Nadar Saraswathi College of Engineering & Technology

Engineering Excellence for Empowerment

NSCET E-LEARNING PRESENTATION

LISTEN … LEARN… LEAD…

ELECTRICAL AND ELCTRONICS ENGINEERING

II nd YEAR / IVth SEMESTER

EE8402 – Transmission and Distribution

G.Sujitha M.E
Assistant Professor
Nadar Saraswathi College of Engineering & Technology,
Vadapudupatti, Annanji (po), Theni – 625531.

UNIT 05 – DISTRIBUTION SYSTEMS

Education is not the learning of facts, but the training of the mind to think.

-Albert Einstein

UNIT-5

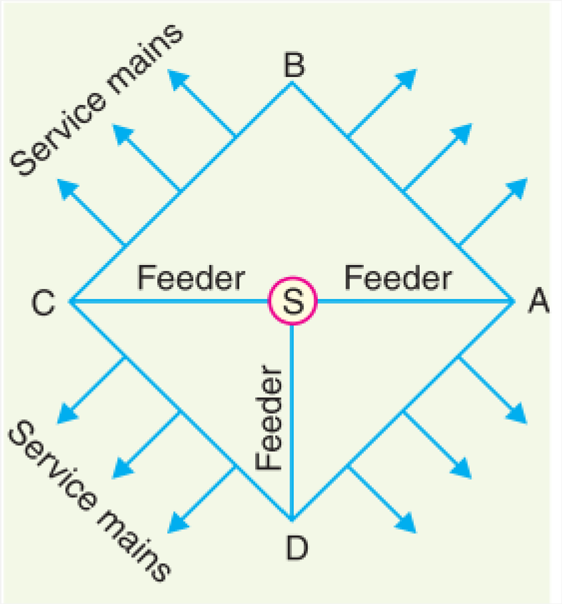
- Distribution Systems
- General aspects
- Kelvin's Law
- AC and DC distributions
- Techniques of Voltage Control and Power factor improvement
- Distribution Loss
- Types of Substations
- Methods of grounding
- Trends in Transmission and Distribution
  - HVAC, HVDC and FACTS

Distribution Systems

That part of power system which distributes electric power for local use is known as **distribution system**.

Distribution system consists of

- Feeders
- Distributors
- Service mains



Feeders

A feeder is a conductor which connects the sub-station to the area where power is to be distributed.

Distributor

A distributor is a conductor from which tappings are taken for supply to the consumers.

Service mains

A service mains is generally a small cable which connects the distributor to the consumers’ terminals.

Classification of Distribution Systems

Depends on Nature of current

- d.c. distribution system
- a.c. distribution system

Depends on types of construction

- Overhead systems
- Underground systems

Depends on Scheme of connection

- Radial system
- Ring main system
- Inter-connected system.

DC Distribution

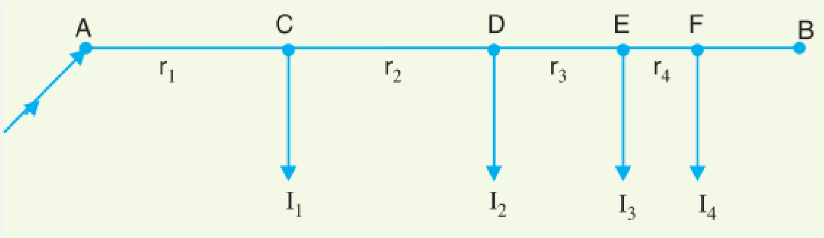
- DC supply is required for the operation of variable speed machinery, electrochemical work and electric traction.

- AC power is converted into DC power at the sub-station is conveyed to the required places for distribution.

<u>Types of Distributors</u>

- Distributor fed at one end
- Distributor fed at both ends
- Distributor fed at the centre
- Ring distributor

<u>Distributor fed at one end</u>



Current fed from point $A = I1 + I2 + I3 + I4$

Current in section $AC = I1 + I2 + I3 + I4$

Current in section $CD = I2 + I3 + I4$

Current in section $DE = I3 + I4$

Current in section $EF = I4$

Voltage drop in section $AC = r1\ (I1 + I2 + I3 + I4)$

Voltage drop in section $CD = r2\ (I2 + I3 + I4)$

Voltage drop in section $DE = r3\ (I3 + I4)$

Voltage drop in section $EF = r4\ I4$

∴ Total voltage drop in the distributor

$= r1\ (I1 + I2 + I3 + I4) + r2\ (I2 + I3 + I4) + r3\ (I3 + I4) + r4\ I4$

Problem

A 2-wire d.c. distributor cable AB is 2 km long and supplies loads of 100A,150A,200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01Ω per 1000 m. Calculate the p.d. at each load point if a p.d. of 300 V is maintained at point A.

Solution

Resistance per 1000 m of distributor = 2 × 0·01 = 0·02Ω

Resistance of section AC, R_{AC} = 0·02 × 500/1000 = 0·01 Ω

Resistance of section CD, R_{CD} = 0·02 × 500/1000 = 0·01 Ω

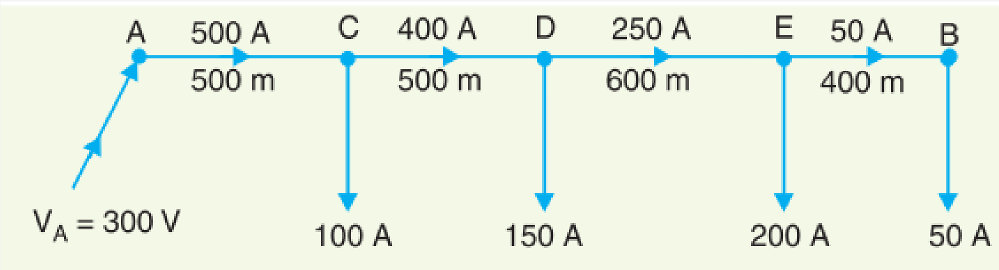
Resistance of section DE, R_{DE} = 0·02 × 600/1000 = 0·012 Ω

Resistance of section EB, R_{EB} = 0·02 × 400/1000 = 0·008 Ω

Current in various section,

I_{EB} = 50 A ; I_{DE} = 50 + 200 = 250 A

I_{CD} = 250 + 150 = 400 A ; I_{AC} = 400 + 100 = 500 A



P.D. at load point C, VC = Voltage at A − Voltage drop in AC

= VA −IAC RAC

= 300 − 500 × 0·01 = **295 V**

P.D. at load point D, VD = V C − ICD RCD

= 295 − 400 × 0·01 = **291 V**

P.D. at load point E, VE = V D − IDE RDE

= 291 − 250 × 0·012 = **288 V**

P.D. at load point B, VB = V E − IEB REB

= 288 − 50 × 0·008 = **287·6 V**

Distributor fed at both ends

(i)Two ends fed with equal voltages

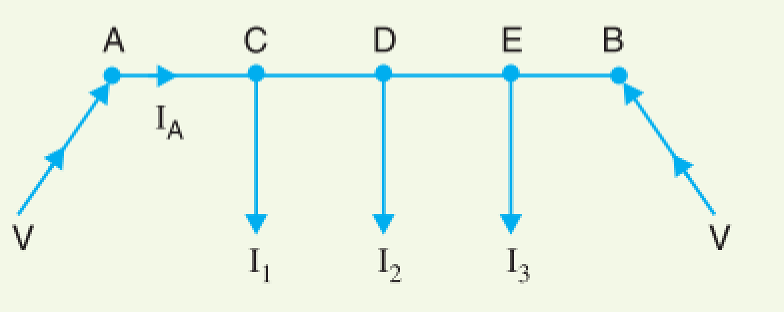
Current distribution in various
Section of distributor,

$I_{AC} = I_A$

$I_{CD} = I_A - I_1$

$I_{DE} = I_A - I_1 - I_2$

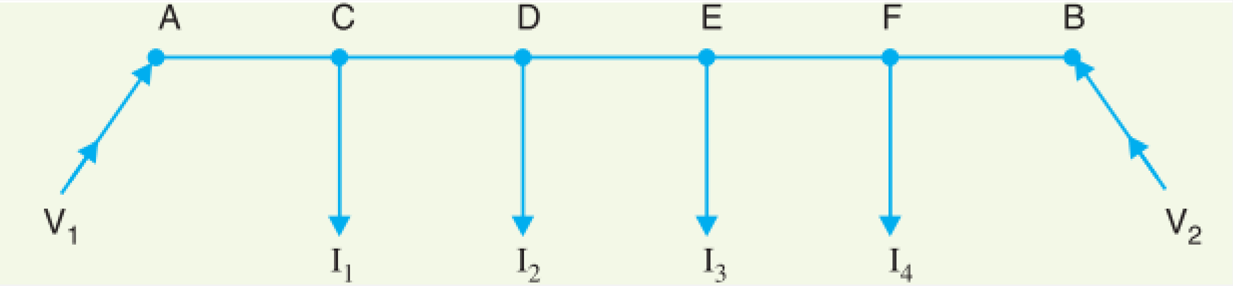
$I_{EB} = I_A - I_1 - I_2 - I_3$



Voltage drop between A and B = Voltage drop over AB

$= I_A R_{AC} + (I_A - I_1) R_{CD} + (I_A - I_1 - I_2) R_{DE} + (I_A - I_1 - I_2 - I_3) R_{EB}$

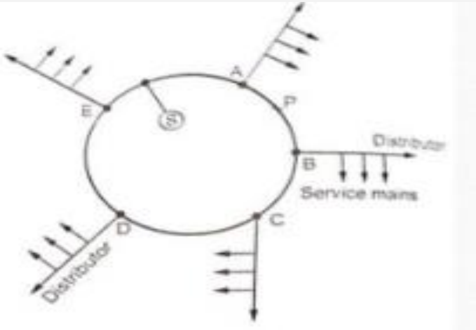
(ii)Two ends fed with unequal voltages



The distributor *A B* fed with unequal voltages
end *A* being fed at V 1 volts and end *B* at V 2 volts.

Voltage drop between *A* and *B* = Voltage drop over *A B*
$V1 - V2$ = Voltage drop over *A B*

<u>Ring Distributor</u>



- A distributor arranged to form a closed loop and fed at one or more points is called a ring distributor.
- Such a distributor starts from one point, makes a loop through the area to be served, and returns to the original point.
- The principal advantage of ring distributor is that by proper choice in the number of feeding points, great economy in copper can be affected.

Problem: **A 2-wire d.c. ring distributor is 300 m long and is fed at 240 V at point A. At point B, 150 m from A, a load of 120 A is taken and at C, 100 m in the opposite direction, a load of 80 A is taken. If the resistance per 100 m of single conductor is 0·03 Ω, find :(i) current in each section of distributor**

(ii) voltage at points B and C

Solution

Resistance per 100 m of distributor= 2 × 0·03 = 0·06Ω

Resistance of section *AB*, *RAB* = 0·06 × 150/100 = 0·09 Ω

Resistance of section *BC*, *RBC* = 0·06 × 50/100 = 0·03 Ω

Resistance of section *CA*, *RCA* = 0·06 × 100/100 = 0·06 Ω

currents sections *BC* and *CA* will be (*IA*−120) and (*IA*−200) respectively.

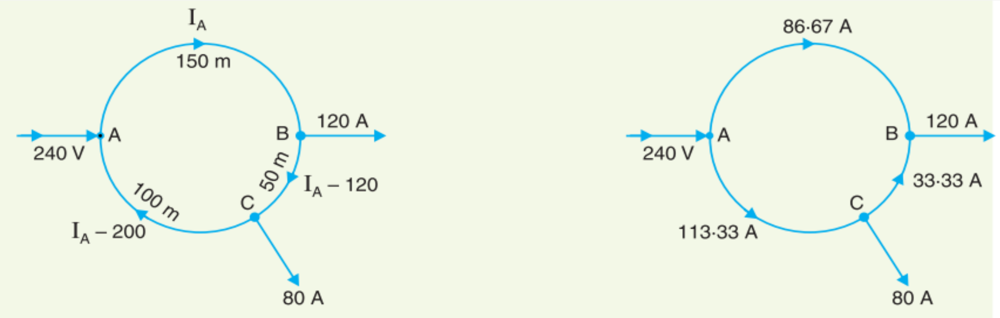
IAB RAB + *IBC RBC* + *ICA RCA* = 0

0·09 *IA* + 0·03 (*IA* − 120) + 0·06 (*IA* − 200) = 0

$0{\cdot}18\ I_A = 15{\cdot}6$

$\therefore I_A = 15{\cdot}6/0{\cdot}18$

$= 86{\cdot}67$ A



Current sections,

$I_{AB} = I_A = 86{\cdot}67$ A

$I_{BC} = I_A - 120 = 86{\cdot}67 - 120 = -\ 33{\cdot}33$ A

$I_{CA} = I_A - 200 = 86{\cdot}67 - 200 = -113{\cdot}33$ A

Voltage at point *B*,

$V_B = V_A - I_{AB}\ R_{AB} = 240 - 86{\cdot}67 \times 0{\cdot}09 = 232{\cdot}2$ V

Voltage at point *C*,

$V_C = V_B + I_{BC}\ R_{BC} = 232{\cdot}2 + 33{\cdot}33 \times 0{\cdot}03 = 233{\cdot}2$ V

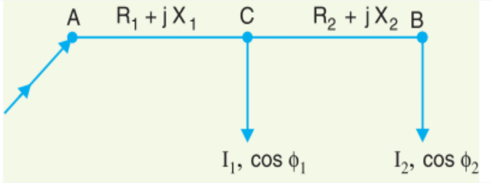
AC Distribution

- In a.c. system,the voltage drops are due to the combined effects of resistance, inductance and capacitance.
- Additions and subtractions of currents or voltages are done vectorically
- Power factor (p.f.) has to be taken into account. Loads tapped off form the distributor are generally at different power factors.

<u>Methods of solving AC distribution problems</u>

- ➢ Power factors referred to receiving end voltage
- ➢ Power factors referred to respective load voltages

Power factors referred to receiving end voltage



Impedance of section AC, $\overrightarrow{Z_{AC}} = R_1 + j X_1$

Impedance of section CB, $\overrightarrow{Z_{CB}} = R_2 + j X_2$

Load current at point C, $\overrightarrow{I_1} = I_1 (\cos \phi_1 - j \sin \phi_1)$

Load current at point B, $\overrightarrow{I_2} = I_2 (\cos \phi_2 - j \sin \phi_2)$

Current in section CB, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = I_2 (\cos \phi_2 - j \sin \phi_2)$

Current in section AC, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$

$$= I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)$$

Voltage drop in section CB, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2 (\cos \phi_2 - j \sin \phi_2)(R_2 + j X_2)$

Voltage drop in section AC, $\overrightarrow{V_{AC}} = \overline{I_{AC}}\,\overline{Z_{AC}} = \left(\overline{I_1} + \overline{I_2}\right) Z_{AC}$

$$= [I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)]\,[R_1 + j X_1]$$

Sending end voltage, $\overrightarrow{V_A} = \overrightarrow{V_B} + \overrightarrow{V_{CB}} + \overrightarrow{V_{AC}}$

Sending end current, $\overrightarrow{I_A} = \overrightarrow{I_1} + \overrightarrow{I_2}$

Power factors referred to respective load voltages

$$\text{Voltage drop in section } CB = \vec{I_2}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + j\,X_2)$$

$$\text{Voltage at point } C = \vec{V_B} + \text{Drop in section } CB = V_C \angle \alpha \text{ (say)}$$

$$\vec{I_1} = I_1 \angle -\phi_1 \quad w.r.t. \text{ voltage } V_C$$

$$\vec{I_1} = I_1 \angle -(\phi_1 - \alpha) \qquad w.r.t. \text{ voltage } V_B$$

$$\vec{I_1} = I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)]$$

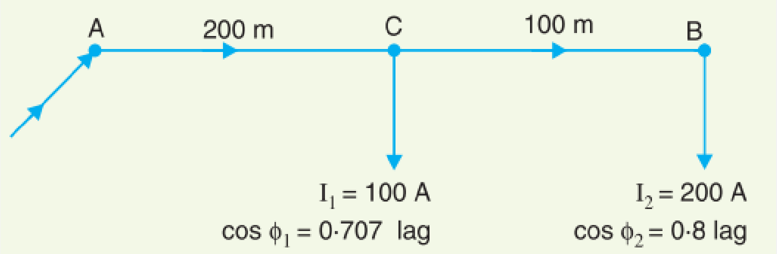
$$\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2}$$

$$= I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)] + I_2(\cos\phi_2 - j\sin\phi_2)$$

$$\text{Voltage drop in section } AC = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}}$$

$$\text{Voltage at point } A = V_B + \text{Drop in } CB + \text{Drop in } AC$$

<u>Problem:</u>A single phase a.c. distributor AB 300 metres long is fed from end A and is loaded as under :(i)100 A at 0·707p.f. lagging 200 m from point A (ii) 200 A at 0·8 p.f. lagging 300 m from point A The load resistance and reactance of the distributor is 0·2 Ω and 0·1 Ω per kilometre. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end.



<u>Solution</u>

Impedance/km=$(0·2+j0·1)\Omega$

Impedance of section AC, $\overrightarrow{Z_{AC}} = (0·2 + j\,0·1) \times 200/1000 = (0·04 + j\,0·02)\,\Omega$

Impedance of section CB, $\overrightarrow{Z_{CB}} = (0·2 + j\,0·1) \times 100/1000 = (0·02 + j\,0·01)\,\Omega$

Load current at point B, $\vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2) = 200\,(0{\cdot}8 - j\,0{\cdot}6)$

$= (160 - j\,120)$ A

Load current at point C, $\vec{I_1} = I_1(\cos\phi_1 - j\sin\phi_1) = 100\,(0{\cdot}707 - j\,0{\cdot}707)$

$= (70{\cdot}7 - j\,70{\cdot}7)$ A

Current in section CB, $\vec{I_{CB}} = \vec{I_2} = (160 - j\,120)$ A

Current in section AC, $\vec{I_{AC}} = \vec{I_1} + \vec{I_2} = (70{\cdot}7 - j\,70{\cdot}7) + (160 - j\,120)$

$= (230{\cdot}7 - j\,190{\cdot}7)$ A

Voltage drop in section CB, $\vec{V_{CB}} = \vec{I_{CB}}\,\vec{Z_{CB}} = (160 - j\,120)\,(0{\cdot}02 + j\,0{\cdot}01)$

$= (4{\cdot}4 - j\,0{\cdot}8)$ volts

Voltage drop in section AC, $\vec{V_{AC}} = \vec{I_{AC}}\,\vec{Z_{AC}} = (230{\cdot}7 - j\,190{\cdot}7)\,(0{\cdot}04 + j\,0{\cdot}02)$

$= (13{\cdot}04 - j\,3{\cdot}01)$ volts

Voltage drop in the distributor $= \vec{V_{AC}} + \vec{V_{CB}} = (13{\cdot}04 - j\,3{\cdot}01) + (4{\cdot}4 - j\,0{\cdot}8)$

$= (17{\cdot}44 - j\,3{\cdot}81)$ volts

Magnitude of drop $= \sqrt{(17\cdot44)^2 + (3\cdot81)^2}$ = **17·85 V**

Voltage Control

- When the load on the supply system changes, the voltage at the consumer's terminals also changes. The variations of voltage at the consumer's terminals are undesirable and must be kept within prescribed limits.

Methods of voltage control

- By excitation control
- By using tap changing transformers
- Auto-transformer tap changing
- Booster transformers
- Induction regulators
- By synchronous condenser

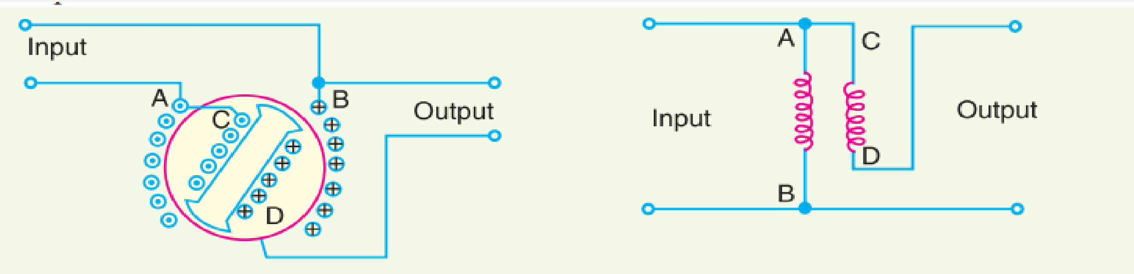
Excitation control

- When the load on the supply system changes, the terminal voltage of the alternator also varies due to the changed voltage drop in the synchronous reactance of the armature.
- The voltage of the alternator can be kept constant by changing the field current of the alternator in accordance with the load.
- This is known as **excitation control** method.

Types of automatic voltage regulator

- Tirril Regulator
- Brown-Boveri Regulator

Induction regulators



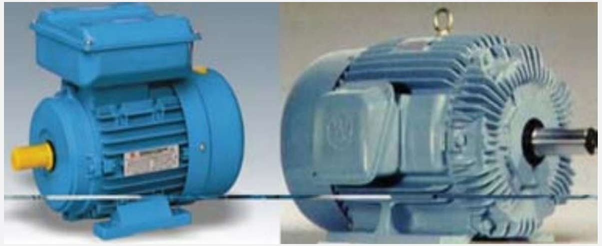
- An induction regulator is essentially a constant voltage transformer, one winding of which can be moved w.r.t. the other, thereby obtaining a variable secondary voltage.
- The primary winding is connected across the supply while the secondary winding is connected in series with the line whose voltage is to be controlled.

Types

- Single phase
- 3 phase

Synchronous condenser

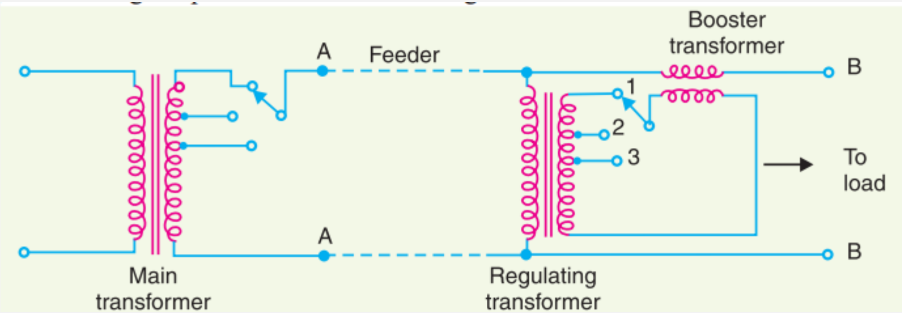
- The voltage at the receiving end of a transmission line can be controlled by installing specially designed synchronous motors called synchronous condensers at the receiving end of the line.



- The synchronous condenser supplies wattless leading kVA to the line depending upon the excitation of the motor.

- This wattless leading kVA partly or fully cancels the wattless lagging kVA of the line, thus controlling the voltage drop in the line.

Booster Transformer



- The secondary of the booster transformer is connected in series with the line whose voltage is to be controlled.
- The primary of this transformer is supplied from a regulating transformer fitted with on-load tap-changing gear.
- The booster transformer is connected in such a way that its secondary injects a voltage in phase with the line voltage.

Methods of grounding

Neutral Grounding

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

Advantages

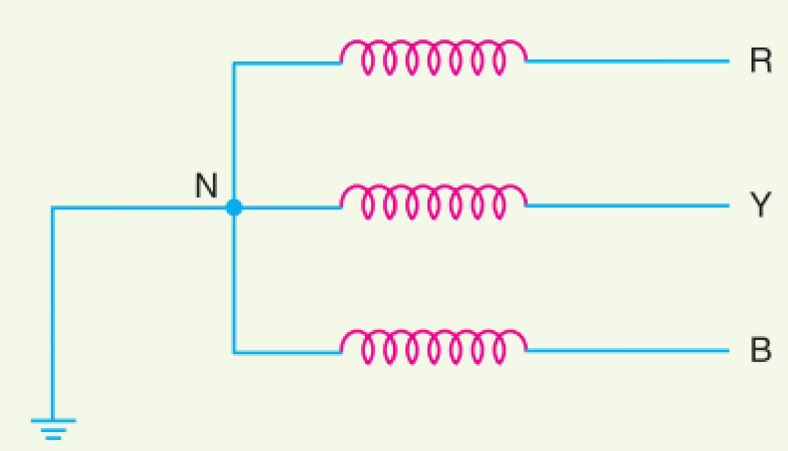
- Voltages of the healthy phases do not exceed line to ground voltages *i.e.* they remain nearly constant.
- The over voltages due to lightning are discharged to earth.
- It provides greater safety to personnel and equipment.
- It provides improved service reliability**.**

Methods of Neutral Grounding

- Solid or effective grounding
- Resistance grounding
- Reactance grounding
- Peterson-coil grounding

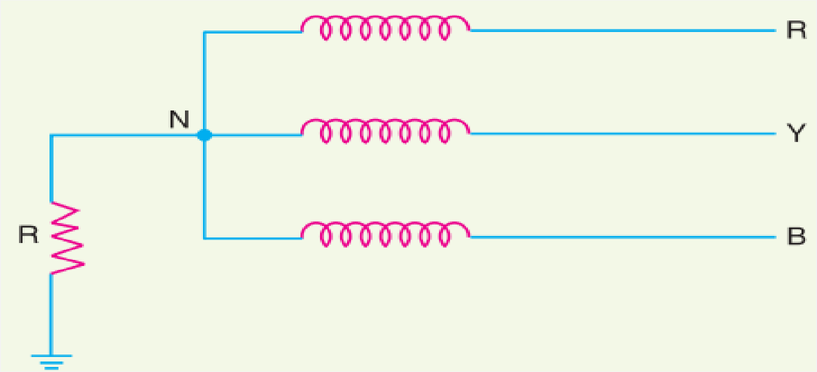
Solid grounding

- When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called **solid grounding** or effective grounding.



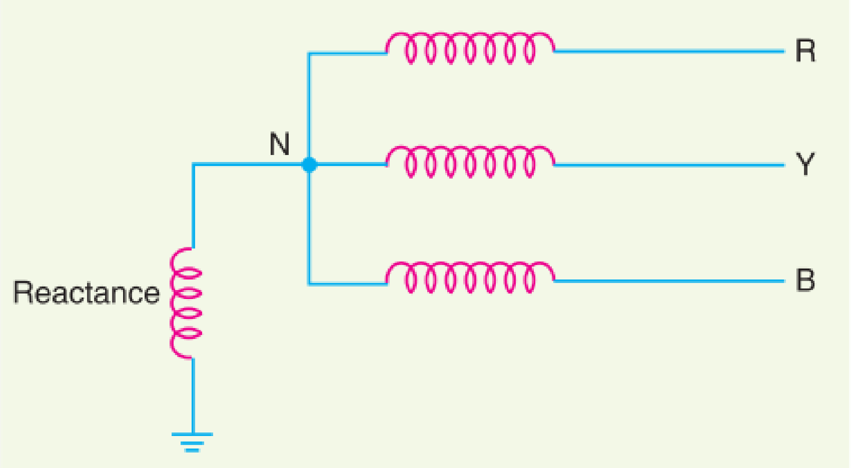
Resistance grounding

- To limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called **resistance grounding**.
- When the neutral point of a 3-phase system (e.g.3-phasegenerator, 3-phase transformer etc.) is connected to earth (i.e. soil) through a resistor, it is called resistance grounding.



Reactance grounding

- In this system, a reactance is inserted between the neutral and ground.
- The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can to changed to obtain the conditions similar to that of solid grounding.



Substation

- The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a **sub-station.**

- Sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of sub-stations.

- It should be located at a proper site.

- It should be easily operated and maintained.

- It should involve minimum capital cost.

Types of substations

According to service requirement

- Transformer sub-stations
- Switching substations
- Power factor correction substations
- Frequency changer substations
- Converting substations
- Industrial substations

According to constructional features

- Indoor sub-station
- Outdoor sub-station
- Underground sub-station
- Pole-mounted sub-station

Transformer sub-stations

- Those sub-stations which change the voltage level of electric supply are called transformer sub-stations. These sub-stations receive power at some voltage and deliver it at some other voltage.

Switching sub-stations

- They simply perform the switching operations of power lines.

Power factor correction sub-stations

- Those sub-stations which improve the power factor of the system are called power factor correction sub-stations.
- These sub-stations generally use synchronous condensers as the power factor improvement equipment.

Frequency changer sub-stations

- Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilisation.

Converting sub-stations

- Those sub-stations which change a.c. power into d.c. power are called converting sub-stations. These sub-stations receive a.c. power and convert it into d.c. power with suitable apparatus (*e.g.* ignitron) to supply for such purposes as traction, electroplating, electric welding etc.

Industrial sub-stations

- Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

Indoor sub-stations

- For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

Outdoor sub-stations

- For voltages beyond 66 kV, equipment is invariably installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

Comparison between outdoor and Indoor substation

S.No.	Particular	Outdoor Sub-station	Indoor Sub-station
1	Space required	More	Less
2	Time required for erection	Less	More
3	Future extension	Easy	Difficult
4	Fault location	Easier beacuse the equipment is in full view	Difficult because the equipment is enclosed
5	Capital cost	Low	High
6	Operation	Difficult	Easier
7	Possibility of fault escalation	Less because greater clearances can be provided	More

Underground sub-stations.

- In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

Pole-mounted sub-stations

- This is an outdoor sub-station with equipment installed overhead on *H*-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such substations.

HVAC and HVDC transmission

<u>Investment cost:</u>

DC transmission requires fewer conductors than AC transmission - 2 conductors per DC circuit whereas three conductors per 3 phase AC circuit. HVDC allows line supporting towers to be smaller and, hence, requires lesser right-of-way. Thus, clearly, HVDC transmission line would cost lesser than an HVAC line.

<u>Losses:</u>

Skin effect is absent in DC. Also, corona losses are significantly lower in the case of DC. An HVDC line has considerably lower losses compared to HVAC over longer distances.

Controllability:

Due to the absence of inductance in DC, an HVDC line offers better voltage regulation. Also, HVDC offers greater controllability compared to HVAC.

Asynchronous interconnection:

AC power grids are standardized for 50 Hz in some countries and 60 Hz in other. It is impossible to interconnect two power grids working at different frequencies with the help of an AC interconnection. An HVDC link makes this possible.

Interference with nearby communication lines:

Interference with nearby communication lines is lesser in the case of HVDC overhead line than that for an HVAC line.

Short circuit current:

In longer distance HVAC transmission, short circuit current level in the receiving system is high. An HVDC system does not contribute to the short circuit current of the interconnected AC system.

Thank you