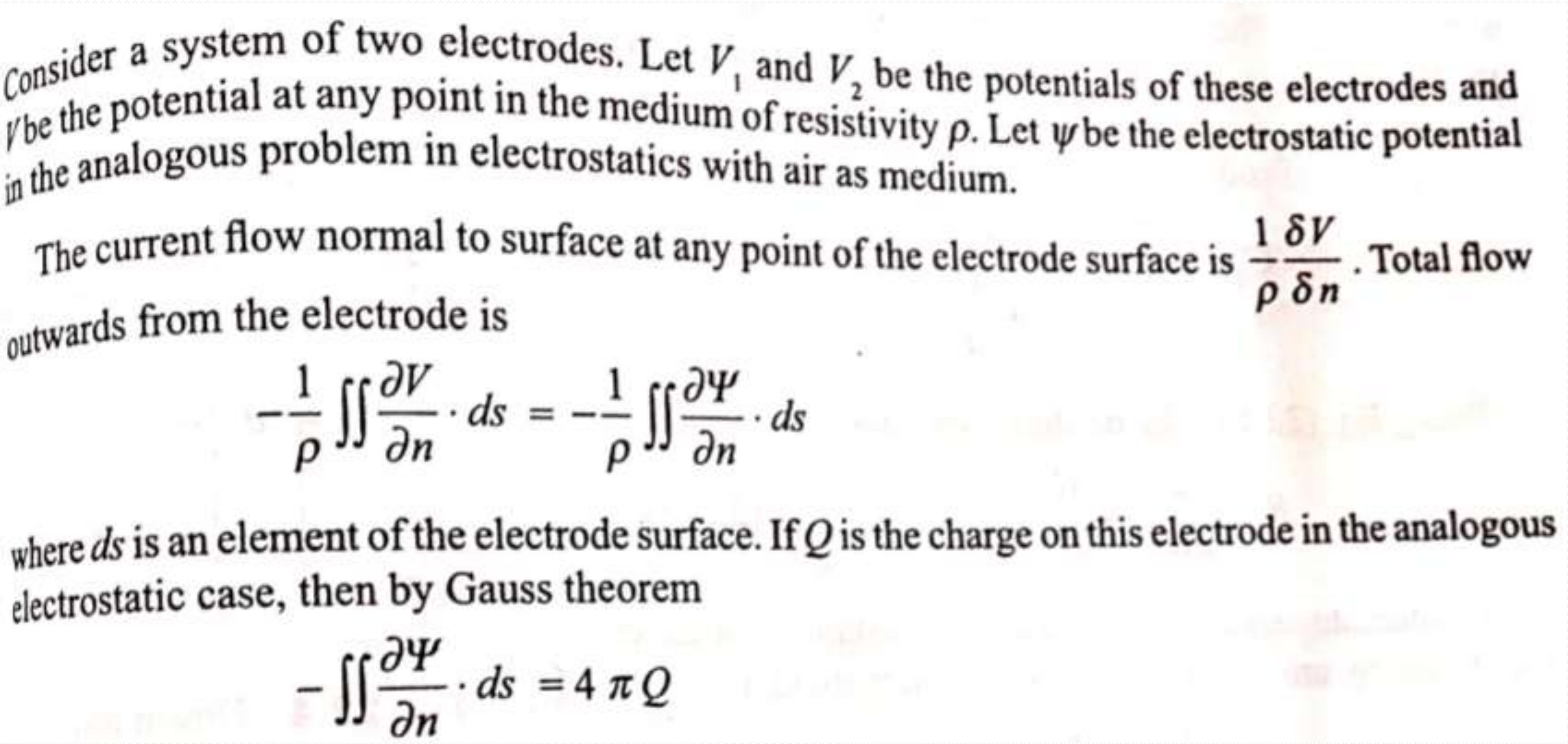
The variation of *e*, *i* and *E* with distance *x* is shown in Fig. 1 (b). The voltage between the hemispherical electrode and a point at infinity (i.e., $x=\infty$) is

$$E=\frac{\rho I}{2\pi B} \qquad (4)$$

The earth resistance is

$$R=\frac{E}{I}=\frac{\rho I}{2\pi B} \qquad (5)$$

General equation



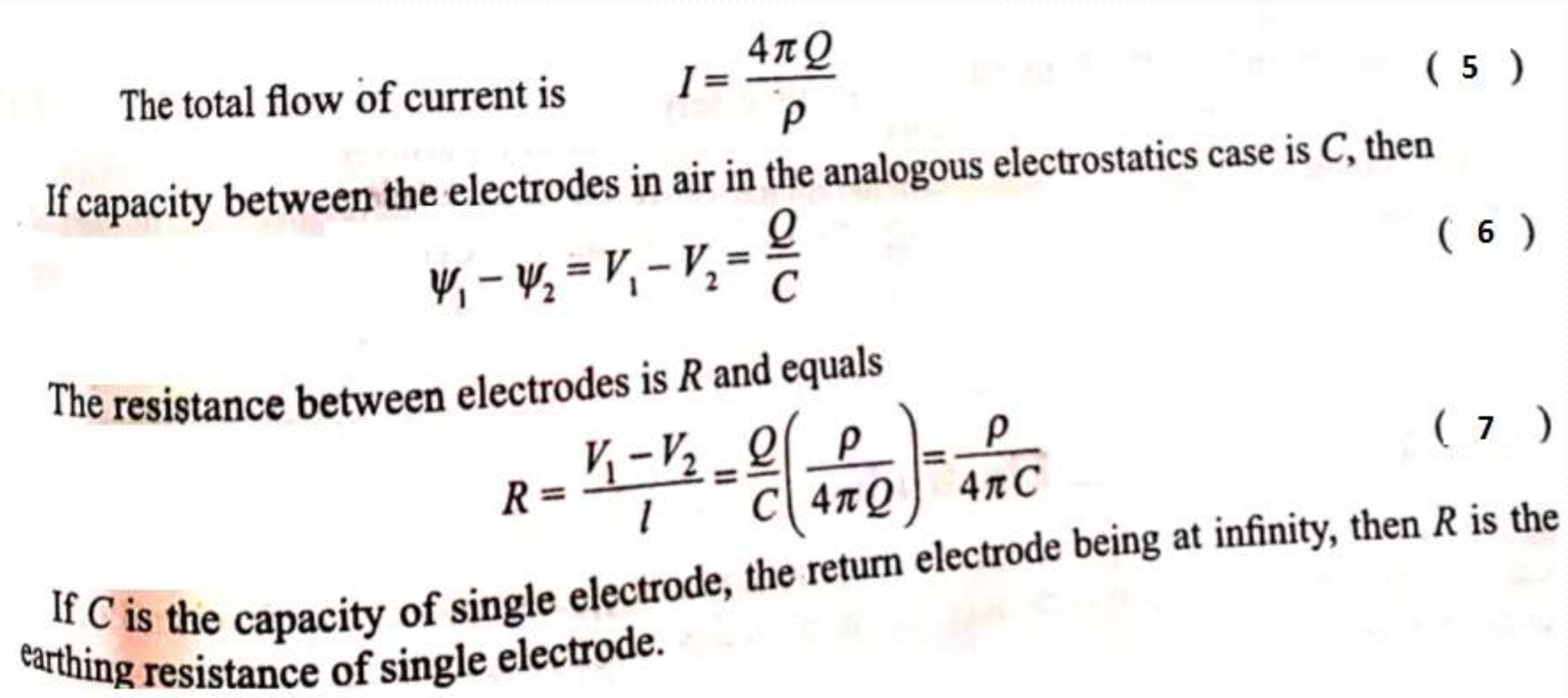
Consider a system of two electrodes. Let V_1 and V_2 be the potentials of these electrodes and V be the potential at any point in the medium of resistivity ρ. Let ψ be the electrostatic potential in the analogous problem in electrostatics with air as medium.

The current flow normal to surface at any point of the electrode surface is $\frac{1}{\rho}\frac{\delta V}{\delta n}$. Total flow outwards from the electrode is

$$-\frac{1}{\rho}\iint\frac{\partial V}{\partial n}\cdot ds = -\frac{1}{\rho}\iint\frac{\partial \Psi}{\partial n}\cdot ds$$

where ds is an element of the electrode surface. If Q is the charge on this electrode in the analogous electrostatic case, then by Gauss theorem

$$-\iint\frac{\partial \Psi}{\partial n}\cdot ds = 4\pi Q$$



The total flow of current is $$I = \frac{4\pi Q}{\rho} \qquad (5)$$

If capacity between the electrodes in air in the analogous electrostatics case is C, then

$$\psi_1 - \psi_2 = V_1 - V_2 = \frac{Q}{C} \qquad (6)$$

The resistance between electrodes is R and equals

$$R = \frac{V_1 - V_2}{I} = \frac{Q}{C}\left(\frac{\rho}{4\pi Q}\right) = \frac{\rho}{4\pi C} \qquad (7)$$

If C is the capacity of single electrode, the return electrode being at infinity, then R is the earthing resistance of single electrode.

Fig. 2 shows a sphere of radius *B*. The capacity of sphere in air is equal to radius, i.e., *B*. Therefore,

$$R = \frac{\rho}{4\pi B} \qquad (8)$$

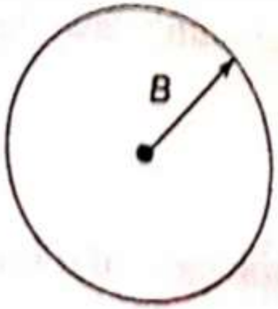


Fig. 2 Spherical electrode

If the electrode is a hemisphere buried with lower half in earth, the resistance would be doubled. Thus,

$$R = \frac{\rho}{2\pi B}$$

The general equation for any electrode is

$$R = \frac{\rho}{2\pi C}$$

where *C* is the electrostatic capacity of the electrode along with its image above the surface earth, the combined electrode being considered as in air.

Driven Rod

Fig. 3 shows a driven rod of length l and diameter d along with its image. The electrode can be considered equivalent to an ellipsoid of revolution in which major axis is very large as compared to minor axis. On the basis of this equivalence, the capacity of rod and its image is

$$C = \frac{2l}{2\ln\frac{4l}{d}} = \frac{l}{\ln\frac{4l}{d}} \qquad (9)$$

Using Eq. (22.13), the earthing resistance is

$$R = \frac{\rho}{2\pi l}\ln\frac{4l}{d} \qquad (10)$$

An alternate expression for earthing resistance of a driven rod, found by uniform current dissipation method, is

$$R = \frac{\rho}{2\pi l}\left(\ln\frac{8l}{d} - 1\right) \qquad (10a)$$

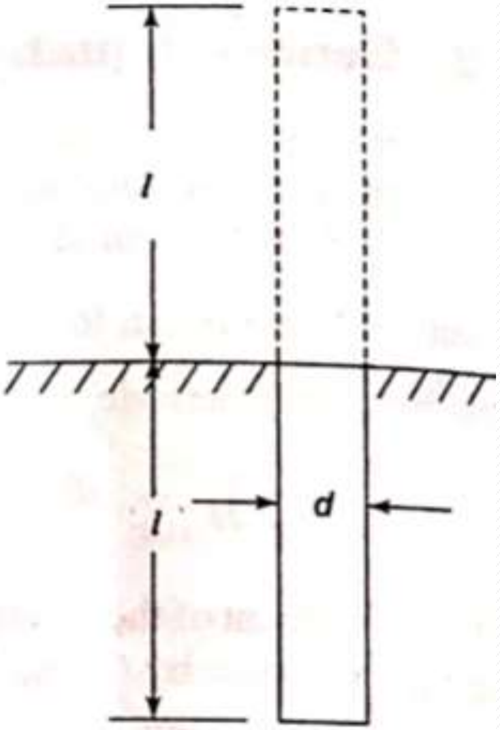
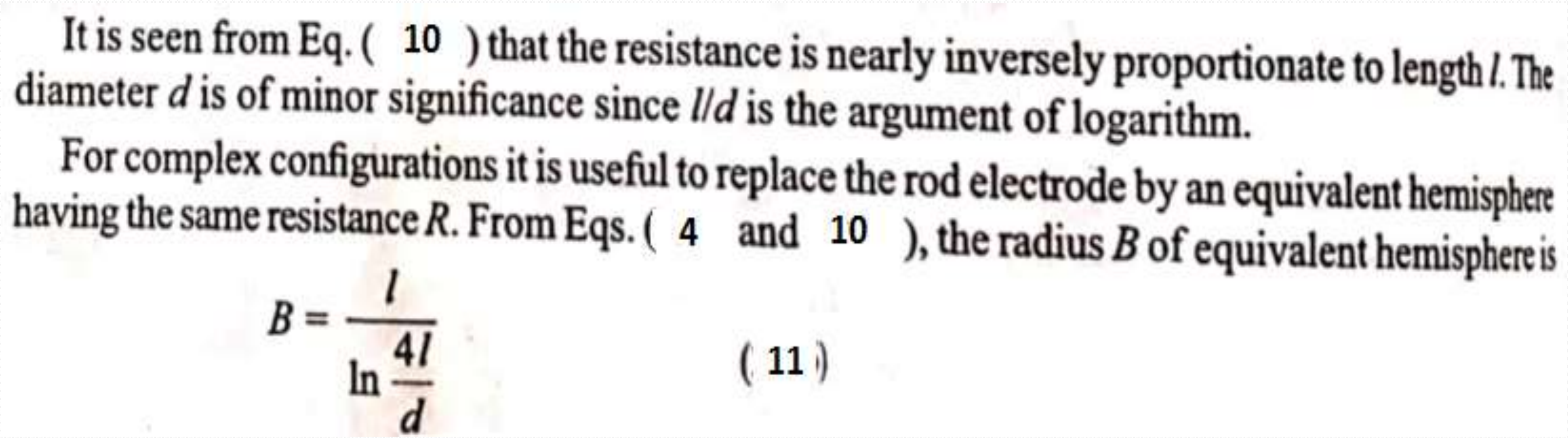


Fig. 3 Driven rod



It is seen from Eq. (10) that the resistance is nearly inversely proportionate to length l. The diameter d is of minor significance since l/d is the argument of logarithm.

For complex configurations it is useful to replace the rod electrode by an equivalent hemisphere having the same resistance R. From Eqs. (4 and 10), the radius B of equivalent hemisphere is

$$B = \frac{l}{\ln \frac{4l}{d}} \qquad (11)$$

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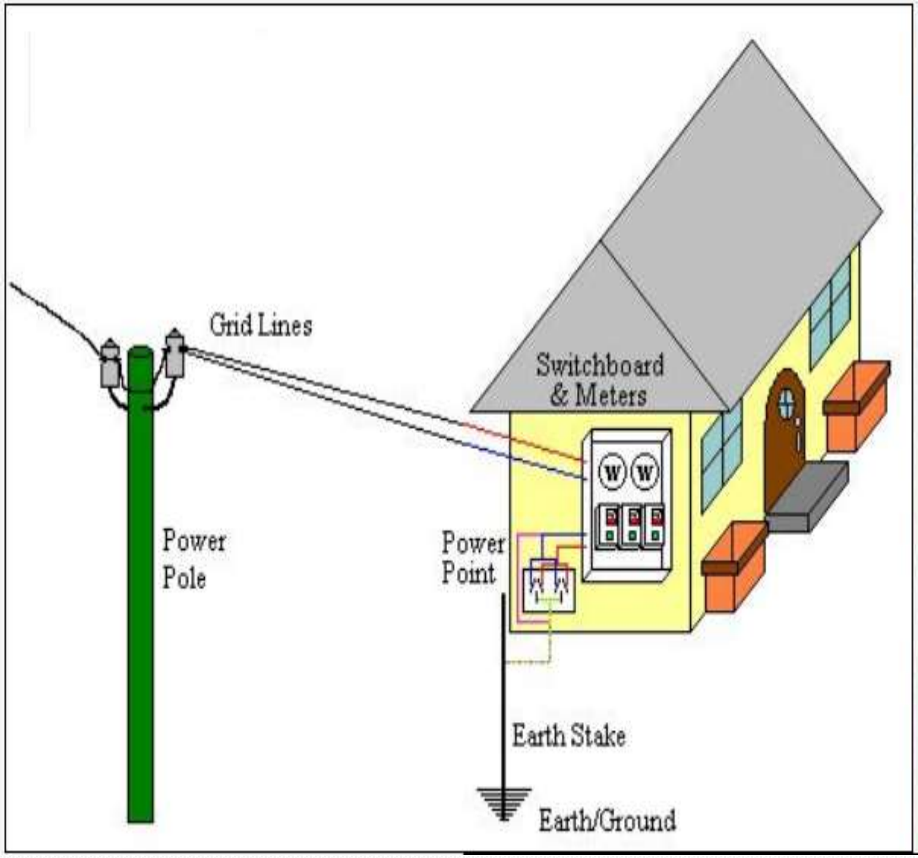

POWER SYSTEM EARTHING

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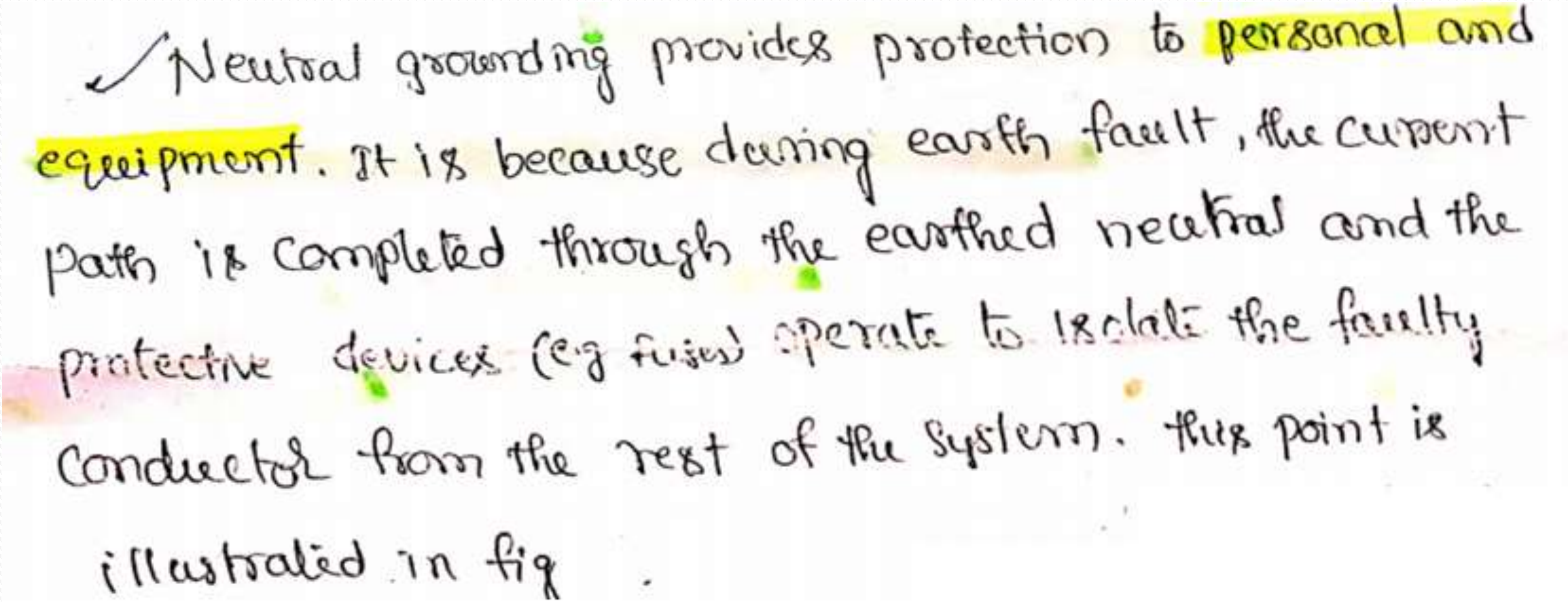
NEUTRAL GROUNDING OR EARTHING

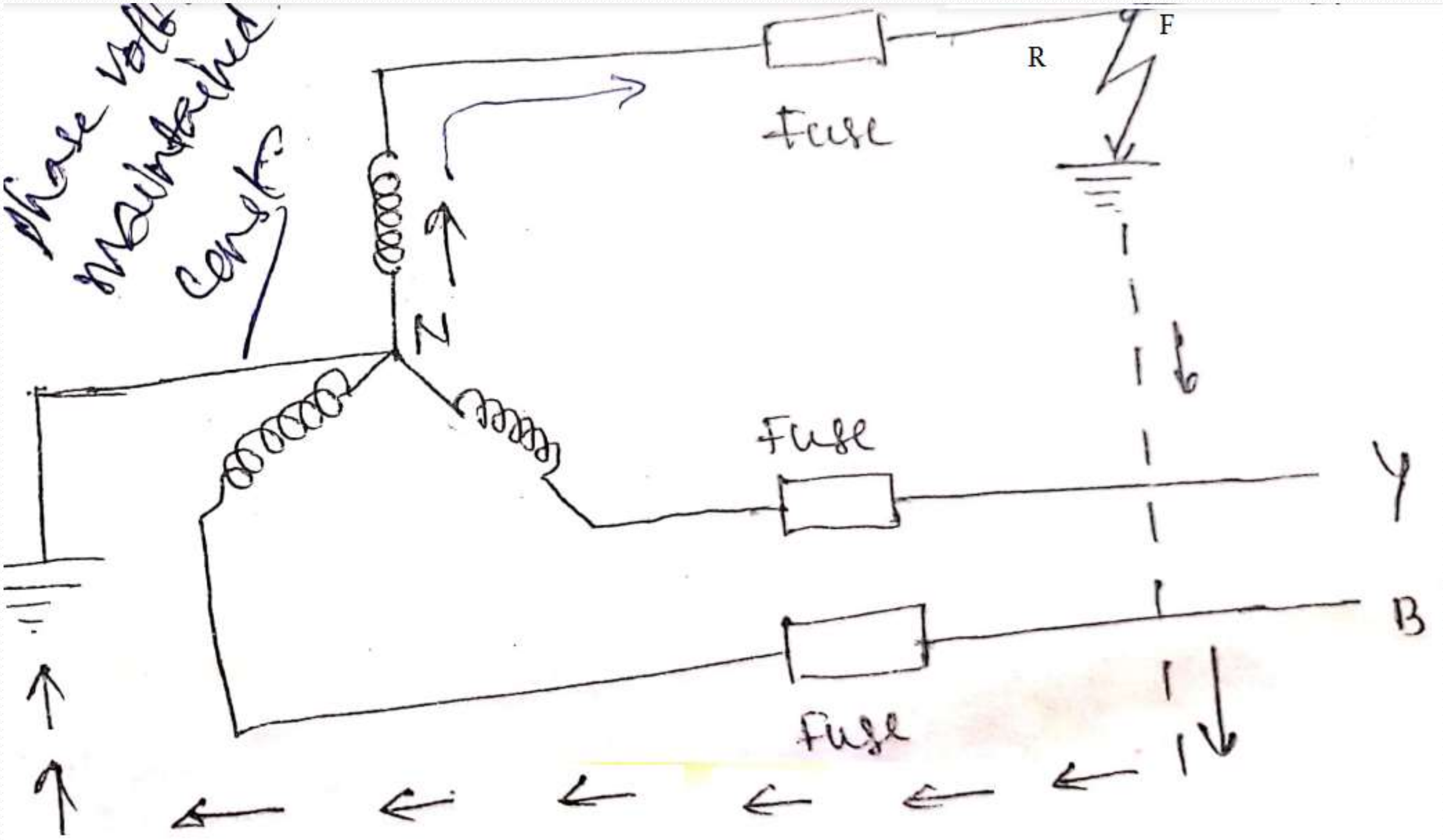
NEUTRAL EARTHING or Grounding. ①

The process of connecting neutral point of 3-phase system to earth either directly or through some circuit element (e.g resistance, reactance) is called neutral earthing

Neutral earthing does not have any influence on the operation of a 3-phase system under balanced steady state conditions. However, the voltage and currents during ground fault conditions are greatly affected



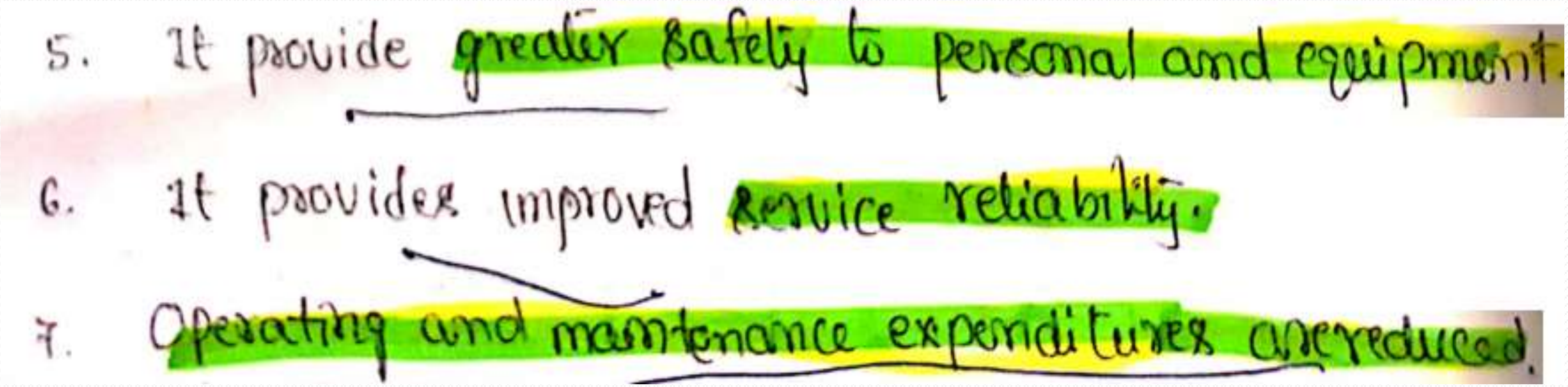
✓ Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (e.g fuses) operate to isolate the faulty conductor from the rest of the system. this point is illustrated in fig .


Phase volt maintained const
F
R
Fuse
N
I
Fuse
Y
B
Fuse

*** Advantages of Neutral Grounding :~

the following are the advantages of neutral groundi

1. Voltages of the healthy phases donot exceed line to ground voltages i.e they remain nearly constant.
2. The high voltages due to arcing grounds are eliminated
3. The protective relays can be used to provide protection against earth faults
4. The over voltages due to lightning are discharged to earth



5. It provide greater safety to personal and equipment.

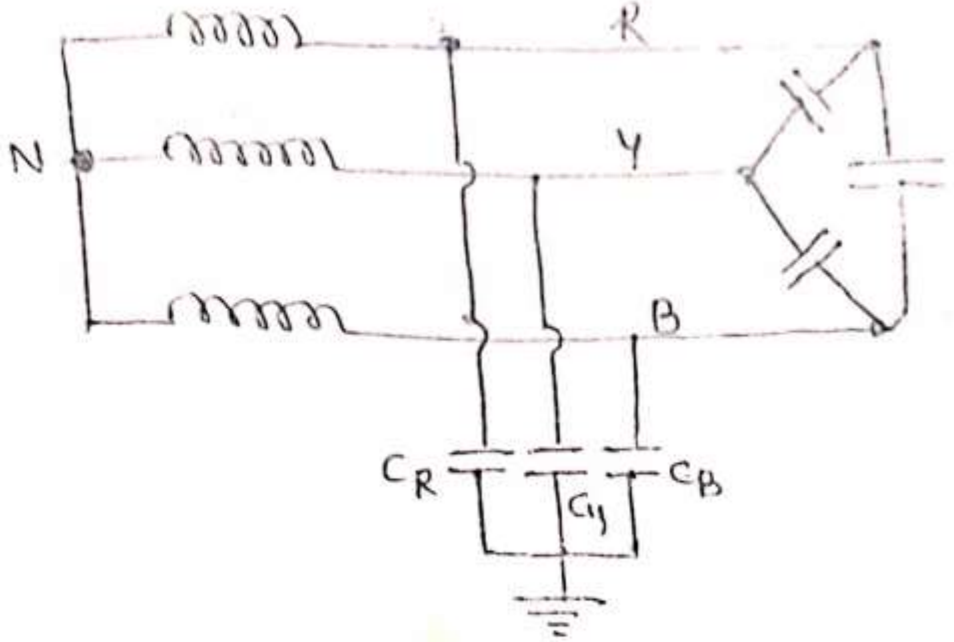
6. It provides improved service reliability.

7. Operating and maintenance expenditures are reduced.

Isollated Neutral (or) Ungrounded System

In an ungrounded neutral system, the neutral is not connected to the ground i.e the neutral is isolated from the ground. therefore, this system is also called "isolated neutral system or free neutral system.

the main feature of an ungrounded ~~neutral~~ neutral is its ability to clear ground faults without interruption. this self clearing feature disappears when the length of line becomes appreciable.


R
N
Y
B
C_R
C_y
C_B

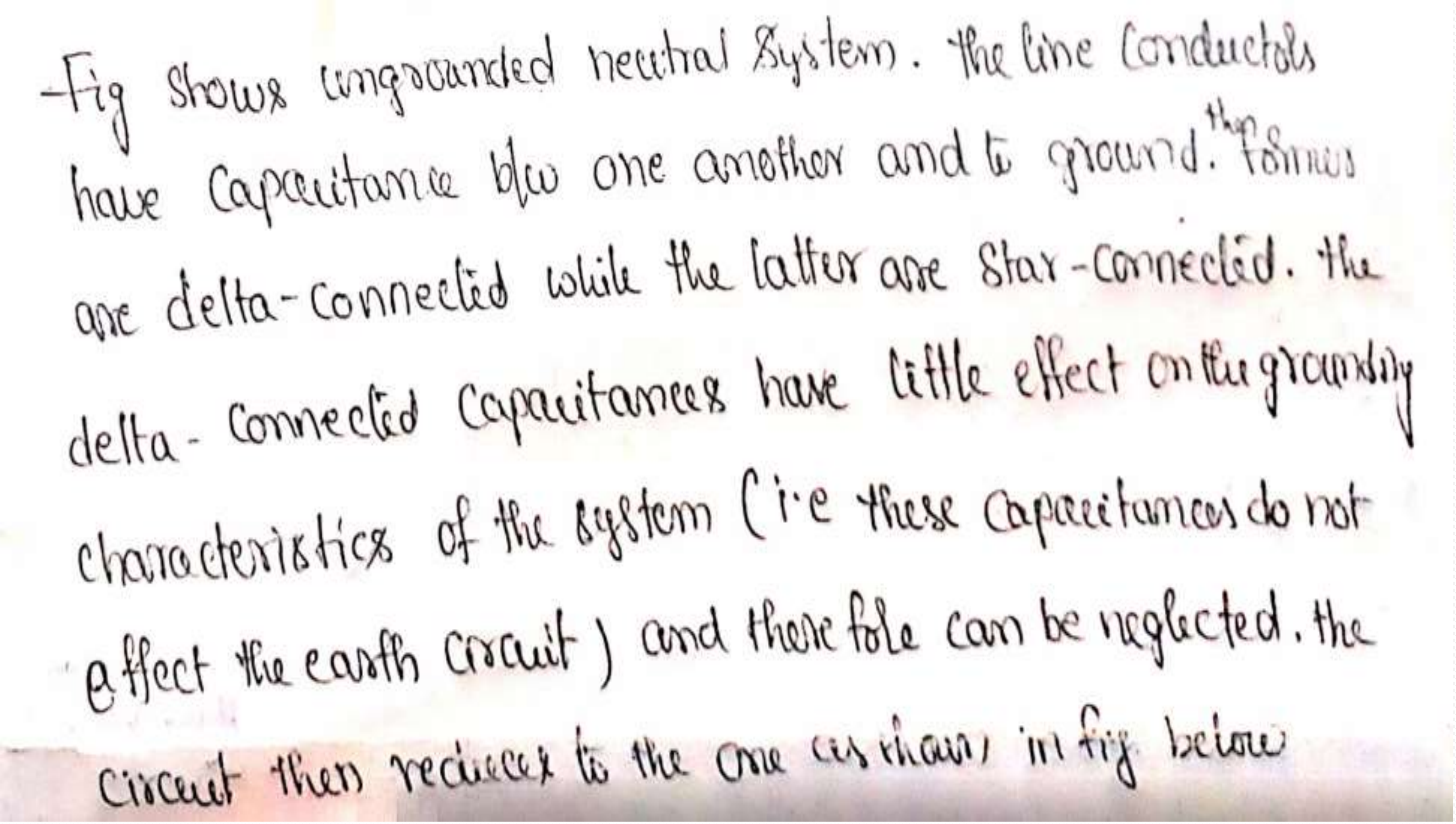
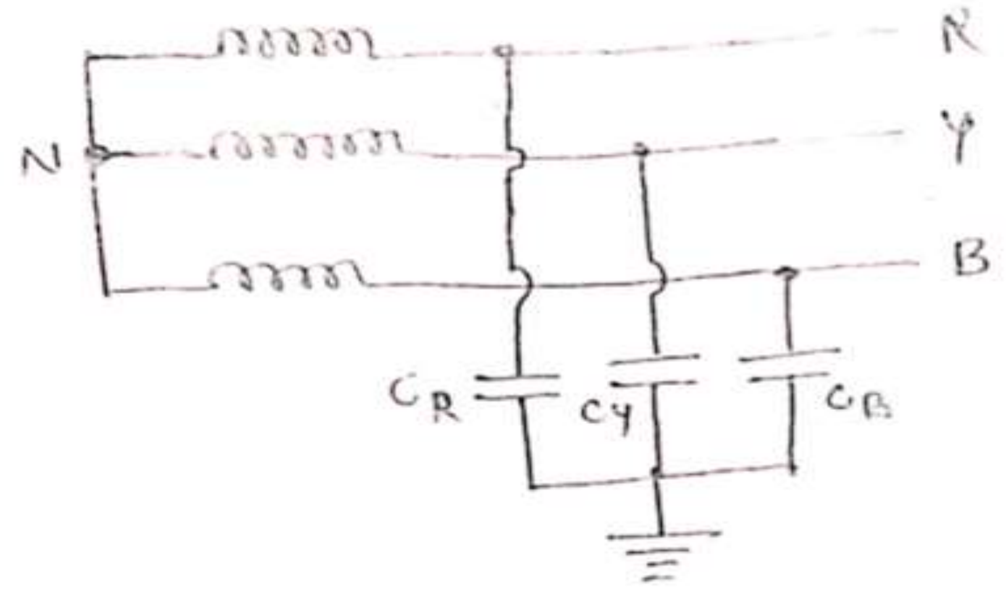


Fig shows ungrounded neutral System. the line Conductors have Capacitance b/w one another and to ground. the formers are delta-connected while the latter are Star-connected. the delta- connected Capacitances have little effect on the grounding characteristics of the system (i.e these capacitances do not affect the earth circuit) and therefore can be neglected. the circuit then reduces to the one as shown in fig below

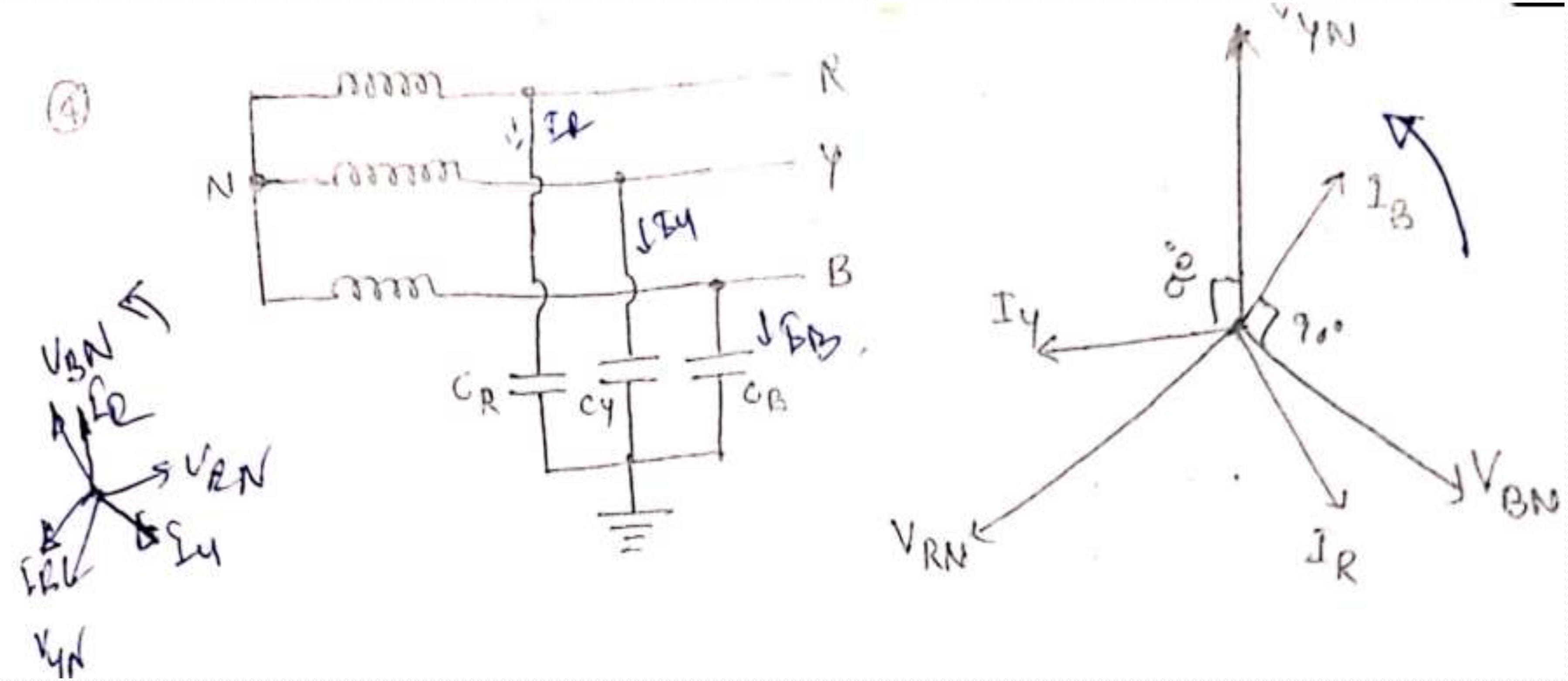

R
Y
B
N
C_R
C_Y
C_B

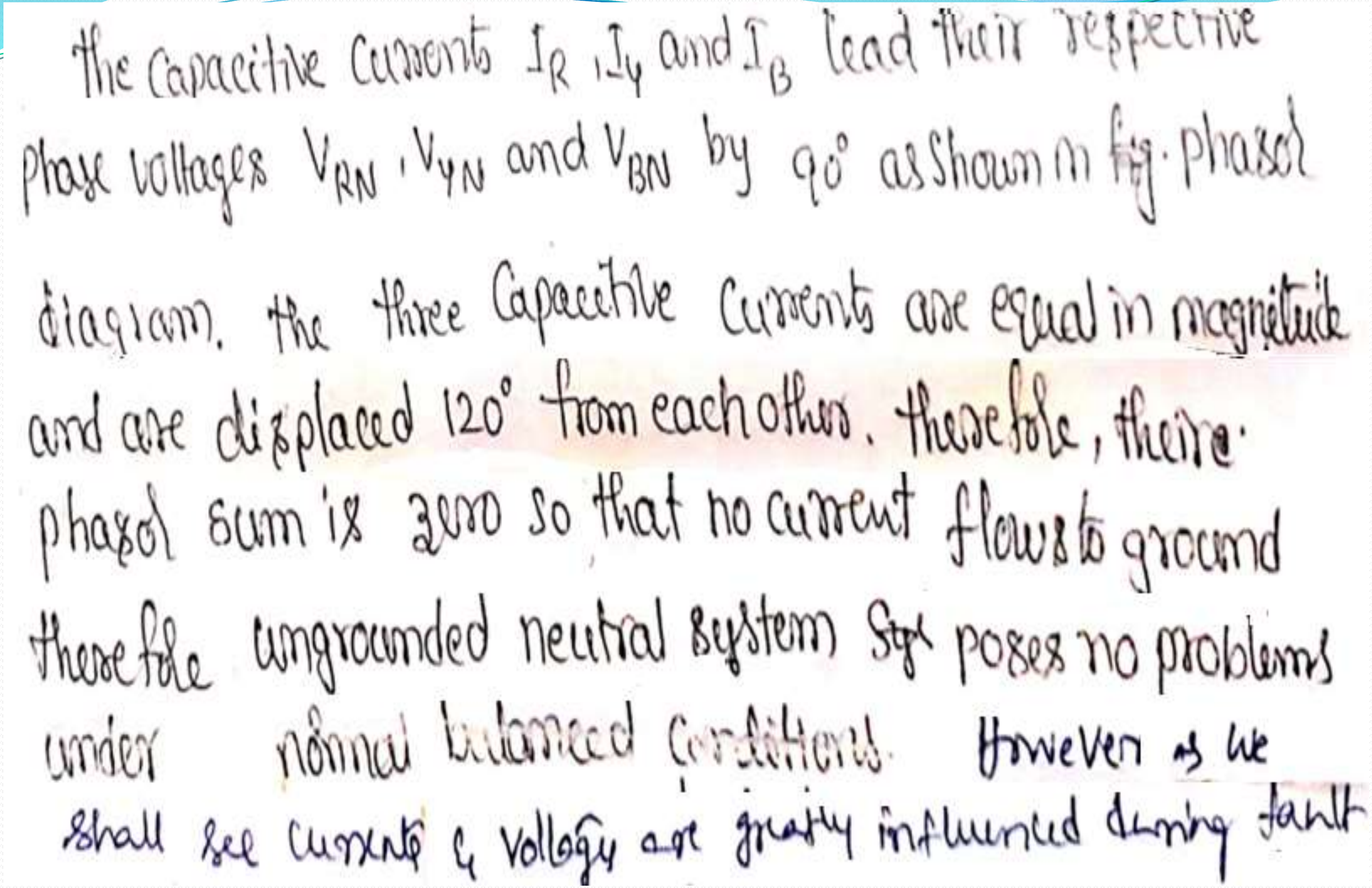
Circuit behaviour under normal conditions :-

Under balanced normal balanced steady state conditions the line assumed to be perfectly transposed so that each conductor has the same capacitance to ground. therefore $C_R = C_Y = C_B = C$ (say). Since the phase voltages V_{RN}, V_{YN} and V_{BN} have the same magnitude and displaced 120° from one another, the capacitive currents I_R, I_Y and I_B will have the same value i.e

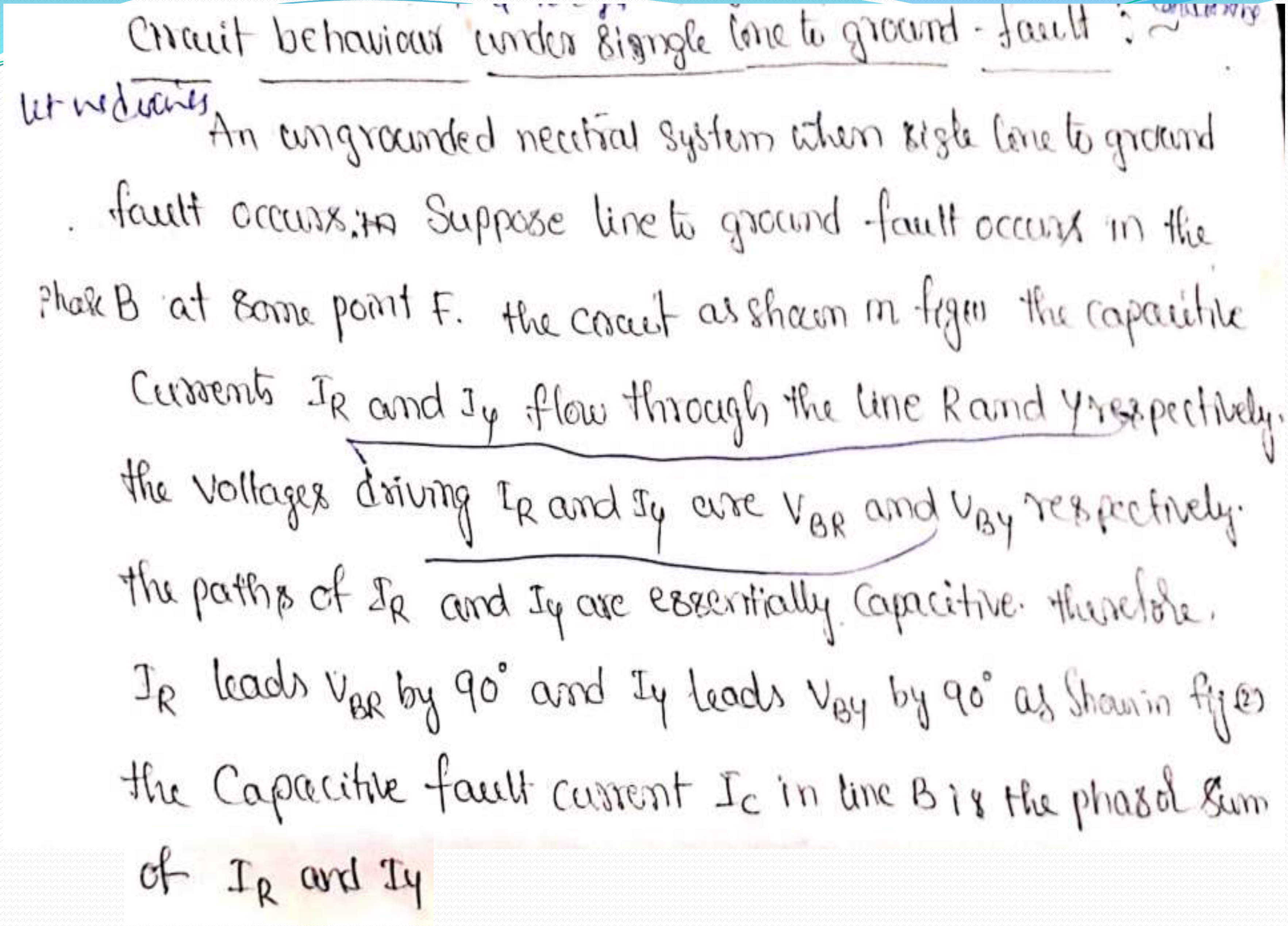
$$I_R = I_Y = I_B = \frac{V_{ph}}{X_C}$$

where X_C = Capacitive reactance of the line to ground


④
R
Y
B
N
I_R
I_{BY}
I_{BB}
C_R
C_Y
C_B
V_{BN}
E_R
V_{RN}
E_Y
E_B
V_{YN}
V_{YN}
I_B
90°
90°
I_Y
V_{RN}
V_{BN}
I_R



the Capacitive Currents I_R, I_Y and I_B lead their respective phase voltages V_{RN}, V_{YN} and V_{BN} by 90° as shown in fig. phasor diagram. the three Capacitive Currents are equal in magnitude and are displaced 120° from each other. therefore, their phasor sum is zero so that no current flows to ground therefore ungrounded neutral system Sys poses no problems under normal balanced conditions. However as we shall see currents & voltages are greatly influenced during fault



Circuit behaviour under single line to ground fault :~

lt reduces An ungrounded neutral system when single line to ground fault occurs: Suppose line to ground fault occurs in the phase B at some point F. the circuit as shown in figure the capacitive currents I_R and I_Y flow through the line R and Y respectively. the voltages driving I_R and I_Y are V_{BR} and V_{BY} respectively. the paths of I_R and I_Y are essentially capacitive. therefore, I_R leads V_{BR} by 90° and I_Y leads V_{BY} by 90° as shown in fig (2) the capacitive fault current I_C in line B is the phasor sum of I_R and I_Y

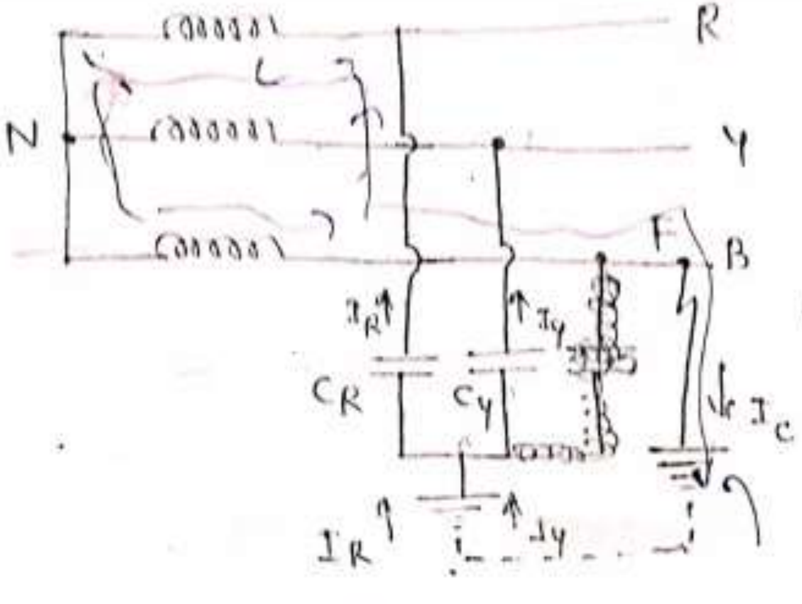
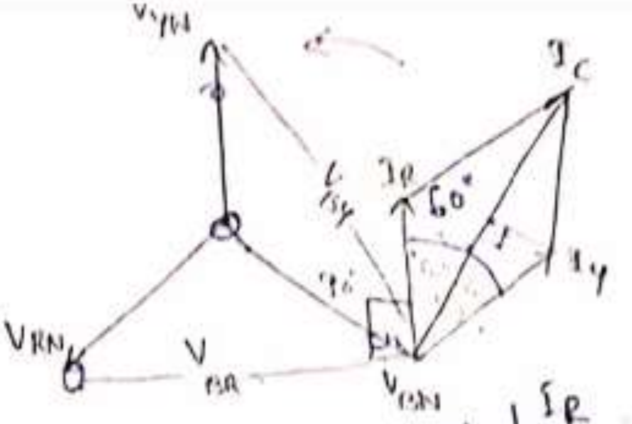


Fig ①



$V_{BR} \perp I_R$

$V_{BY} \perp I_Y$

fig ②

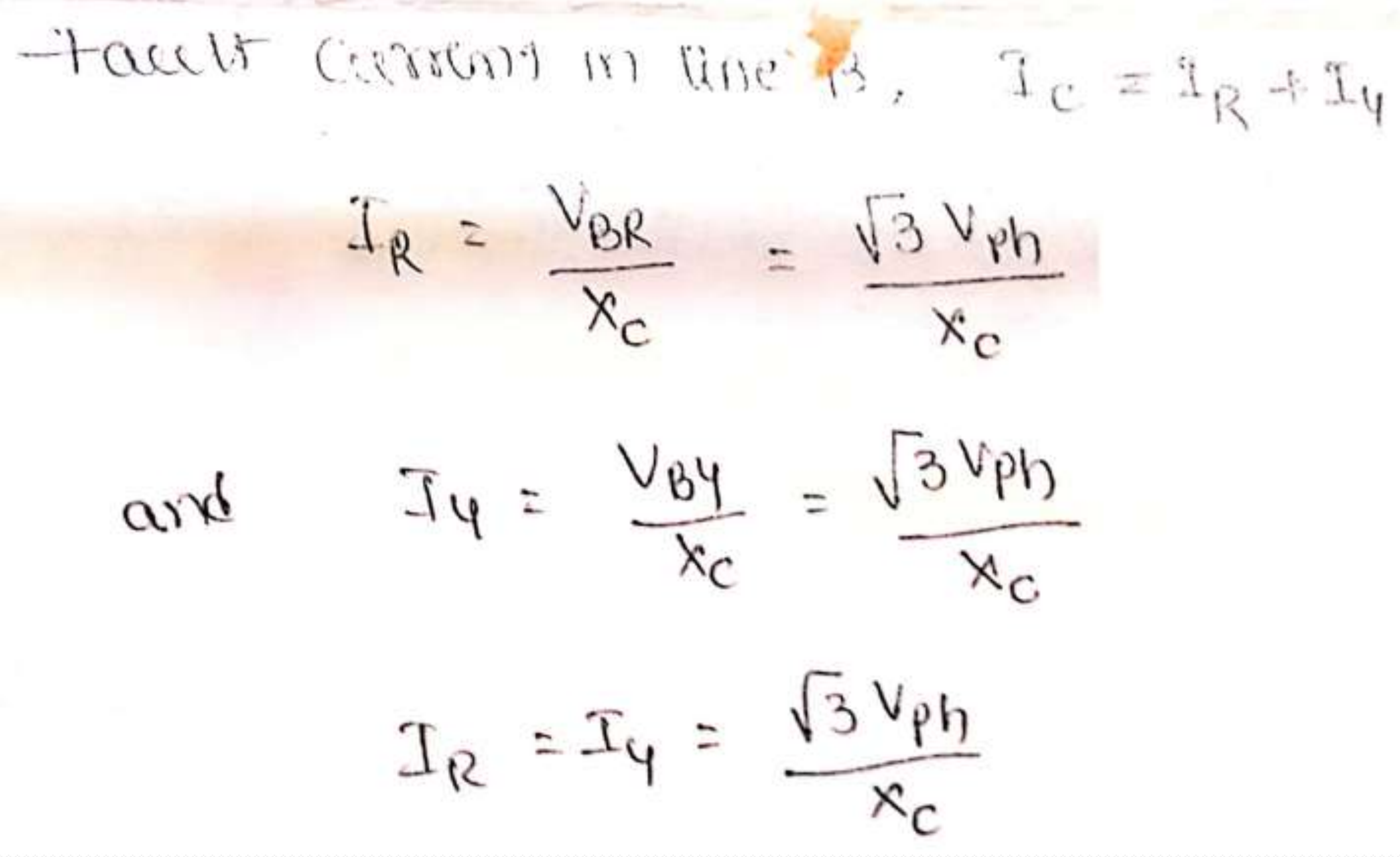
Ref fig 2 $I_R = I_Y = I_P$

angle b/w I_R & I_Y is 60°.

therefore resultant I_C

$$I_C = 2 I_P \cos(60/2)$$

$$= 2 I_P \cos 30 = \sqrt{3} I_P$$



Fault current in line B, $I_C = I_R + I_Y$

$$I_R = \frac{V_{BR}}{X_C} = \frac{\sqrt{3}\,V_{ph}}{X_C}$$

and $$I_Y = \frac{V_{BY}}{X_C} = \frac{\sqrt{3}\,V_{ph}}{X_C}$$

$$I_R = I_Y = \frac{\sqrt{3}\,V_{ph}}{X_C}$$

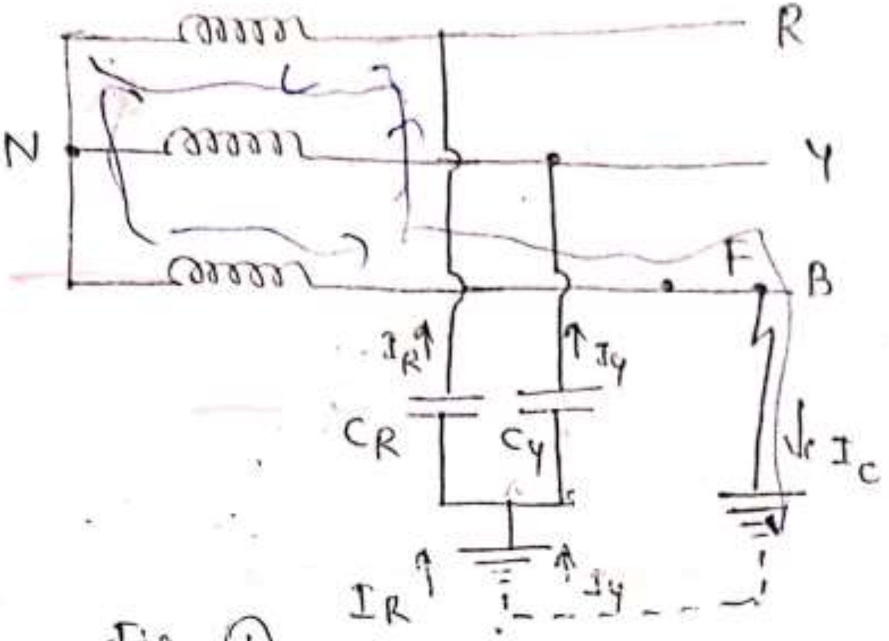


Fig ①

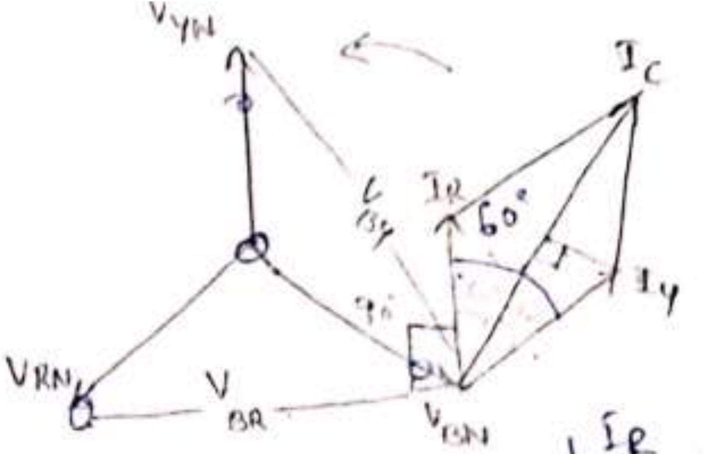


fig ②

$V_{BR} \perp I_R$

$V_{BY} \perp I_Y$

In fig2 $I_y = I_R$

angle b/w I_R & I_y is 60°.

therefore resultant is I_c

$I_c = 2 I_R \cos(60/2)$

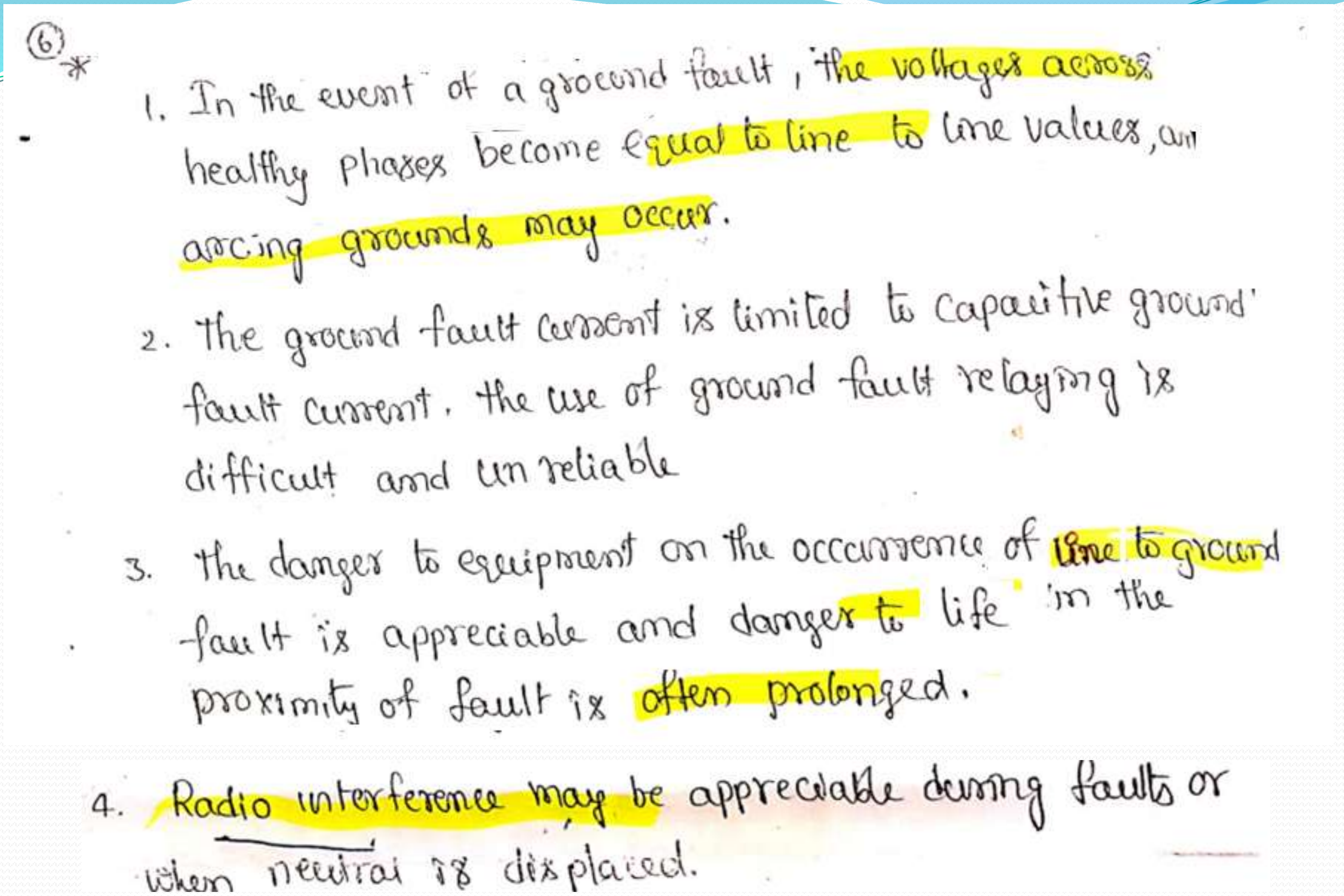
$=2 I_R \cos 30 \quad \sqrt{3} I_R$

Capacitive fault current in line B is

I_c = Phasor sum of I_R and I_y

$$= \sqrt{3} I_R = \sqrt{3} \times \frac{\sqrt{3} V_{ph}}{X_c} = \frac{3 V_{ph}}{X_c}$$

= 3 x per phase capacitive current



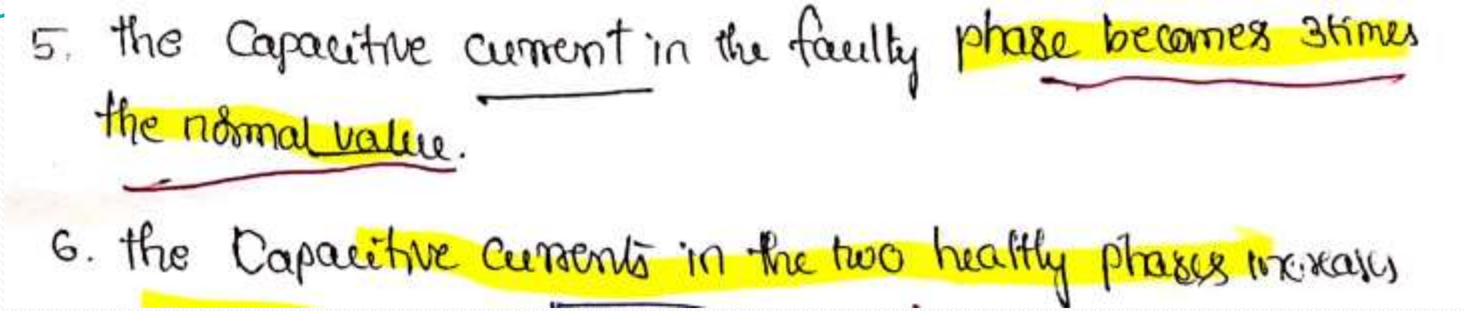
(6) *

1. In the event of a ground fault, the voltages across healthy phases become equal to line to line values, an arcing grounds may occur.

2. The ground fault current is limited to capacitive ground fault current. the use of ground fault relaying is difficult and un reliable

3. the danger to equipment on the occurrence of line to ground fault is appreciable and danger to life in the proximity of fault is often prolonged.

4. Radio interference may be appreciable during faults or when neutral is displaced.



5. the Capacitive current in the faulty phase becomes 3times the normal value.

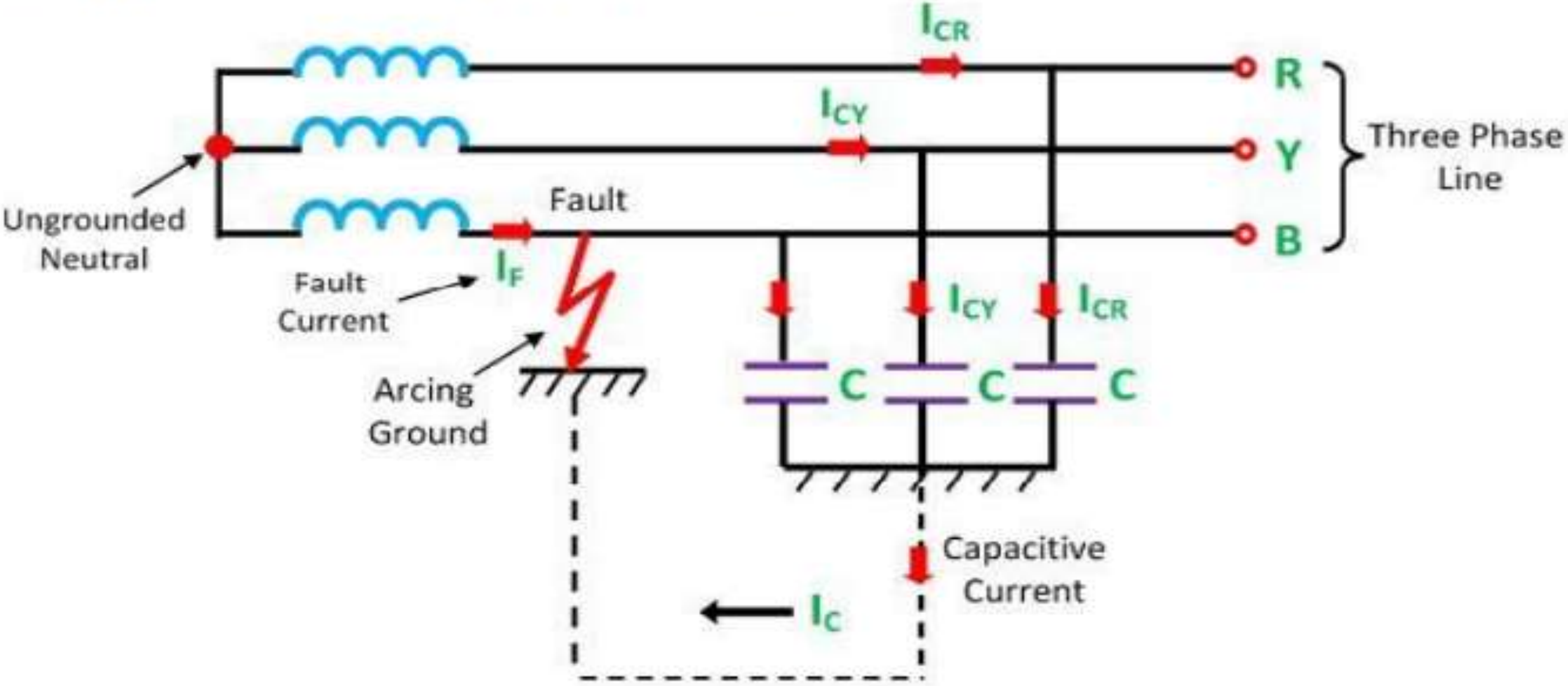
6. the Capacitive currents in the two healthy phases increases

Arcing Ground

Definition: Arcing ground is the surge, which is produced if the neutral is not connected to the earth. The phenomenon of arcing ground occurs in the ungrounded three-phase systems because of the flow of the capacitance current.The capacitive current is the current flow between the conductors when the voltage is applied to it. The voltage across the capacitances is known as the phase voltage. During the fault, the voltage across the capacitance reduces to zero in the faulted phase, while in the other phases the voltage is increased by the factor of $\sqrt{3}$ times.

Arcing Ground Phenomena

In a three phase line, each phase has a capacitance on earth. When the fault occurs on any of the phases, then the capacitive fault current flows into the ground. If the fault current exceeds 4 – 5 amperes, then it is sufficient to maintain the arc in the ionised path of the fault, even though the fault has cleared itself.



The capacitive current over 4 to 5 ampere flows through the fault give rise to an arc in the ionised path of the fault. With the formation of the arc, the voltage across it becomes zero, and therefore the arc is extinguished. The potential of the fault current restored due to which the formation of a second arc takes places. The phenomenon of intermitting arcing is called the arcing grounding.

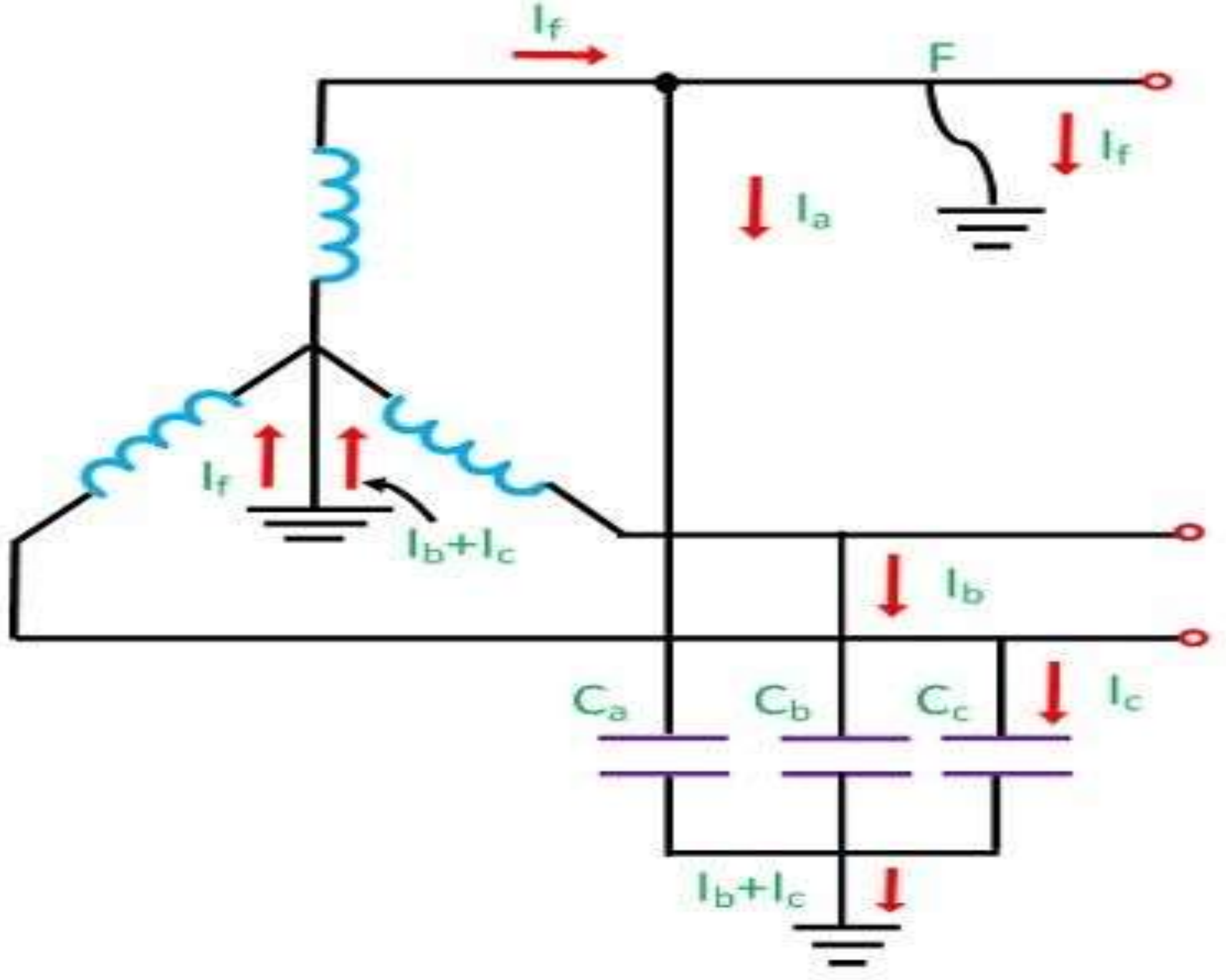
The alternating extinction and reignition of the charging current flowing in the arc build up the potential of the other two healthy conductors due to the setting of the high-frequency oscillations. The high-frequency oscillations are superimposed on the network and produce the surge voltage as high as six times the normal value. The overvoltage damages the healthy conductor at some other points of the system.

METHODS OF NEUTRAL GROUNDING

- The methods commonly used for grounding the system neutral are
- 1.Solid grounding (or effective grounding)
- 2.Resistance Grounding
- 3.Reactance Grounding
- 4.Peterson-coil grounding (or resonant groundings)
- The selection of the type of grounding depends on the size of the unit, system voltage and protection scheme to be used.

1.**Solid grounding**

- A power system is said to be effectively grounded or solidly grounded when the neutral of a generator, power transformer or grounding transformer are directly connected to the ground through a conductor of negligible resistance and reactance.
- A part of a system is said to be solidly grounded when the positive-sequence impedance of the system is greater or equal to the zero sequence resistance, and positive sequence reactance is three times greater than or equal to the zero sequence reactance.



Solidly ground system

Circuit Globe

- For the solidly neutral grounded system, it is necessary that the ground fault current should not exceed 80% of the three-phase fault. It is usually used for keeping the fault current within safe limits.

The main features of effectively grounded neutral system are

1.Ground fault currents is high, its maximum value may sometimes exceed even 3phase short circuit current.

2.In the event of SLG fault, the maximum voltage of healthy phases doesn’t exceed 80% of line to line voltage.

3.Arcing grounds can not occurs because the short circuit current eliminates the influence of capacitive current.

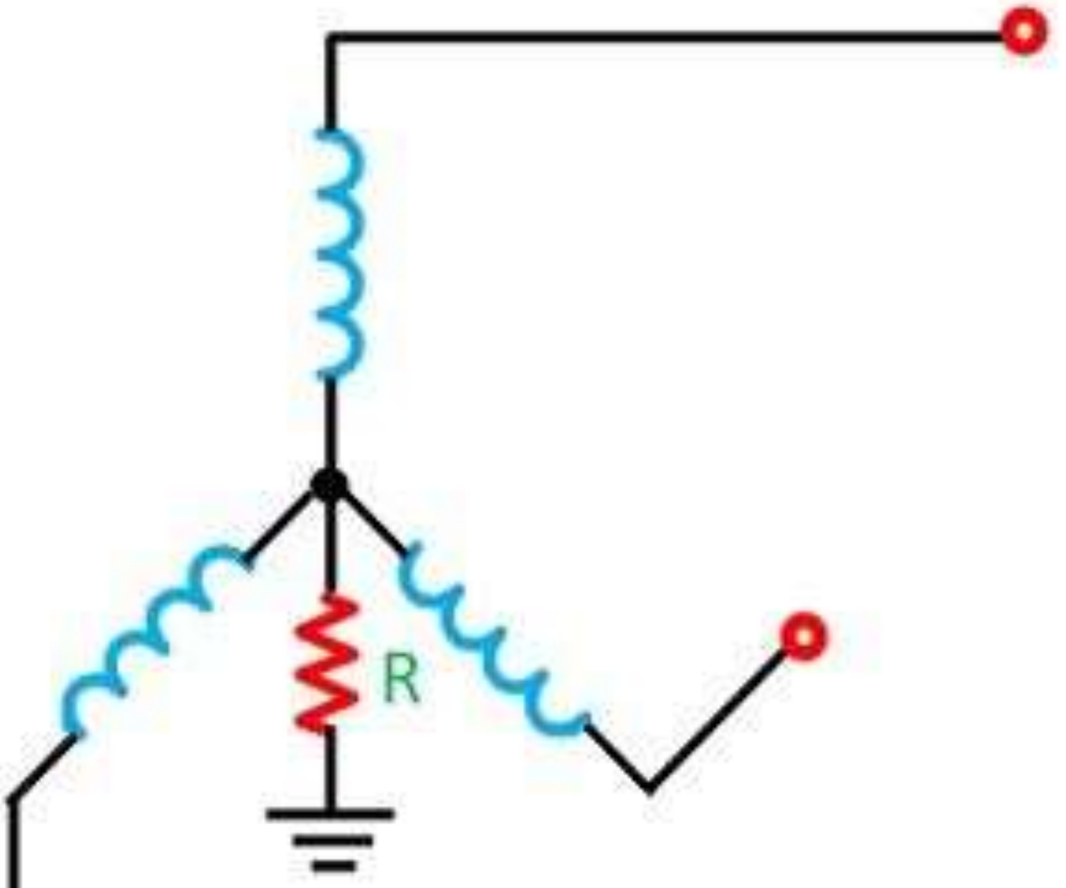
4.Since the ground fault current is high, danger to personnel

5.Ground fault relaying is simple and satisfactory.

6.Because of high fault currents, the interference due to electromagnetic induction with neighboring communication circuits may high.

2. Resistance grounding

- In this type of neutral grounding, the neutral of the system is connected to ground through one or more resistance.
- Resistance grounding limits the fault currents. It protects the system from transient over voltages. Resistance grounding decreases the arcing grounding risk and permits ground-fault protection.
- The value of resistance used in the neutral grounding system should neither be very high nor be very low shown in the figure below.



Resistance Grounding

Circuit Globe

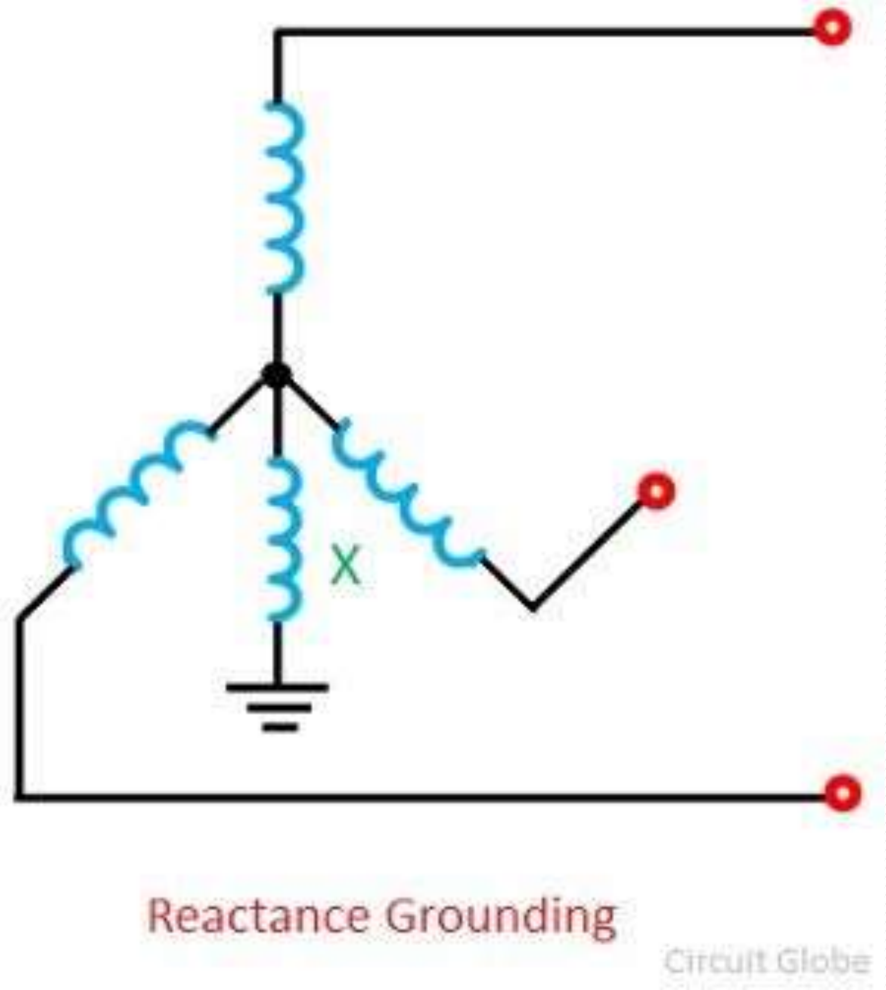
- A very low resistance makes the system to the solidity grounded, whereas a very high resistance makes the system ungrounded.
- The value of resistance is chosen such that the ground-fault current is limited, but still sufficient ground current flows permit the operation of ground faults protections.

The main features of resistance grounded neutral system are

1. The ground fault current is low but higher than the capacitive ground fault current.
2. Ground fault relaying is simple and satisfactory.
3. The power dissipation in the grounding resistance may improve system stability because this power dissipation reduces the accelerating power.

3.Reactance Grounding

- As per IEEE definition reactance grounding means grounding through impedance, the principle element of which is reactance.
- This grounding is used when the zero sequence reactance of system is so low as to cause excessive ground fault current.
- In reactance grounded system, a reactance is inserted between the neutral and ground to limit the fault current as shown in the figure below.
- Let X1,X2,X0 be the +ve,-ve and zero sequence reactance of a system and V be the voltage per phase.


X
Reactance Grounding
Circuit Globe

- If X_0 is negligible as compared to X_1
- $X_1=X_2$
- Ground fault current = $3V/(X_1+X_2+X_0)$ [X_0 is negligible, $X_1=X_2$]

$= 3V/2X_1$

$=1.5$ times 3phase s.c current

If $X_0=X_1$, $X_1=X_2$

Ground fault current = $3V/(X_1+X_2+X_0) = 3V/3X_1 = V/X_1$

If $X_1=X_2=X_0$ and a reactance X_e is connected b/n neutral and earth

Ground fault current $=3V/(X_1+X_2+X_3+3X_e) = V/X_1+X_e$

If X_e is increased , the ground fault current decreases.If X_e is very small , the system behaves as an effectively grounded system.

X_e is very high , the system behaves as an isolated grounded system.

The main features of reactance grounded neutral system are

1.The ground fault current is reduced but is much higher than capacitive ground fault current.

2.Voltages across healthy phases are b/n 0.8 to 1 per unit of line voltage.

3.Arcing grounds are avoided

4. Transient ground fault are converted to controlled current faults.

5.Ground fault relaying is simple and satisfactory.

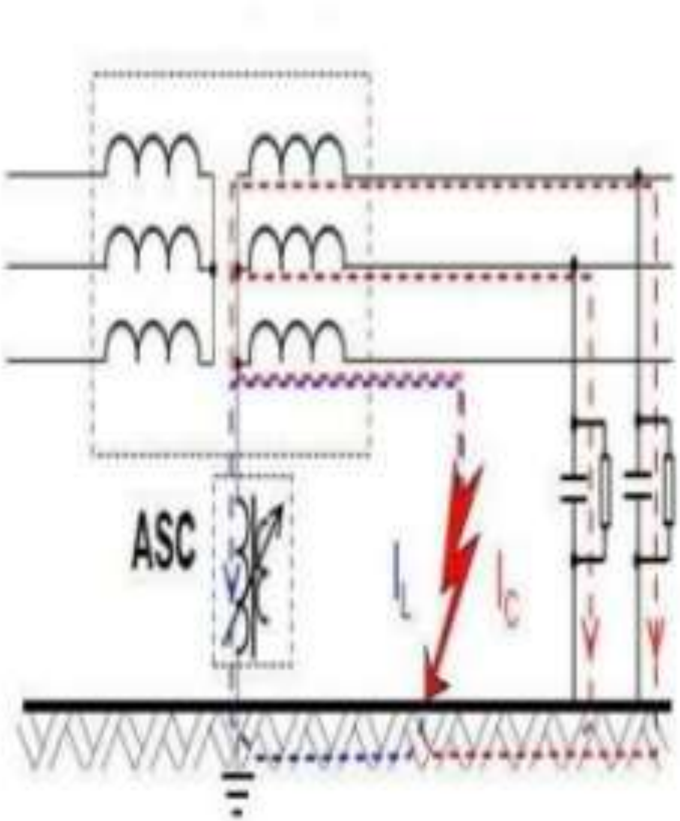
Petersen coils

- Peterson coils are used to in ungrounded 3-phase grounding systems to limit the arcing currents during ground faults.
- The coil was first developed by W. Petersen in 1916.
- However the use of modern power electronics has revolutionized the performance of these classical solutions.

Basic Principle

- When a phase-to-earth fault occurs in ungrounded 3 phase systems, the phase voltage of the faulty phase is reduced to the earth potential as the capacitance of the faulty line is discharged at the fault location, the phase-to-earth voltage of the other two phases rises by √3 times.
- A charging current “I**C**” occurs between these phase-to-earth capacitances, which will continue to flow via the fault path while it remains.
- I**C** is three times the charging current of each phase-to-earth.

Compensated system where –Il=IC.



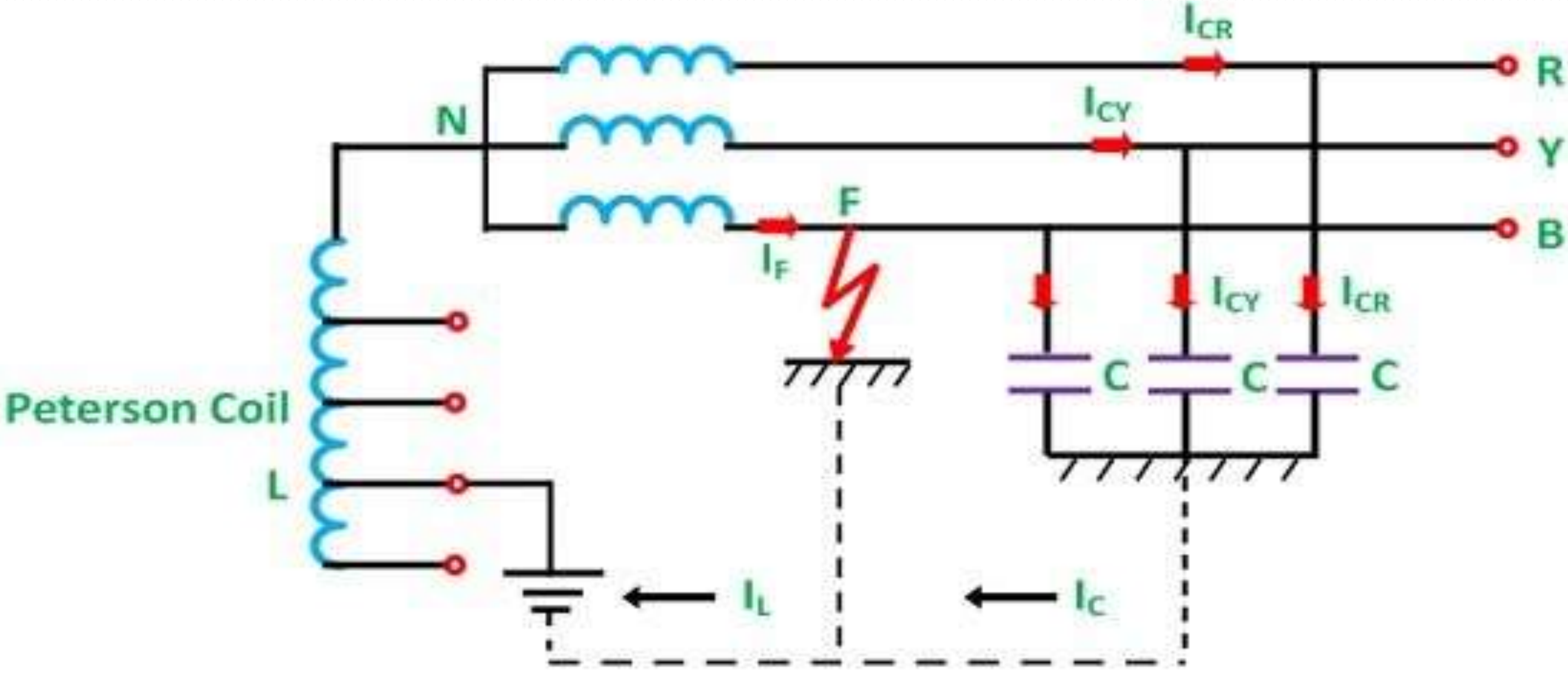
- The Petersen coil may also be referred to as an Arc Suppression Coil (ASC).

Arc suppression coil or Resonant or Peterson coil Grounding

- It was invented by W.Peterson 1916 and is therefore also known as peterson coil grounding.
- Generally the capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth.
- If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current I_f flowing through L (lagging) will be in phase opposition to the capacitive current I_c of the system. If L is so adjusted that $I_L = I_C$ Then the resultant current in the fault will be zero. This condition is known as " Resonant grounding"

Circuit construction

- An arc suppression coil(Peterson coil) is an non-cored coil connected between the neutral and earth as shown in following Figure.
- The reactor is provided with tappings to change the reactance of the coil.
- By adjusting the tappings on the coil , the coil can be tuned with the capacitance of the system i.e resonant grounding can be achieved.



Line-Ground fault on phase B

Circuit Globe

The resultant of I_{CR} and I_{CY} is I_C.

$$I_c = I_{CR} + I_{CY}$$

$$I_{CR} = \frac{V_{CR}}{X_{CR}} = \frac{\sqrt{3}V_P}{X_C}$$

$$I_{CY} = \frac{V_{CY}}{X_{CY}} = \frac{\sqrt{3}V_P}{X_C}$$

$$I_{CR} = I_{CY}$$

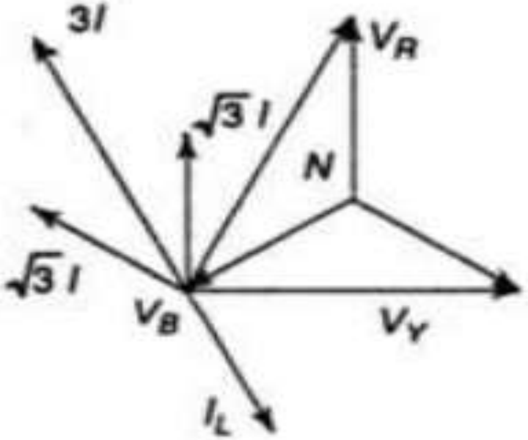
From the phasor diagram

$$I_C = \sqrt{3}I_{CR} = \sqrt{3}I_{CY}$$

$$I_C = \frac{\sqrt{3} \times \sqrt{3}V_P}{X_C} = \frac{3V_P}{X_C}$$

- For balanced conditions
- If I_C is equal to I_L there will be no current through the ground, and there will be no tendency of the arcing grounds to occur. With the help of Peterson coil neutral grounding, arc resistance is reduced to such a small value that it is usually self-extinguishing. Therefore, Peterson coil is also known as a ground fault neutralizer or arc suppression coil.
- Peterson coil is rated for a short time of about 5 minutes, or it is designed to carry its rated current continuously. It reduces the transient fault which occur due to lightning and also minimized the single line-to-ground voltage drops.

Vector Diagram



$$I_L = Vp/\omega L$$

- To obtain an effective cancellation of the capacitive charging currents, I_L to be equal to I_C.

Therefore,

$$Vp/\omega L = 3Vp\omega C$$

From which we get,

$$L = 1/\ (3\omega^2 C)$$

- The value of the inductance in the Petersen coil needs to match the value of the line capacitance which may vary as and when modifications in the transmission lines are carried out.
- Hence, the Petersen coil comes with a provision to vary the inductance.

- The value of the inductance in the Petersen coil needs to match the value of the line capacitance which may vary as and when modifications in the transmission lines are carried out.
- Hence, the Petersen coil comes with a provision to vary the inductance.

ADVANTAGES

- The peterson coil is completely effective in preventing any damage by arcing grounding
- It has the advantage of ungrounded neutral system.

Disadvantages:

The Peterson coil grounding has following disadvantages:

- a. Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.
- b. The lines should be transposed.

Application

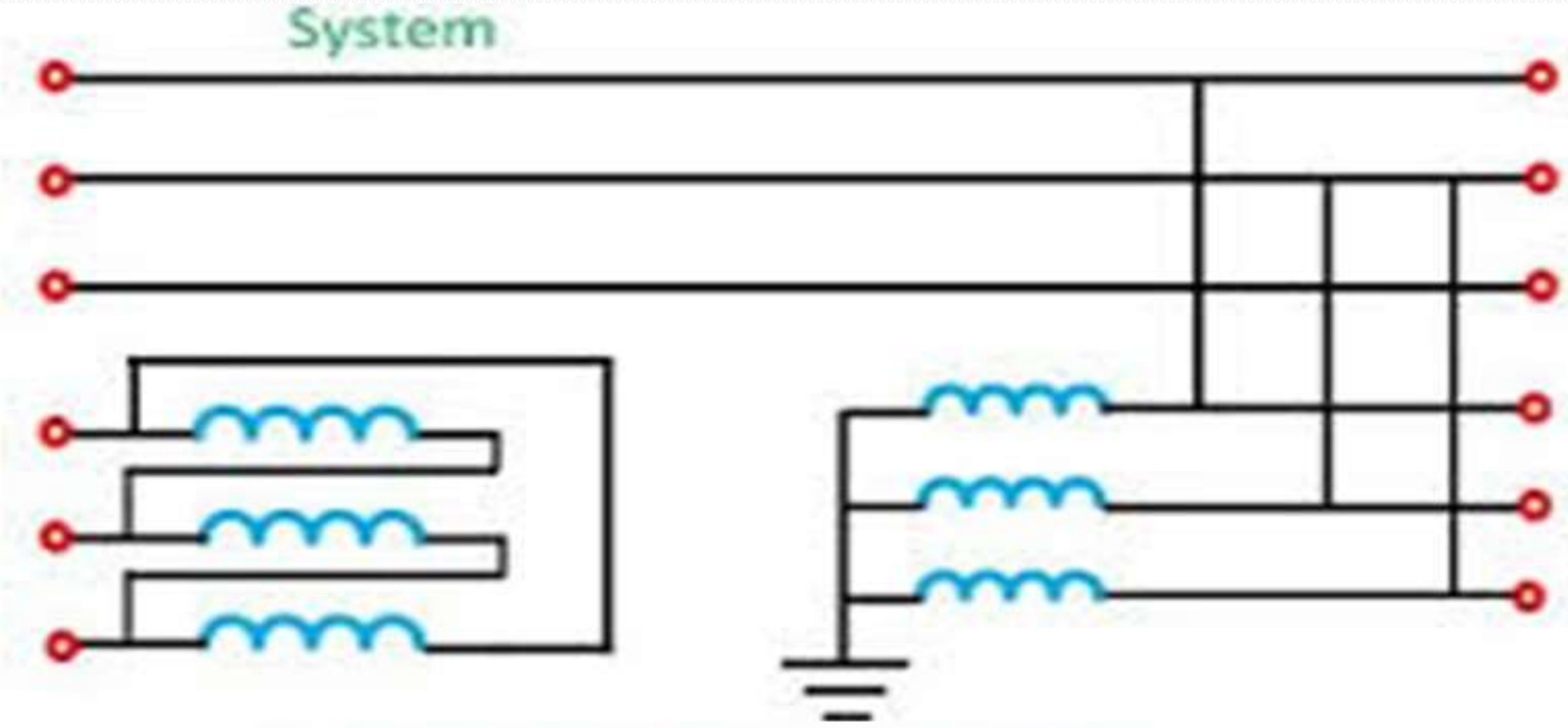
- When a phase to earth fault occurs in ungrounded 3 phase systems, the phase voltage of the faulty phase is reduced to the ground potential.
- This causes the phase voltage in the other two phases to rise by √3 times.
- This increase in voltage causes a charging current, Ic between the phase-to-earth capacitances..

Grounding Transformer

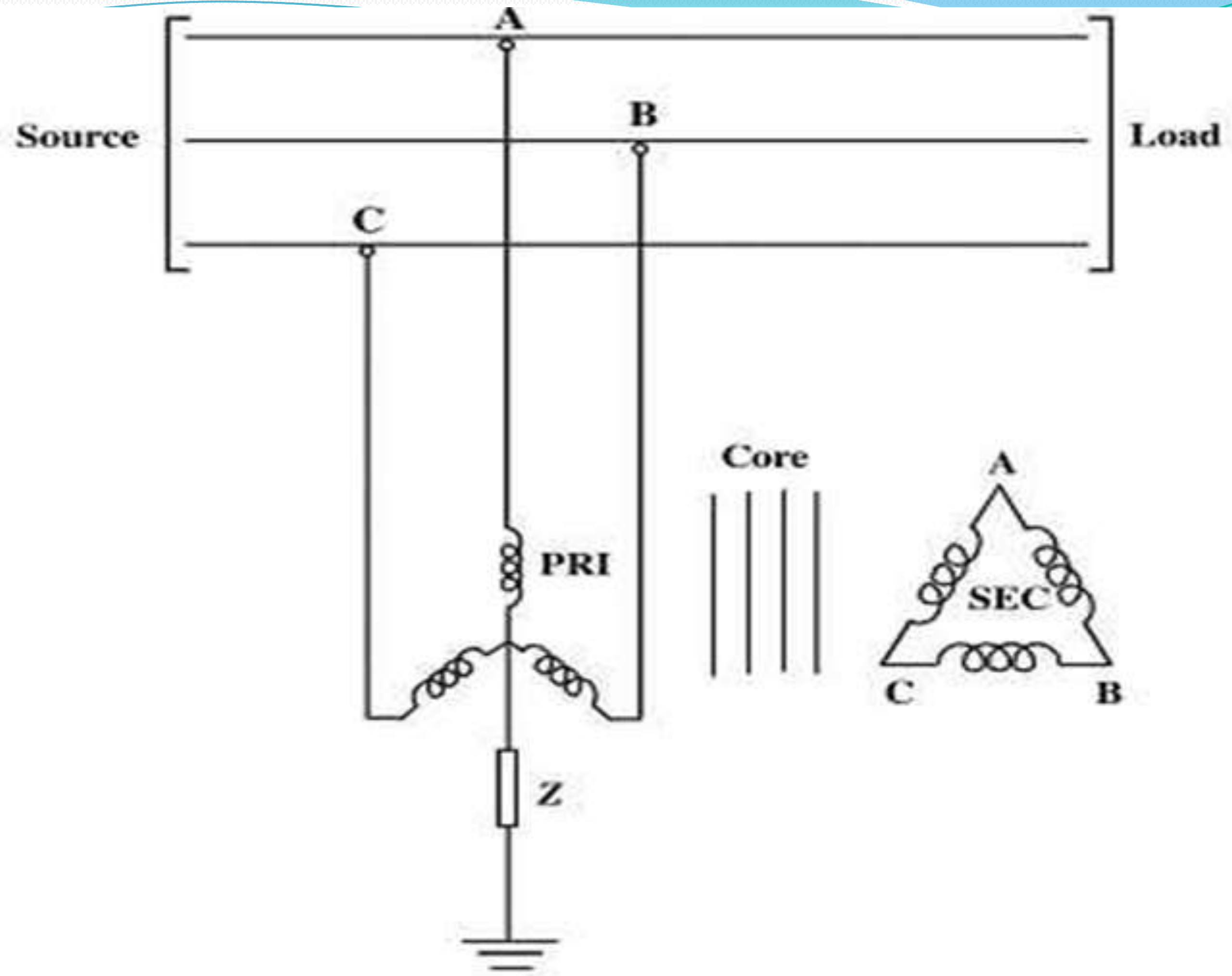
- Sometimes the neutral of the power transformer is not available for grounding(e.g a delta-delta transformer)
- In such situation a special small size star-delta is solely used for grounding. This transformer is known as grounding transformer and it is a step down transformer.
- The star connected primaries are connected to the system and its neutral is grounded.

- The secondary's are generally are delta and do not supply any load but provide a closed path for triple harmonic currents to circulate.
- Under normal balanced condition the current in a grounding transformer is only its own exciting current.
- However a large current may flow in it in the event of single line to ground fault.

- However it should be of sufficient rating to withstand the effect of line-to-ground faults.
- Transformer with zig-zag conditions are also used as grounding transformers.

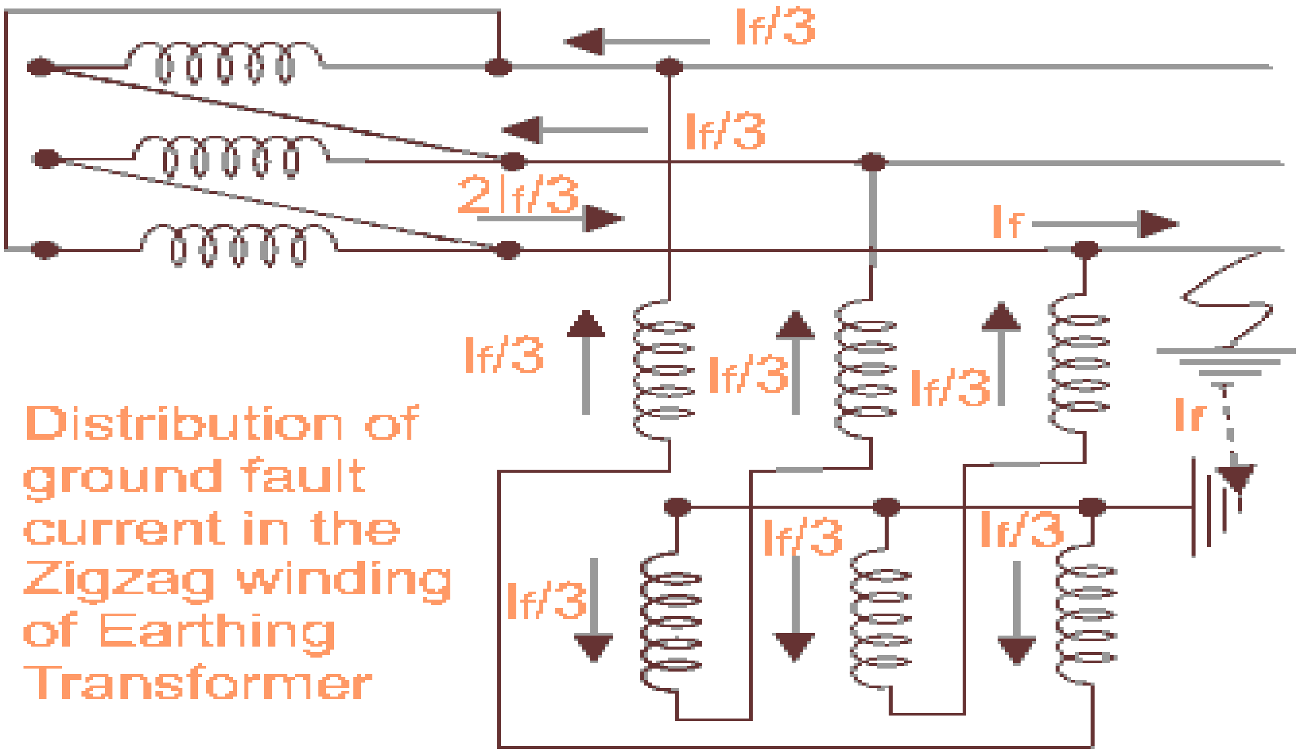


Delta-star transformer grounding



Note:

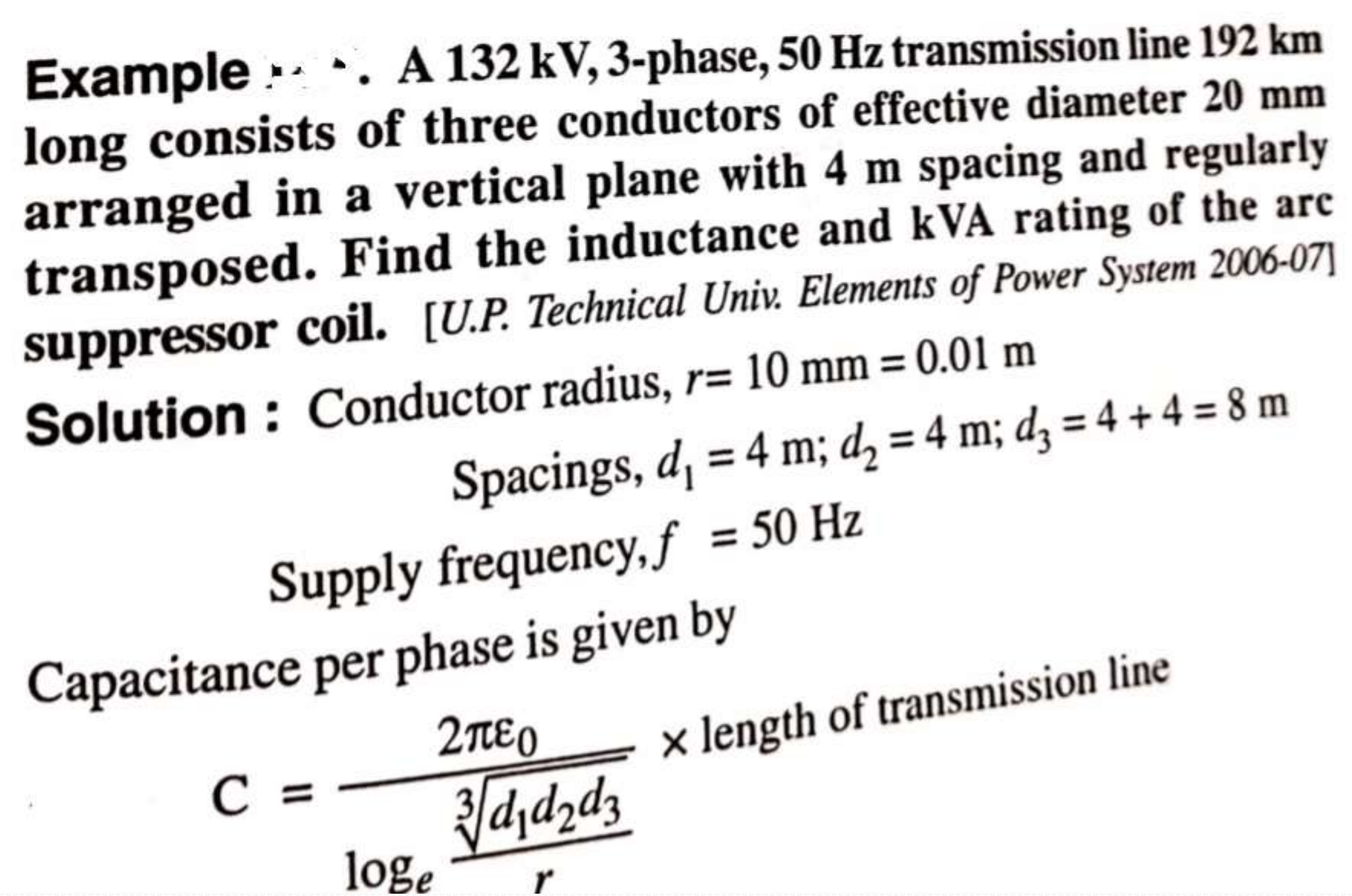
In a normal system the star–delta earthing transformer behaves like a transformer with open circuited secondary drawing a small magnetizing current from the system.



Distribution of ground fault current in the Zigzag winding of Earthing Transformer

This is a core type transformer with three limbs. Every phase winding in zigzag connection is divided into two equal halves.

One half of which is wound on one limb and other half is wound on another limb of the core of transformer.



Example [illegible]. **A 132 kV, 3-phase, 50 Hz transmission line 192 km long consists of three conductors of effective diameter 20 mm arranged in a vertical plane with 4 m spacing and regularly transposed. Find the inductance and kVA rating of the arc suppressor coil.** [*U.P. Technical Univ. Elements of Power System 2006-07*]

Solution : Conductor radius, $r = 10 \text{ mm} = 0.01 \text{ m}$

Spacings, $d_1 = 4 \text{ m}; d_2 = 4 \text{ m}; d_3 = 4 + 4 = 8 \text{ m}$

Supply frequency, $f = 50 \text{ Hz}$

Capacitance per phase is given by

$$C = \frac{2\pi\varepsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \times \text{length of transmission line}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12}}{\log_e \dfrac{\sqrt[3]{4 \times 4 \times 8}}{0.01}} \times 192 \times 10^3 = 1.717\ \mu\text{F}$$

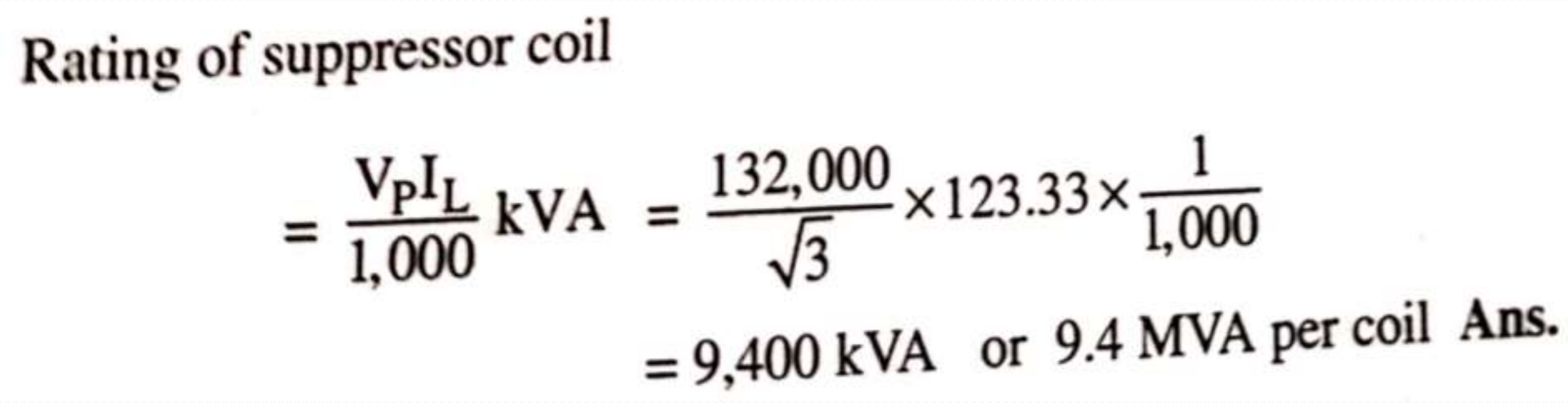
Necessary inductance of Peterson coil

$$L = \frac{1}{3\omega^2 C}$$

$$= \frac{1}{3 \times (2\pi \times 50)^2 \times 1.717 \times 10^{-6}} = 1.967\ \text{H} \quad \textbf{Ans.}$$

For ground fault, the current in the neutral is given by

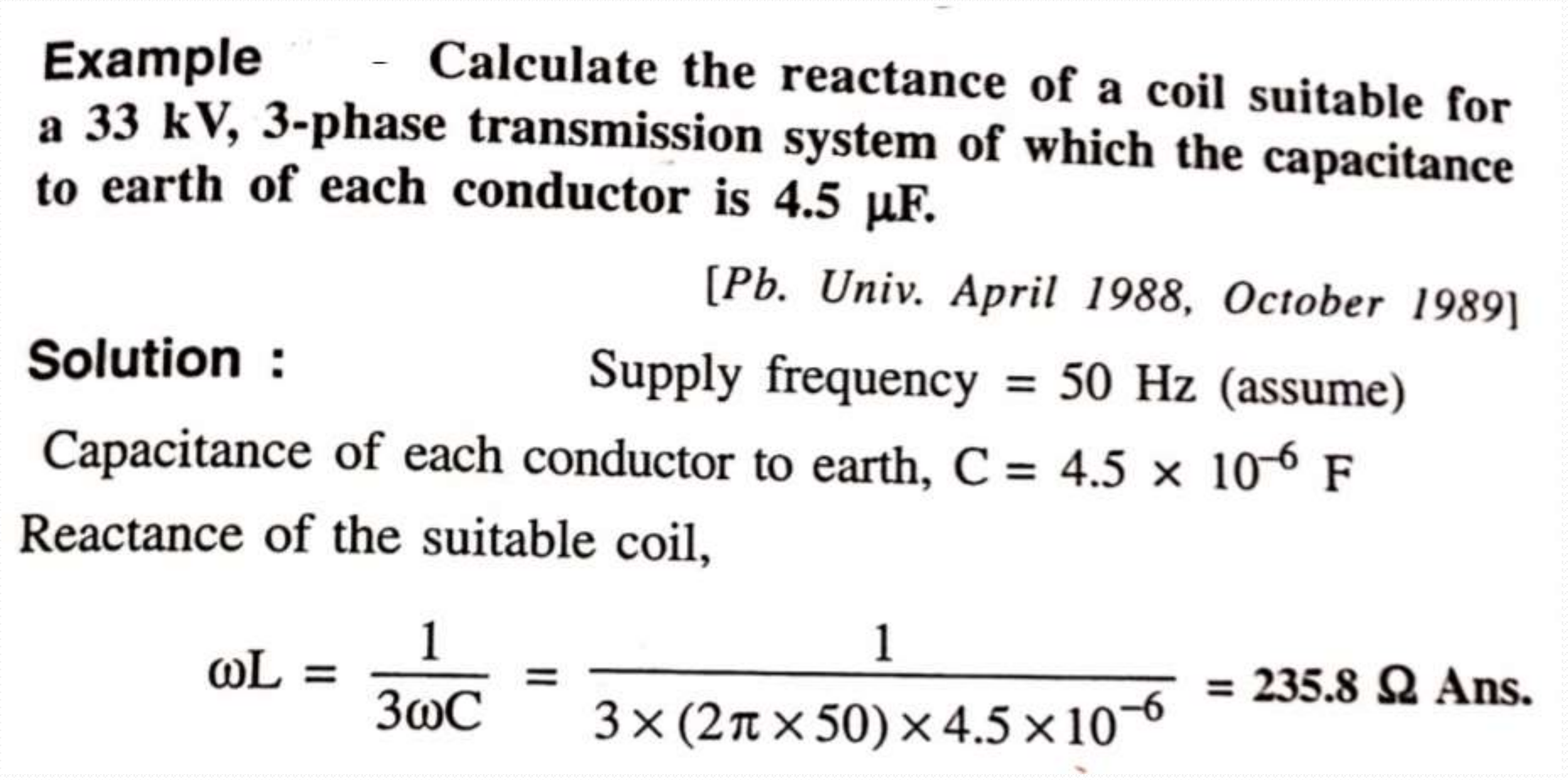
$$I_L = \frac{V_P}{\omega L} = \frac{132{,}000/\sqrt{3}}{2\pi \times 50 \times 1.967} = 123.33\ \text{A}$$



Rating of suppressor coil

$$= \frac{V_P I_L}{1{,}000}\ \text{kVA} = \frac{132{,}000}{\sqrt{3}} \times 123.33 \times \frac{1}{1{,}000}$$

$$= 9{,}400\ \text{kVA} \quad \text{or} \quad 9.4\ \text{MVA per coil}$$ **Ans.**



Example - **Calculate the reactance of a coil suitable for a 33 kV, 3-phase transmission system of which the capacitance to earth of each conductor is 4.5 μF.**

[Pb. Univ. April 1988, October 1989]

Solution : Supply frequency = 50 Hz (assume)

Capacitance of each conductor to earth, $C = 4.5 \times 10^{-6}$ F

Reactance of the suitable coil,

$$\omega L = \frac{1}{3\omega C} = \frac{1}{3 \times (2\pi \times 50) \times 4.5 \times 10^{-6}} = 235.8\ \Omega \text{ Ans.}$$

Eg. A 230kV, 3Φ, 50Hz, 200km long tr line has a capc to earth of 0.02 μF/km/ph. cal. the inductance & kVA rating of peterson coil used for earthing the above systems

Sol) $f = 50\,Hz$

$C = 200 \times 0.02 = 4 \times 10^{-6}\,F$

Required inductance of peterson coil is

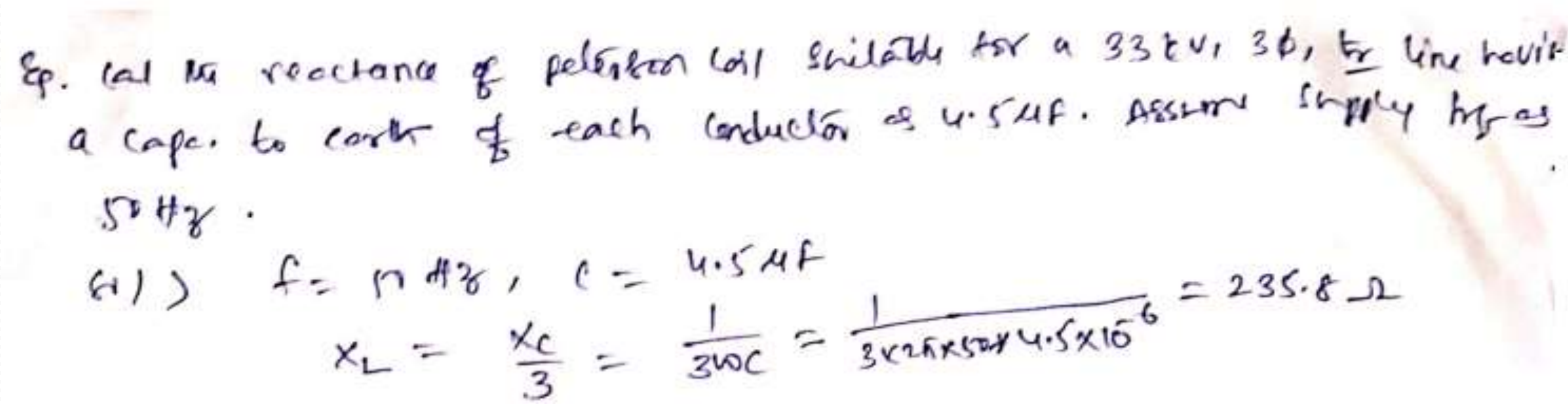
$$L = \frac{1}{3\omega^2 C} = 0.85\,H$$

current thr peterson coil $= I_F = \frac{V_{ph}}{X_L} = \frac{230 \times 10^3 / \sqrt{3}}{2\pi \times 50 \times 0.85} = 500\,A$

Voltage across peterson coil $V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{230 \times 1000}{\sqrt{3}}\,V$

Rating of peterson coil $= V_{ph} * I_F = \frac{230 \times 10^3}{\sqrt{3}} * 500 * \frac{1}{1000}\,kVA$

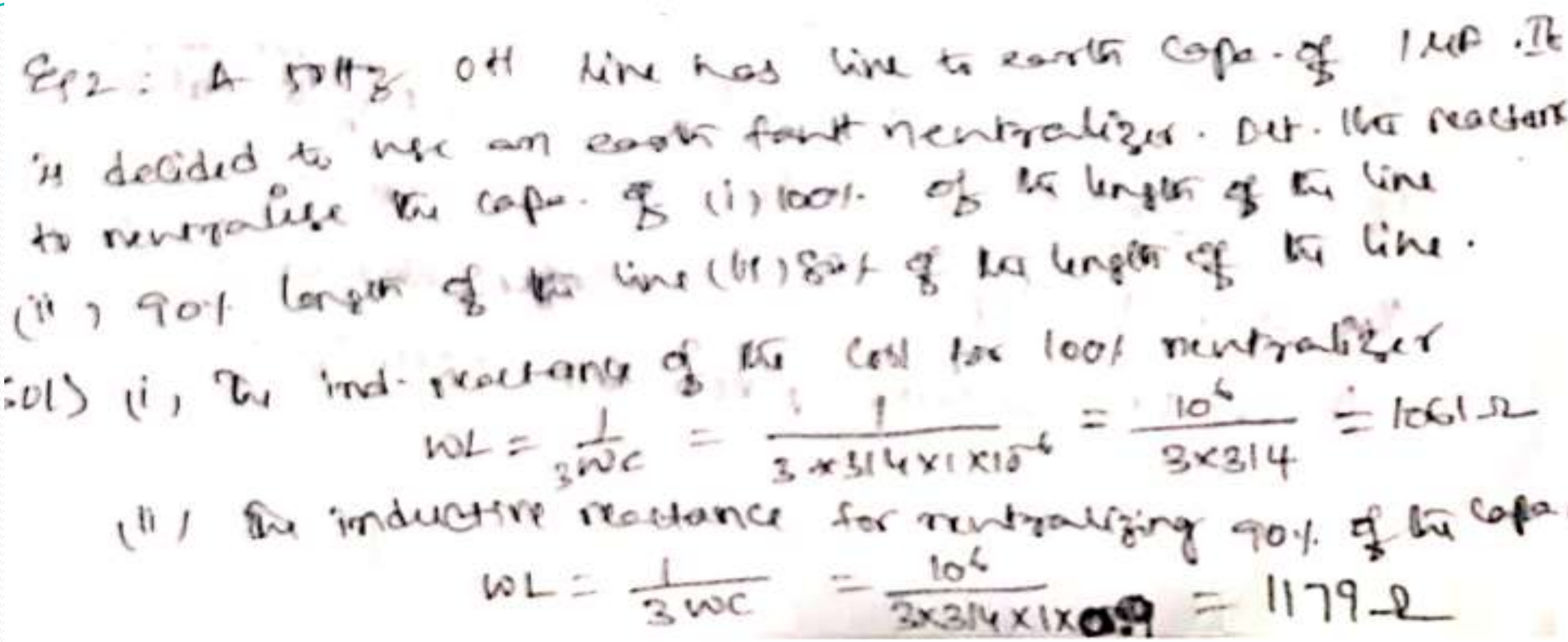
$= 66.397\,MVA$



Ep. cal the reactance of peterson coil suitable for a 33kV, 3ϕ, tr line having a capa. to earth of each conductor as 4.5μF. Assume supply freq as 50Hz.

Sol) $f = 50\,Hz$, $C = 4.5\,\mu F$

$$X_L = \frac{X_C}{3} = \frac{1}{3\omega C} = \frac{1}{3\times 2\pi\times 50\times 4.5\times 10^{-6}} = 235.8\,\Omega$$



Ex 2: A 50Hz, OH line has line to earth capa. of 1μF. It is decided to use an earth fault neutralizer. Det. the reactance to neutralise the capa. of (i) 100% of the length of the line (ii) 90% length of the line (iii) 80% of the length of the line.

Sol) (i) The ind. reactance of the coil for 100% neutralizer

$$\omega L = \frac{1}{3\omega C} = \frac{1}{3\times314\times1\times10^{-6}} = \frac{10^6}{3\times314} \doteq 1061\,\Omega$$

(ii) The inductive reactance for neutralizing 90% of the capa.

$$\omega L = \frac{1}{3\omega C} = \frac{10^6}{3\times314\times1\times0.9} = 1179\,\Omega$$