MALLAREDDYCOLLEGEOFENG INEERING &T ECHNOLOGY

(AutonomousInstitution–UGC,Govt.ofIndia)

(AffiliatedtoJNTUH,Hyderabad,ApprovedbyAICTE-AccreditedbyNBA&NAAC–'A'Grade-ISO9001:2015Certified)

Maisammaguda,Dhulapally(PostVia.Hakimpet),Secunderabad–500100,TelanganaState,INDIA.

DEPARTMENTOFELECTRICAL&ELECTRONICS ENGINEERING

DIGITALNOTES

ON

POWERSYSTEMS-I

For

B.TECH
IIYEAR-I
SEM (2024-25)

MALLAREDDYCOLLEGEOFENGINEERINGANDTECHNOLOGYII-YEARB. TechEEE-ISEM **L/T/P/C**

(R22A0205) POWERSYSTEM-I –

prerequisite:BasicElectricalEngineering,ElectricalMachines-I,ElectricalMachines-IICOURSEOBJECTIVES:

1. **Tounderstandthedifferenttypesofpowergeneratingstations.**
2. **Tounderstandtheconceptsofoverheadlineinsulators.**
3. **Toillustratetheeconomicaspectsofpowergenerationandtariffmethods.**
4. **Toevaluatethetransmissionlineparameterscalculations**
5. **Tounderstandtheconceptofcorona**

UNIT-I

GENERATION OFELECTRICPOWER:ConventionalSources:Hydro station,SteamPower Plant,NuclearPower Plant.Non-Conventional Sources(Qualitative Treatmentonly):OceanEnergy,TidalEnergy,WindEnergy,Fuel Cells,&SolarEnergy,Cogeneration--Energyconservationand storage.

UNIT-II

ECONOMICSOFGENERATION:Introduction,definitionsofconnectedload,maximumdemand, demandfactor,loadfactor,diversityfactor,Loaddurationcurve,numberandsizeofgeneratorunits.Base load and peak load plants. Cost of electrical energy-fixed cost, runningcost . types of Tariff

Simple, flatrate,block-rate,two-part ,powerfactortariffmethodsandnumericalproblems.

UNIT-III

OVERHEADTRANSMISSIONLINES:lineconductors,inductanceandcapacitanceofsinglephaseandthreephase linewithsymmetricalandunsymmetricalspacing,compositeconductortransposition,bundledconductors,andskin and proximity effects.

UNIT-IV

PERFORMANCEOFTRANSMISSIONLINES:Representationoflines,shorttransmissionlines,mediumlength lines, nominalT and PI-representations, and long transmission lines (Rigorous Solution Method).The equivalentcircuitrepresentationofalongLineA,B,C,Dconstants,FerrantiEffect,SkinandProximity effects,conceptofSurgeImpedance, NumericalProblems.

UNIT-V

NDCDISRTIBUTION: ClassificationofdistributionsystemscomparisionofDCvsACandundergroundvsover-head distribution systems. Voltage drop calculations (numerical problems) inD.Cdistributors for the following cases : radial D.C distributor fed at one end and at the both the ends (equal/unequal voltages) and ring main distributor.

TEXTBOOKS:

1. **W.D.StevensonElementsofPowerSystemAnalysis,FourthEdition,McGrawHill, 1984.**
2. **C.L.WadhwaGeneration,DistributionandUtilizationofElectricalEnergy,Second Edition, New Age International,2009.**

REFERENCEBOOKS::

1. **C.L.Wadhwa ElectricalPowerSystems,FifthEdition,NewAgeInternational,2009**
2. **M.V.DeshpandeElementsofElectricalPowerStationDesign,ThirdEdition,WheelerPub.1998**
3. **H.Cotton&H.Barber-TheTransmissionandDistributionofElectrical Energy by V. K. MehtaandRohit Mehta**

COURSEOUTCOMES:

Attheendofthiscourse,studentswilldemonstratetheabilityto

1. **AssessthefunctioningofconventionalandNon-Conventionalgeneratingstations.**
2. **Understandtheconceptsofeconomicsofgenerationlikepowertariffmethods.**
3. **Analyzeandevaluatethetransmissionlineparameters.**
4. **Determinetheperformanceoftransmissionlinesusingvarioussolutionmethods**
5. **Understandtheconceptsofoverheadlineinsulatorsandcorona.**

4.	PumpStorageScheme	
5.	Masscurve	
6.	VarioustermsrelatedtoHydrology	
NUCLEARPOWERSTATION		
1.	NuclearFissionandChainreaction	
2.	Nuclearfuels.-PrincipleofoperationofNuclearReactor	
3.	ReactorComponents:Moderators,Controlrods,Reflectorsand Coolants	
4.	Radiationhazards:ShieldingandSafetyprecautions	
5.	TypesofNuclearreactorsandbriefdescriptionofPWR,BWR and FBR	
6.	**Non-Conventional Sources(Qualitative Treatmentonly**)	
7.	OceanEnergy&TidalEnergy	
8.	GenerationofElectricPowerbyWindEnergy	
9.	FuelCells,&SolarEnergy,Cogeneration--Energyconservationand storage	
UNIT II **ECONOMICSOFGENERATION**		
1.	Introduction,definitionsofconnectedload	
2.	maximumdemand,demandfactor,loadfactor,diversityfactor, Loaddurationcurve	
3.	numberandsizeofgeneratorunits	
4.	Baseloadandpeakloadplants	
5.	Costofelectricalenergy-fixedcost,runningcost,Tariffon chargetocustomer	

UNITIV PERFORMANCEOFSHORT,MEDIUMANDLONGTRANSMISSIONLINES		
1.	ClassificationofLines-Introduction	
2.	PerformanceofSingle-PhaseShortTransmissionLines	
3.	PerformanceofThreePhaseShortTransmissionLines ABCD Parameters	
4.	PerformanceofShortTransmissionLinesUsingABCD Parameters	
5.	MediumTransmissionLines	
6.	EndCondenserMethod	
7.	NominalTMethod	
8.	NominalπMethod	
9.	MediumTransmissionLineUsingABCDConstants	
10.	LongTransmissionLines	
11.	AnalysisofLongTransmissionLine(RigorousMethod)	
12.	LongTransmissionLine(ABCDParameters)	
UNIT–IV FACTORSGOVERNINGTHEPERFORMANCEOFTRANSMISSIONLINES		
1.	Introduction	
2.	SurgeImpedance	
3.	SurgeImpedanceLoading	
4.	Corona	
5.	FactorsAffectingCorona	
6.	Criticaldisruptivevoltage	

7.	AdvantagesandDisadvantagesofCorona	
8.	CoronaPower Loss	
9.	SkinEffect	
10.	ProximityEffect	
11.	FerrantiEffect	
12.	ChargingCurrentInTransmissionLine	
13.	InductiveInterferencewithNeighboringCommunication Circuits	
UNITV OVERHEADLINEINSULATORS		
1.	Introductiontotypesofinsulators	
2.	Potentialdistributionoverastringofsuspensioninsulators	
3.	StringEfficiency,Methodsofequalizingthepotential	
4.	Gradingofinsulators-CapacitancegradingandStaticShielding	
5.	NumericalProblemsoninsulators	

UNIT-1

THERMALPOWERSTATIONS

INTRODUCTION:

- Thermalenergyis the major sourceofpowergenerationin India. More than60% ofelectric power is produced by steam plants in India. India has large deposit of coal (about 170billiontones),5thlargestinworld.IndiancoalsareclassifiedasA-Ggradecoals.
- In Steam power plants, the heat of combustion of fossil fuels is utilized by the boilers to raise steam at high pressure and temperature. The steam soproducedisusedin drivingthe steam turbines or sometimes steam engines couples to generators andthusin generating electrical energy.
- Steam turbines or steam engines used insteam power plants notonlyactasprimemovers but also asdrivesfor auxiliary equipment,such as pumps,stokersfansetc.
- Steam power plants may be installed either to generate electrical energy only or generate electrical energy along with generation of steam for industrial purposes such as in paper mills, textile mills, sugar mills and refineries, chemical works, plastic manufacture, food manufacture etc.
- The steam for process purposes is extracted from a certain section of turbine and the remaining steam is allowed to expand in theturbine.Alternatively theexhauststeammay be used for process purposes.
- Thermalstationscanbeprivateindustrialplantsandcentralstation.

CoalClassification

CoalType	kJ/kg	kWh/kg	kCal/kg
Peat	8000	28800000	1912
Lignite	20000	72000000	4780
Bituminous	27000	97200000	6453
Anthracite	30000	108000000	7170

AdvantagesandDisadvantagesofaThermalPowerPlantAdvantages:

- Lessinitialcostascomparedtoothergeneratingstations.
- Itrequireslesslandascomparedtohydropowerplant.
- Thefuel(i.e.coal)ischeaper.

- Thecostofgenerationislesserthanthatofdieselpowerplants.

Disadvantages:

- Itpollutestheatmospherenduetotheproductionoflargeamountofsmoke.This isoneofthe causes of global warming.
- Theoverallefficiencyofathermalpowerstationislow(lessthan30%).
- Requireslongtimeforerectionandputintoaction.
- CostlierinoperatingincomparisonwiththatofHydroandNuclearpowerplants.
- Requirementofwaterinhugequantity.

Selectionofsiteforthermalpowerplant

- **Nearness to the load centre:** Thepowerplantshouldbeasnearaspossibletotheloadcentre to the centre of load .So that the transmission cost and losses are minimum. This factor is most important when Dc supply system is adopted. However in the case of AC supply when transformation of energy from lower voltage to higher voltage and vice versa ispossible power plantscanbeerectedatplacesotherthanthatofloadprovidedotherconditionsare favorable.
- **Water resources:** For the constructionand operating ofpower plant large volumes ofwater are required for the following reasons
  - Toraisethesteaminboiler.
  - Forcoolingpurposesuchasincondensers
  - Asacarryingmediumsuchasdisposalofash.
  - Fordrinkingpurposes.
  - This could be supplied from either rivers or underground water resources. Thereforehavingenoughwatersupplies indefinedvicinitycanbeafactorintheselection ofthe site.
- **Availability of Coal:** Huge amount of coal is required for raising the steam. Since the government policy is to use the only low grade coal with 30 to 40 % ash content for power generationpurposes,thesteampowerplantsshouldbelocatednearthecoalminestoavoid the transport of coal & ash.
- **Land Requirement:** The land is required not only for setting up the plant butforotherpurposes also such as staff colony, coal storage, ash disposal etc.

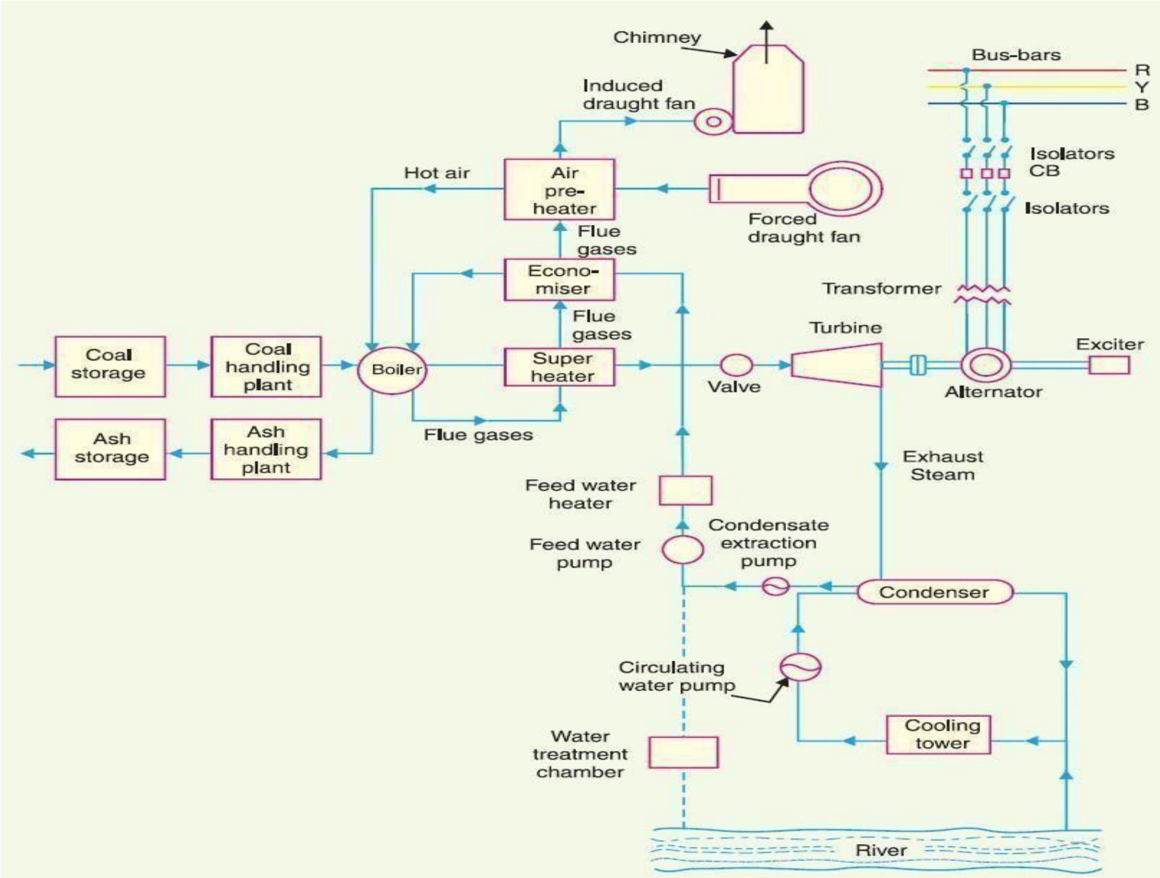
- **Eg:**For2000MWplant,thelandrequirementmaybeoftheorderof200-250acres.Asthecostof the land adds up tothe final cost of the plant, it should be available at a reasonable price. Land should be available for future extension.

- **TransportationFacilities**:Thefacilitiesmustbeavailablefortransportation of heavy equipment and fuels e.g near railway station.
- **Labour supplies:** Skilled and unskilled laborers should be available at reasonable rates near the site of the plant.
- **Ash Disposal:** Ash is the main waste product of the steam powerplant andwithlowgrade coal, it may be 3.5 tones per day , somesuitablemeans fordisposal of ash should be though of. It maybe purchased bybuilding contractors, or it canbe used for brickmaking near the plant site. Ifthe site is nearthe coalmine it canbe dumped intothe disused mines.Incaseof site locatednear ariver,seaorlake ash can be dumpedinto it.
- **Distance from populated area:** The continuous burning of coal at the power station Produces smoke,fumesandash which pollutethe surroundingarea. Such a pollutiondue to smokeisdangerousfor the people living around the area. Hence, the siteof aplant should be at a considerable distance from the populatedarea.

MajorComponentsofaThermalPowerPlant

- **CoalHandlingPlant**
- **PulverizingPlant**
- **DraftorDraughtfan**
- **Boiler**
- **AshHandlingPlant**
- **TurbineandGenerator**
- **Condenser**
- **CoolingTowerAndPonds**
- **FeedWaterHeater**
- **Economiser**

- ❖ **SuperheaterandReheater**
- ❖ **Airpreheater**
- ❖ **AlternatorwithExciter**
- ❖ **Protectionandcontrolequipment**
- ❖ **Instrumentation**



BOILER

Schematic arrangement of Steam Power Station

- ❖ A boiler (or steam generator) is a closed vessel in which water, under pressure, is converted into steam. The heat is transferred to the boiler by all three modes of heat transfer i.e. conduction, convection and radiation.
- ❖ Majortypesofboilersare:(i)firetubeboilerand(ii)watertubeboiler

- Generallywatertubeboilersareusedforelectricpowerstations.

FireTubeBoiler

- Theboiler is namedsobecausetheproductsofcombustionpassthroughthetubes which are surrounded by water.
- Dependingonwhether thetubeis verticalorhorizontalthefiretubeboileris divided into two types
  - Verticaltubeboiler
  - Horizontaltubeboiler
- Afiretubeboilerissimple,compactandruggedinconstruction.Itsinitialcostislow.
- Waterbeing moreandcirculationbeingpoortheycannot meetquicklytochanges in steam demand.
- As water and steam, both are in the same shell,higher pressure of steamarenot possible,themaximumpressurewhichcanbe had is 17.5kg/cm^{2}withacapacityof 15,000kg of steam per hour.
- Forthesameoutputtheoutershellofafiretubeboilerismuchlargerthanthatofawater tube boiler.
- In the event of a sudden and major tube failure.Steam explosionsmay be causedinthe furnace due to rush of highpressure water intothe hot combustionchamber which may generate large quantities of steam in the furnace.
- Firetubeboilersuseisthereforelimitedtolowcostsmallsizeandlowpressureplants.

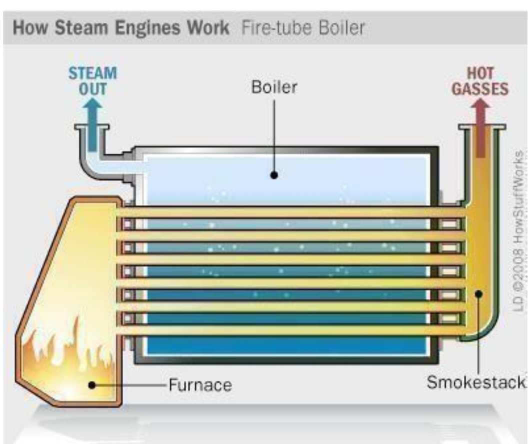


Figure:FireTubeBoiler

WaterTubeBoilers

- Inthisboiler,thewaterflowsinsidethetubesandhotgasesflowoutsidethetube.
- Watertubeboilerareclassifiedas
- Verticaltubeboiler
- Horizontaltubeboiler
- Inclinedtubeboiler
- Thecirculationofwaterintheboilerismaybenaturalorforced.
- ForCentralsteampowerplantslargecapacityofwatertubeboilersareused.
- Thetubesarealwaysexternaltothe drum theycanbe built insmallersizeand therefore withstand high pressure.
- Theboilerdrumcontainsbothsteamandwater,theformerbeingtrappedfromthetopof the drum where the highest concentration of dry steamexists.

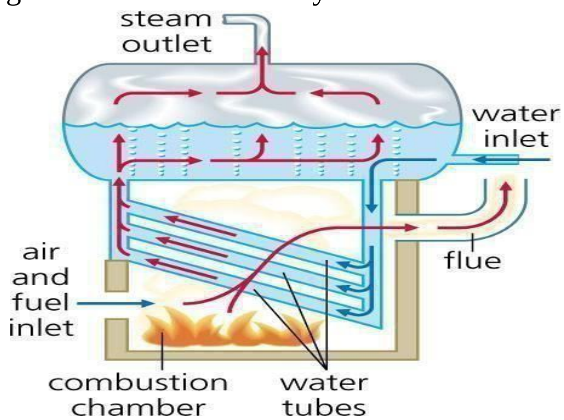


Figure:WatertubeboilerSUPERHEATER

ANDREHEATERS

- Thefunctionofthe superheateristo removethelast trashof moisturefrom the saturatedsteamleavingtheboilertubesandalsoincreasesitstemperatureabovethe saturation temperature.
- Forthispurposetheheatofthecombustiongasesfromthefurnaceisutilized.
- Superheatedsteamisthatsteamwhichcontainsmoreheatthanthesaturated steamatthesamepressure.Theadditionalheatprovidesmoreenergyto the turbinehence

poweroutputismore.

- Superheatedsteamcauses lessererosionoftheturbinebladesandcanbe transmitted for longer distance with little heat loss
- Asuperheatermaybeconventiontype,radianttypeorcombination.However, convention super heaters are more commonly used.

Figure:Superheaters

REHEATER

- Inadditiontosuperheatermodernboilerhas reheateralso.Thefunctionofthe reheateristosuperheatthepartlyexpandedsteamfromtheturbine,thisensurethat the steam remain dry through the last stage of the turbine.
- Areheatermaybeconventiontype,radianttypeorcombination.

FeedWaterHeaters: These heatersareused toheat the feedwaterbymeansofblendsteam before it is supplied to the boiler. Necessity of heating feed water before feeding it back to the boiler arises due to the following reasons.

- FeedWaterheatingimproveoverallefficiency.
- Thedissolvedoxygenwhichwould otherwisecauseboilercorrosionareremoved in the feed water heater.
- Thermalstressesduetocoldwaterenteringtheboilerdrumareavoided.
- Quantityofsteamproducedbytheboilerisincreased.

- Someotherimpuritiescarriedbysteamandcondensate,duetocorrosionin boiler and condenser, are precipitated outside the boiler.

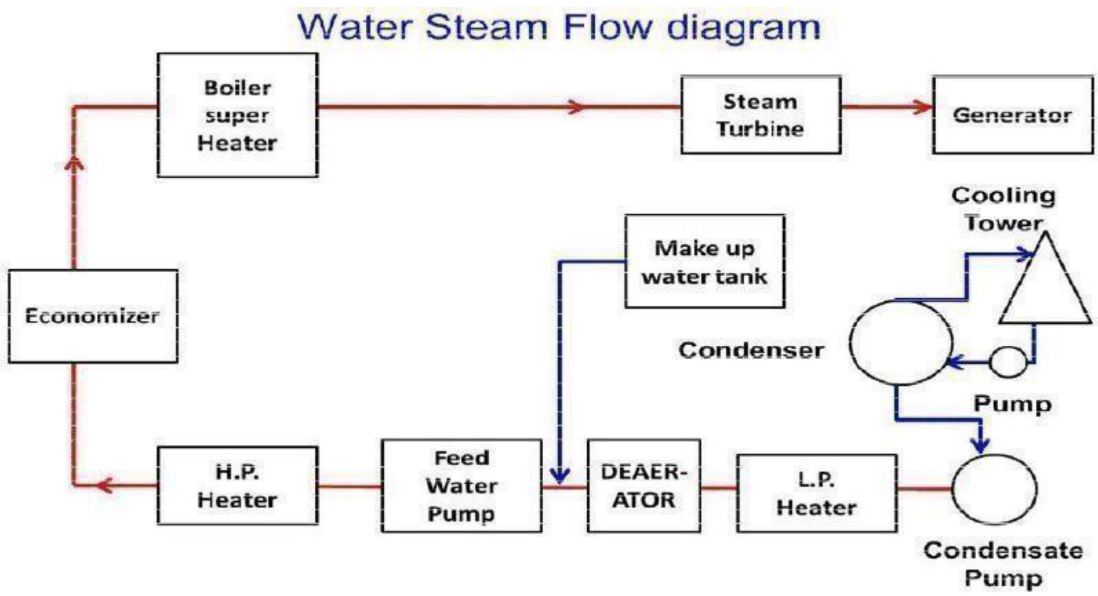


Figure:Watersteamflowdiagram

ECONOMIZER

- Boilers are provided with economizer and air pre-heaters to recover heat from the flue gases. An increase of about 20% in boiler efficiency is achieved by providing both economizer and air pre-heaters.

- Economizer alone gives only 10-12% efficiency increase, causes saving in fuel consumption 5-15 %. The feed water from the high pressure heaters enters the economizer and picks up heat from the flue gases afterthelowtemperature superheater.
- Economizer can be classified as an inline or staggered arrangement based on the typeof tube arrangement.
- Forpressureof70Kg/cm^{2}ormoreeconomizerbecomesanecessity.
- Thetubesarearrangedinparallelcontinuousloops.

- Feedwaterflowsthroughthetubesandthefluegasesoutsidethetubesacrossthem.

The feedwatershouldbesufficientlypurenottocause formingofscalesandcause internal corrosion and under boiler pressure.

- Thetemperatureofthefeedwaterenteringtheeconomizershouldbehighenoughsothat moister from the flue gases doesnot condense on the economizer tubes.

AIRPREHEATERS

- Afterthefluegases leaveeconomizer,somefurtherheatcanbeextractedfrom them and is used to heat the incoming air for combustion.
- Airpreheatersmaybeoffollowingtypes:
  - Platetype
  - Tubulartype
  - Regenerativetype
- Coolingoffluegasesby20^{0}increasetheefficiencyoftheplantby1%.
- The use of air preheaters is more economical with pulverized fuel boilers because the temperature of flue gases going out is sufficientlylarge andhigh airtemperatures (250to 350^0 C) is always desirable for bettercombustion.
- Air preheaters should have high thermal efficiency, reliability of operation, less maintenance charges, should occupy small space,shouldbe reasonableininitial costand should be accessible.
- Inordertoavoidcorrosionoftheairpreheaters,thefluegasesshould notbecooled below the dew point.

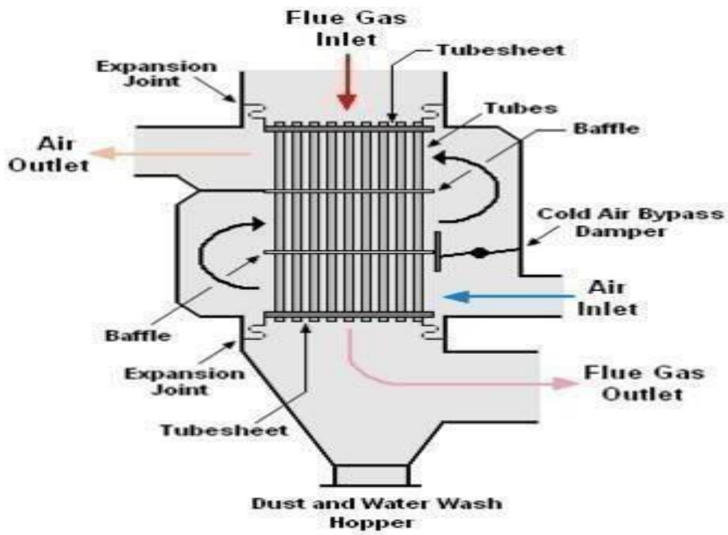


Figure:AirPreheater

STEAMTURBINES

- Steamenteringfromasmallopeningattainsaveryhighvelocity.
- Thevelocityattainedduringexpansiondepends ontheinitialandfinal content of the steam.
- Thedifference ininitialand finalheat contentrepresentthe heatenergytobe converted to kinetic energy.

Therearetwotypesofsteamturbines:

1) Impluseturbineand2)ReactionTurbine

ImpuseTurbine:

- In this turbine there are alternate rows of moving and fixed blades. The moving blades are mounted on the shaft and fixed blades are fixed to the casing of the turbine.

- Asetoffixednozzleisprovidedandsteamispassedthroughthesenozzles.The in steamdue to pressure andinternal energyisconverted to K.E.Thesteam comesoutofthenozzleswithveryhighvelocityandimpingesontherotorblades.

- Thedirectionofsteamflowchangeswithoutchangingitspressure.

- Thusduetothechangeinmomentumtheturbinerotorstartsrotating.

ReactionTurbine:

- Reactionturbine havenonozzles.Thesetwohavealternaterowsofmovingandfixed blades. The moving blades are mounted on shaft, while fixed blades arefixed in casing of turbine.
- When high pressure steam passes through fixed blades, then steam pressure drops down and velocity of steam increases.
- As steam passes over moving blades, the steam expandsandimparts energy,resulting in reduction in pressure and velocity ofsteam.

Note:Turbinesusedinthermalpowerstationsare Impuse,Reactionorcombined.
Generallymultistage turbinesareused.H.PsteamafterdoingworkintheH.P stagepasses over stage.moreworkisextractedthereby,withconsequentincreaseinthermalefficiency.

Compoundingofsteamturbines:

Singlestageturbinesareoflowefficiency.

Incompounding,anumberofrotorsareconnectedorkeyedtothesameshaft

Twotypesofcompoundingareused:velocitycompoundingandpressurecompounding

Governingofsteamturbines:

Governingsignifiestheprocessofcontrollingthevolumeofsteamtomeet theload fluctuation.

Figure:SteamTurbines

CONDENSERS

Thefunctionofthecondenseristocondensethesteamexitingtheturbine.The condenserhelpsmaintainlowpressureattheexhaust.Two types of condensers are used.

Table:JetandSurfaceCondensers

Jetcondenser(contacttype)	Surfacecondenser(non-contacttype)
Exhauststeammixeswithcoolingwater.	Steamandwaterdonotmix.
Temperatureofthecondensateandcooling waterissamewhileleavingthecondenser.	Condensatetemperaturehigherthanthe cooling water temperature at outlet.
Condensatecannotberecovered.	Condensaterecoveredisfedbacktotheboiler.
Heatexchangedbydirectconduction	Heattransferthroughconvection.
Lowinitialcost	Highinitialcost.
Highpowerrequiredforpumpingwater.	Condensateisnotwastedsopumpingpoweris less.

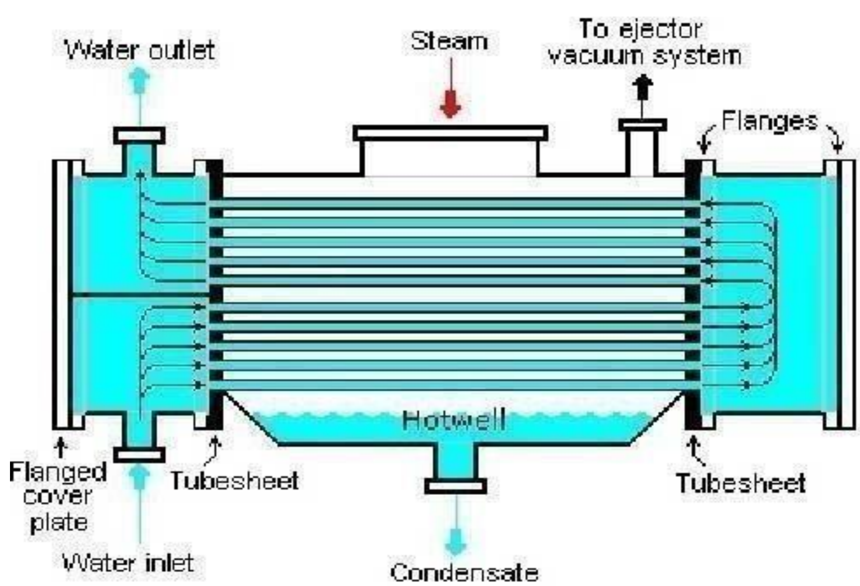
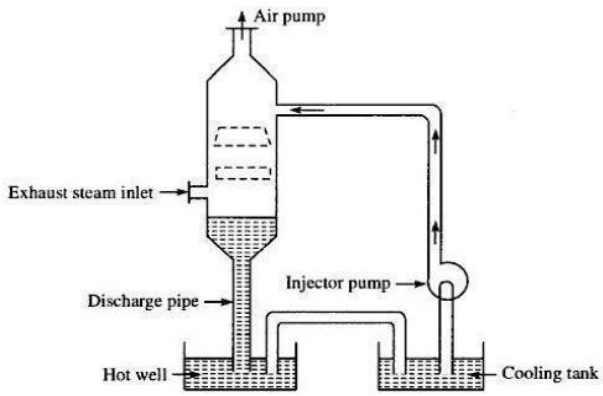


Figure:SurfaceCondenser



DEAERATORS

- A deaerator is a device that is widely used for the removal of oxygen and other dissolved gases from the feed water to steam-generating boilers.
- In particular, dissolved oxygen in boiler feed waters will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and forming oxides (rust).
- Therearetwobasictypesofdeaerators,
  1. thetray-typean
  2. thespray-type
- The tray-type (also called the cascade-type) includes a vertical domed deaerationsectionmounted ontop ofahorizontalcylindricalvesselwhich serves as the deaerated boiler feedwater storage tank.
- Thespray-typeconsistsonlyofahorizontal(orvertical)cylindricalvesselwhich servesasboth thedeaerationsection andtheboilerfeedwaterstoragetank.

COOLINGTOWERSANDSPRAYPONDS

- Condensersneedhugequantityofwatertocondensethesteam.
- Wateris ledintotheplantsbymeans ofcirculatingwaterpumpsandafterpassing through the condenser is discharged back into theriver.
- Ifsuchasourceisnotavailableclosedcoolingwatercircuitisusedwherethe

warmwatercomingoutofthecondenseriscooledandreused.

- Insuchcasespondsandcoolingtowersareusedwherethewaterlosesheattothe atmosphere.

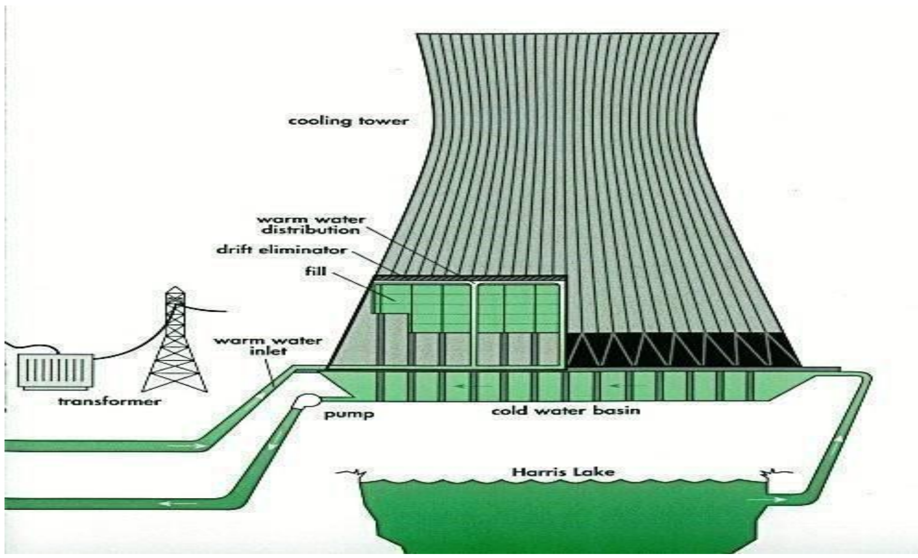
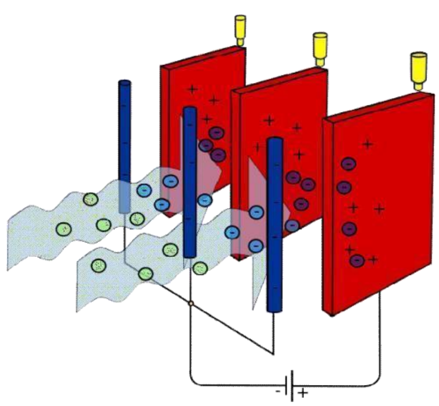


Figure:CoolingTowerELECTROSTATI

C PRECIPITATORS

- ❖ Anelectrostaticprecipitator(ESP),orelectrostaticaircleanerisaparticulate collectiondevicethatremovesparticlesfromaflowinggas(suchasair)using theforceofaninducedelectrostaticcharge.



- ❖ thebasicideaofanESP:
- ❖ *Charging*
- ❖ *collecting.*
- ❖ *removing*

- Everyparticleeitherhasorcanbegivenacharge—positiveornegative.
- WeimpartanegativechargetoalltheparticlesinagasstreaminESP.
- Thenagroundedplatehavingapositivechargeissetup.
- Thenegativelychargedparticlewouldmigratetothegroundedcollectionplateand be captured.
- Theparticleswouldquicklycollectontheplate,creatingadustlayer.Thedustlayerwould accumulate until we removed it.
- Thestructuraldesignandoperationofthedischargeelectrodes(rigid-frame,wiresorplate) and collection electrodes.
    - tubulartypeESP
    - platetypeESP
- Themethodofcharging
    - single-stageESP
    - two-stageESP
- Thetemperatureofoperation
    - cold-sideESP
    - hot-sideESP
- Themethodofparticleremovalfromcollectionsurfaces
    - wetESP
    - DryESP

AshHandlingPlant

In ThermalPowerPlant'scoal isgenerally usedasfuel andhencetheashisproducedas thebyproductof Combustion.Ash generatedin powerplantis about30-40%of total coal consumptionandhencethesystemisrequiredtohandleAshforitsproperutilizationor disposal. The steam power plant produces 5000of tons ash daily (2000MW)

Theashmaybe

- FlyAsh(Around80%isthevalueofflyashgenerated)
- Bottomash(Bottomashis20% oftheashgenerated incoal based power stations.

FlyAsh

AshgeneratedintheESPwhichgotcarriedoutwiththefluegasisgenerallycalledFlyash. It alsoconsists ofAir pre heater ash& Economizer ash (it is about 2 % ofthe totalash content).

Bottom ash

Ashgeneratedbelowfurnaceofthesteamgeneratoriscalledthebottomash.

Theoperationofashhandlingplantsis…….

- Removalofashfromthefurnaceashhoppers
- Transferoftheashtoafillorstorage
- anddisposalofstoredash

Theashmaybedisposedinthefollowingway…….

- Wastelandsitemaybereservedforthedisposalofash.
- Buildingcontractormayutilizeittofillthelowlyingarea.
- Deeppondsmaybemadeandashcanbedumped intothese ponds to fillthem completely
- Whenseaborncoalisused,barragemaytaketheashtoseafor disposal into water grave.

Themodernashhandlingsystemusuallyusedinlargesteampowerplantsare…….

- Beltconveyorsystem
- Pneumatic system
- Hydraulicsystem
- Steam jet system

Beltconveyorsystem

- Inthissystemtheashismadetoflow throughawatersealoverthebeltconveyorinorder to coolit down and then carriedout to a dumping siteover the belt.
- Itcandeliver3tonnesofashperhourwithaspeedof0.3m/minute.

❑Thelifeofbeltis5years.itisusedinsmallpowerplant

Pneumaticsystem

❑Inthissystemair isemployedasamediumtodriving theashthroughapipeoveralong distance.

❑Thissystemcanhandle5-30tonnesofashper hour ❑This

is used for disposal of fly ash

Hydraulicsystem

❑Inthissystemastreamofwatercarriesashalongwithit ina closedchannelanddisposed it off to the proper site.

❑Itisoftwotypeshighpressuresystemandlowpressuresystem.

Steamjetsystem

❑Thissystememploysjetsofhighpressureblowinginthedirectionofashtravel through aconveyingpipe in which ash from theboilerash hopperis fed.

❑Itisemployedinsmallandmediumsizeplant

❑Steamconsumptionis110kgpertonneofmaterialconveyed.

NUCLEARPOWERSTATION

Basics

- Atomsconsistofnucleusandelectrons.
- Thenucleusiscomposedofprotonsandneutrons.
- Protonsarepositivelychargedwhereasneutronsareelectricallyneutral.
- Atomswithnucleihavingsamenumberofprotonsbutdifferenceintheirmassesare called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.
- NaturalUraniumconsistsof$_{92}U^{238}$(99.282%),$_{92}U^{235}$(0.712%)and$_{92}U^{234}$
- 92U^{235}isusedasfuelinnuclearpowerplants.

EnergyfromNuclearReactions

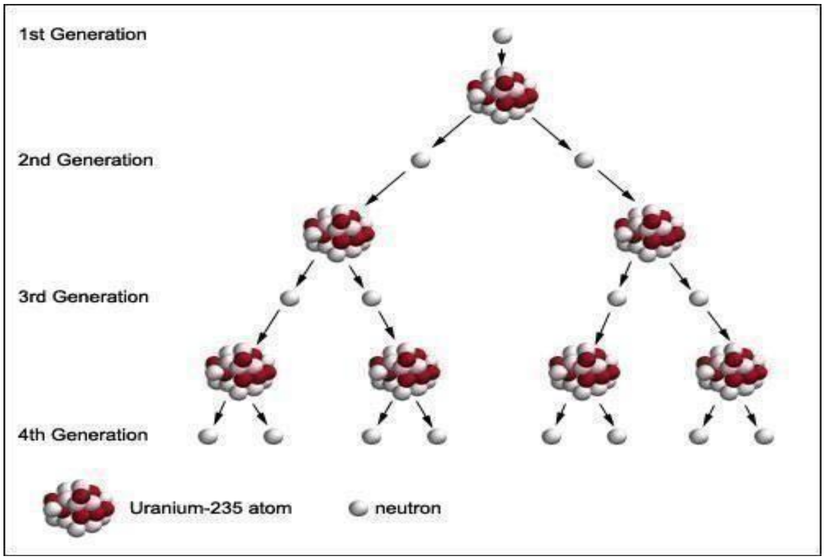
- Thesumofmassesofprotonsandneutronsexceedsthemassoftheatomicnucleus andthisdifferenceiscalledmassdefectΔm.

- Inanuclearreactionthemassdefectisconvertedintoenergyknownasbindingenergy according to Einstein's equation ($E=\Delta m\ c^2$).
- Fissioningoneamuofmassresultsinreleaseof931MeVofenergy.
- Ithasbeenfoundthatelementhavinghigherandlowermassnumbersareunstable. Thus thelowermassnumberscanbefusedorthehighermassnumberscanbe fissioned to produce more stable elements.
- Thisresultsintwotypesofnuclearreactionsknownasfusionandfission.
- ThetotalenergyperfissionreactionofU^{235}isabout200MeV.
- Fuelburn-uprate istheamount ofenergyinMW/daysproducedbyeachmetrictonof fuel.

NuclearFission

Nuclearfissionis the reactionbywhichaheavy nucleus(thatisonewitha highvalueofZ)is hit withasmallparticle,asaresultofwhichitsplitsintotwo(occasionallymore)smaller nuclei.

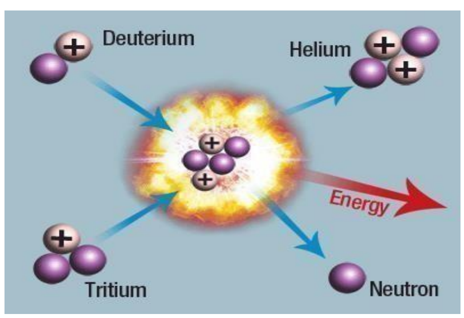
Before the reaction		After the reaction	
${}^{1}_{0}n$	1.008665	${}^{140}_{54}Xe$	139.9216
${}^{235}_{92}U$	235.0439	${}^{94}_{38}Sr$	93.9154
		$2\ {}^{1}_{0}n$	2.0173
Total mass	236.0526	Total mass	235.8543



NuclearFusion

Fusion is the opposite of fission, it is the joining together of two lightnucleito form a heavierone(plusasmallfragment).Forexampleiftwo2Hnuclei(twodeuterons)canbemade to come together they can form He and a neutron.

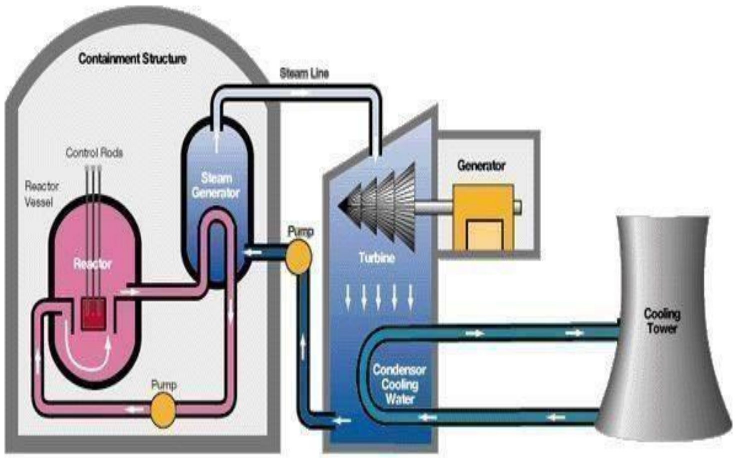
$$^{2}H + {}^{2}H \rightarrow {}^{3}He + n$$



NuclearFusion

NuclearPowerPlant

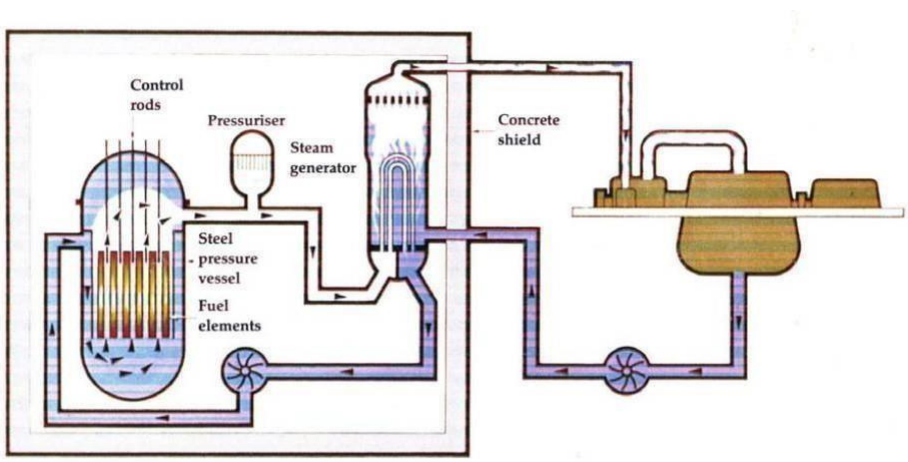
- A nuclear power plant isa thermal powerstationin which the heat source isoneor morenuclear reactors.Asin a conventional thermal powerstation theheat is used to generatesteamwhichdrivesasteamturbineconnectedtoageneratorwhichproduces electricity.



SchematicofaNuclearPowerPlant

PressurizedWaterReactor(PWR)

- The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched(about 3.2%U235)uranium dioxide asa fuel in zirconium alloycans.
- The fuel,whichis arranged inarraysoffuel"pins"andinterspersedwiththemovablecontrol rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator.
- The high-pressure water isthen passed through asteam generator, which raisessteaminthe usual way.

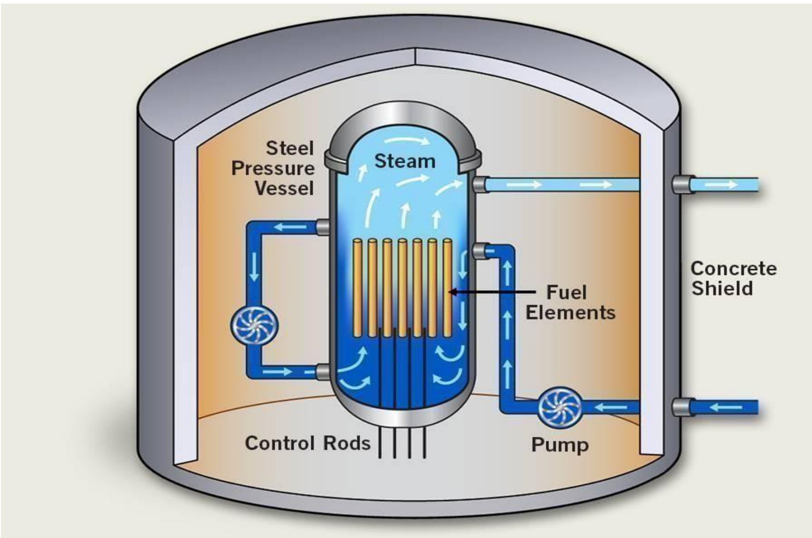


PressurizedWaterReactor

BoilingWaterReactors(BWR)

❑ The second type of water cooled and moderated reactor does awaywiththesteamgenerator and, by allowing the water within thereactor circuit to boil, it raisessteam directly for electrical power generation. Such reactors, known as Boiling Water Reactors (BWRs), throughout the world.

BoilingWaterReactor



❑This,however,leadstosomeradioactivecontaminationofthesteamcircuitandturbine,whichthen requiresshieldingof thesecomponentsin addition to thatsurroundingthe reactor.

FastBreederReactors

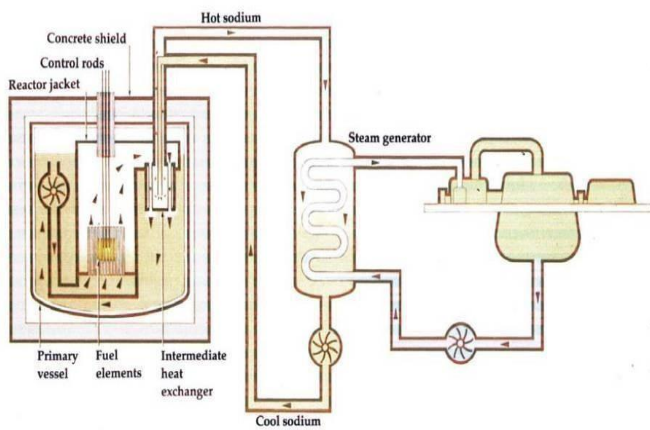
❑Alloftoday'scommerciallysuccessfulreactorsystemsare"thermal"reactors,usingslowor thermal neutrons to maintain thefission chain reaction in the U^{235} fuel. Even with the enrichment levels used in the fuel for such reactors, however, byfarthelargestnumbers of atoms present are U^{238}, which are not fissile.

❑Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.

Plutonium is fissile and some of it is consumed in situ, while some remains in the spent fuel together with unused U^{235}. These fissile components can be separated from the fission productwastesandrecycledtoreducetheconsumptionofuraniuminthermalreactorsbyup to40%, although clearly thermal reactors still require a substantial net feed of natural uranium.

Itispossible,however,todesignareactorwhichoverallproducesmorefissilematerialinthe form of Plutonium than it consumes. This is the fast reactor inwhich the neutrons are unmoderated, hence the term "fast".

- The physics of this type of reactor dictates a core with a high fissileconcentration,typically around 20%, and made ofPlutonium. In order tomake it breed, the activecore is surrounded by material (largely U238) left over from the thermal reactor enrichment process. This materialis referred toas fertile,because it converts tofissilematerialwhenirradiatedduring operation of the reactor.
- The successful development of fast reactors has considerable appeal in principle. This is because they have the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilize the existingstocksofdepleteduranium, which would otherwise have no value.



FastBreederReactors

FactorsforSiteSelectionofNPPs

1. AvailabilityofWater:workingfluid
2. DistancefromPopulatedArea:dangerofradioactivity
3. Nearnesstotheloadcentre:reductionintransmissioncost
4. DisposalofWaste:radioactivewaste

5. AccessibilitybyRailandRoad:transportofheavyequipment

AdvantagesofNPPs

1. Reducesdemandforfossilfuels
2. Quantityofnuclearfuelismuchless:thusreducingtransportandresultingcosts
3. Areaoflandrequiredisless:comparedtoaconventionalplantofsimilarcapacity
4. Productionoffissilematerial
5. Locationindependentofgeographicalfactors:exceptwaterrequirement

DisadvantagesofNPPs

1. Notavailableforvariableloads(loadfactor-0.8):asthereactorscannotbecontrolledto respond quickly
2. Economicalreasonshouldbesubstantial
3. Riskofleakageofradioactivematerial
4. Furtherinvestigationonlifecycleassessmentandreliabilityneedstobedone
5. Perceptionproblems

ComparisonofPWRandBWR

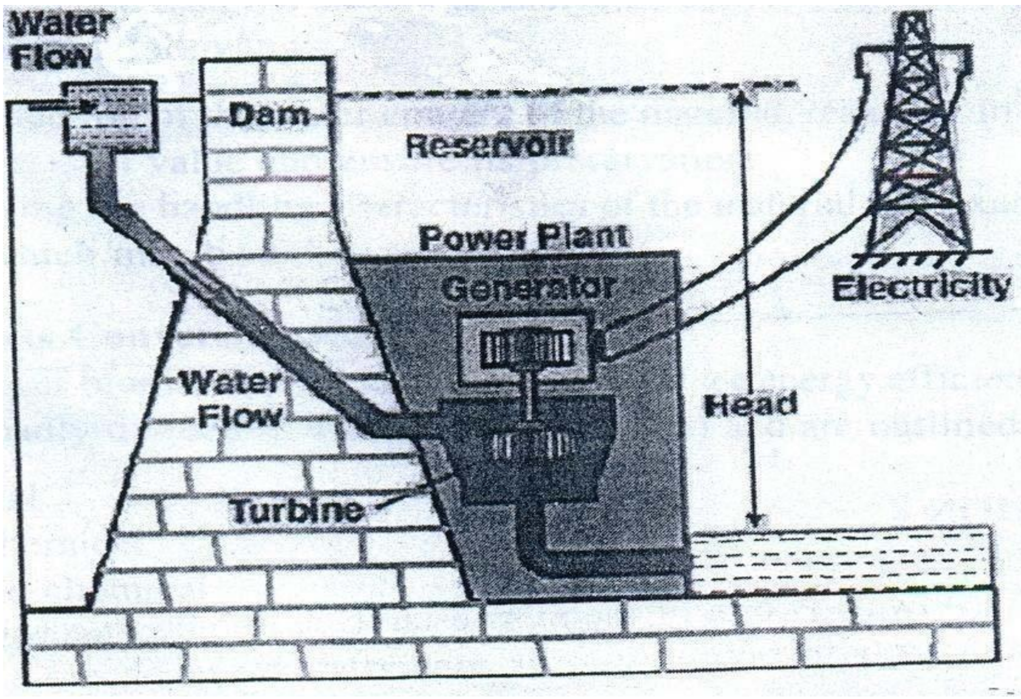
PWR	BWR
Advantages	Advantages
• Relativelycompactinsize • Possibilityofbreedingplutoniumby providing a blanket of U-238 • Highpowerdensity • Containmentoffissionproductsdue to heat exchanger • Inexpensive‘lightwater’canbeused asmoderator,coolantandreflector • Positivepowerdemand coefficient i.e.thereactorrespondstoload increase	• Elimination of heat exchanger circuit resultsin reduction in cost and gainin thermal efficiency (to about 30%) • Pressure inside in the reactor vessel is considerably lower resulting in lighter and less costly design • BWRcycleismoreefficientthanPWR as the outlet temperature of steam is much higher • Metalsurfacetemperatureislowersince boiling of water is inside thereactor • BWRismorestablethanPWRandhence is commonly known as a self-controlled reactor

Disadvantages	Disadvantages
• Moderator remains under high pressureandhenceastrongpressure vessel is required • Expensivecladdingmaterialis requiredtopreventcorrosion • Heatlossoccursduetoheat exchanger • Elaboratesafetydevicesarerequired • Lacksflexibilityi.e.thereactorneedsto be shut down for recharging and there is difficulty in fuelelement	• Possibilityofradio-activecontamination in the turbine mechanism • Wastageofsteammayresultinlowering of thermalefficiencyonpartloadoperation • PowerdensityofBWRisnearlyhalfthatof PWR resulting in large sizevessel • Possibilityofburn-outoffuelismoreas waterboilingisonthesurfaceoffuel. • BWRcannotmeetasuddenincreasein load

HYDROELECTRICPOWERSTSTION&HYDRAULICTURBINESHYDROPOWER:

Hydro-energyisknownastraditionalrenewableenergysource. Itisbasedonnatural circulatingwaterflowanditsdropfromhighertolowerlandsurfacethatconstitutesthe potential. Inorderto convert this potentialto applicable electric energy, water flow should be led to and drive a hydraulic turbine, transforming hydro energy into mechanical energy, thelatteragaindrivesaconnectedgeneratortransformingthemechanicalenergyintoelectric energy.Ashydroenergyexploitationanditsutilizationarecompletedatthesametime.I.e.the exploitationoffirstenergysourceandtheconversionofsecondaryenergysourceoccur simultaneously, unlike the coalpower generation which should have two orders; first order is exploitationoffuel,secondorderisgeneration,sohydropowerhastheadvantagesoverthermalpower generation.

Mankindhasusedtheenergyoffallingwaterformanycenturies,atfirstinmechanical form and since the late 19th century by further conversion to electrical energy. Historically, hydropowerwasdevelopedonasmallscaletoservelocalitiesinthevicinityoftheplants.With the expansion and increasing load transfer capability oftransmission networks, power generation wasconcentratedinincreasinglylargerunitsandto benefit fromtheeconomiesresulting from development on a larger scale.



GeneralLayoutofadambasedhydroelectricplant

Sites selected for development tended to be the most economically attractive; in this regard, higher heads and proximity to load centers were significant factors. For this reason, development was not restricted to large sites, and hydro stations todayrange from less than 1 MWe capacityto more than 10,000 MWe. The efficiencyofhydroelectric generation is more than twice that of competing thermal power stations.

TYPESOFPROJECT

Capacity,unitsizeandselectionofEquipment,theirCharacteristicsandSpecifications for designofhydropowerstationdependupontypeofhydroelectricdevelopmentand classificationwithrespecttoheadandsize.Therearethreemaintypesofhydropowerschemes thatcanbecategorizedintermsofhowtheflowatagivensiteiscontrolledormodified.These are:

Run-of-riverplants(noactivestorage);and

Plantswithsignificantstorage
Pumpedstorage

In a run-of-river project, the natural flow of the river is relatively uncontrolled. In a storageproject,thefillingandemptyingofthe impoundedstoragealongwiththepatternofthe naturalstream flow controls the flow inthe river downstream fromthe storage impoundment.

Run-of-river plants can be located at the downstream end of a canal fall, open flume, orpipelinedivertingthe stream’s flow arounda watersupplydam orfalls. Theavailable flow governsthecapacityoftheplant.Theplanthaslittleornoabilitytooperateatflowrateshigherthanthat available at the moment.

Inaconventionalplant,adam,whichstores waterinareservoirorlakeimpoundment, controls the river flows. Water is released according to electric, irrigation, water supply, or flood control needs. Constructing a dam and storage reservoir can increase the percentage of time that a project can produce a given level of power. Base load plants- those operated at relatively constant output-may have either a small capacity relative to the river flow or may have a significant storage reservoir. Storage reservoirs can be sized for storing water during wet yearsorwetseasons. Alternatively,theycan besizedtoprovidewaterforweekly ordaily peak generation. A storage reservoir allows using available energy that might otherwise be wasted as spill.

Plantswithstorageatbothheadandtailracearepumpedstorageproject.

RunoftheRiverSchemesorDiversionSchemes

This type of development aims at utilizing the instantaneous discharge of the stream. So the discharge remains restricted to day to day natural yield from the catchments; characteristicsofwhich willdependonthehydrologicalfeatures.Diurnalstorageissometime provided for optimum benefits. Development of a river in several steps where tail race dischargesfromheadraceinflowsfordownstreampowerplantsformsaninterestingvariation of this case and may require sometimes special control measures.

Small scale power generation also generallyfall in the categoryand mayhave special control requirement especially if the power is fed into a large grid.

StorageSchemes

Insuch schemesannual yield from thecatchment is stored in full orpartiallyand then released according to some plan for utilization of storage. Storage may be for single purpose such as power development or may be for multi purpose use which may include irrigation, flood control, etc. therefore, design of storage works and releases from the reservoir will be governedbytheintendedusesofthestoredwater.Iftheschemeisonlyforpowerdevelopment, thenthe best use of the water will be by releasing according to the power demand. Schemes with limited storagemaybedesigned aspeaking units. Ifthewater project formsapart ofthe large grid, then the storage is utilized for meeting the peak demands. Such stations could beusefully assigned with the dutyof frequency regulation of the system.

PumpStorageScheme

Principle

The basic principle of pumped storage is to convert the surplus electrical energy available in a system in off-peak periods, to hydraulic potential energy, in order to generate power in periods when the peak demand on the system exceeds the total available capacityof the generating stations.

By using the surplus scheme electrical energy available in the network during low-demand periods, water is pumped from a lower pond to an upper pond. In periods of peak demand, thepower stationisoperatedinthegeneratingmode i.e. water fromtheupper pond is drawn through the same water conduit system to the turbine for generating power.

Therearetwomaintypesofpumpedstorageplants:

Pumped-storage plants and

Mixedpumped-storageplants.

Pump-storage plants: In this type only pumped storage operation is envisaged without any scopefor conventional generation ofpower. Theseareprovided in places where the run-offis poor. Further, they are designed only for operation on a day-to-day basis without room for flexibility in operation.

Mixedpumped-storageplants: Inthistype,inadditiontothepumpedstorageoperation,someamountof extra energy can be generatedby utilizingthe additional natural run-off duringa year. These can be designed for operation on a weekly cycle or other form of a longer period byproviding for additional storage and afford some amount of flexibility in operation.

CLASSIFICATIONOFHYDROPOWERPLANTS

Assuchtherearenohardandfastrulestoclassify Hydropowerplants.Someofthebasisisas follows:

BasedonHydraulicCharacteristics

Based on Head

BasedonCapacity

BasedonTurbineCharacteristics

Based on Load Characteristics

BasedonInterconnection

HydropowerProjectbasedonHydraulicCharacteristics:

Runoffriverplant(Diversionplant)

Storageplant(Impoundmentplant) Pumped storage plant

Tidalplant

RunoffRiverPlant(DiversionPlant)

Insomeareasoftheworld,theflowrateand elevationdropsofthewaterare consistent enough that hydro electric plants can be built directlyin the river.

The water is utilized as it comes in the river.

Practically,waterisnotstoredduringfloodperiodsaswellasduringlowelectricity demand periods, hence water is wasted.

Runoffriverplantmaybewithoutpondageorwithpondage.

Theplantswithpondageareprovidedwithabarragetostorethewater,totakecareofdaily variation.

Duringgoodflowconditions–cansupplybaseloadandduringlowflowconditions-cansupply peak load

Seasonalchangesinriverflowandweatherconditionsaffecttheplant'soutput;henceitis in limited use unless interconnected with grid.

flowsthatoccurinthestreamattheintakeandflowsdownstreamofthepowerhousearevirtually identical to pre-development flows.

Run-of-riverfacilitiesuselowdamstoprovidelimitedstorageofwater–atmostdaily pondage.

Inarun-offriverSHPscheme,throughdiversionstructurewaterisdivertedtowater conductor system to the powerhouse.

Waterimpoundedindamforstorageandreleasedinphasedmannertogeneratepowerandfurtherusedfor irrigation is shown in (figure 1.5.1).

SiteSelectionforHydropowerPlants

- **AvailabilityofWater:**Run-offdataformanyyearsavailable
- **WaterStorage:**forwateravailabilitythroughouttheyear
- **HeadofWater:**mosteconomichead,possibilityofconstructingadamtogetrequiredhead
- **GeologicalInvestigations:**strongfoundation,earthquakefrequencyisless
- **WaterPollution:**excessivecorrosionanddamagetometallicstructures
- **Sedimentation:**capacityreducesduetogradualdepositionofsilt
- **SocialandEnvironmentalEffects:**submergenceofareas,effectonbiodiversity(e.g. western ghat), cultural and historic aspects
- **AccesstoSite:**fortransportationofconstructionmaterialandheavymachinerynewrailway lines or roads may be needed
- **Multipurpose:**powergeneration,irrigation,floodcontrol,navigation,recreation;because initial cost of power plant is high because of civil engineering construction work

ClassificationofHydropowerPlants

Accordingtowaterflowregulation:

1. Runoffriverplantswithoutpondage
2. Runoffriverplantswithpondage
3. Hydroelectricplants withstoragereservoir

According to Load:

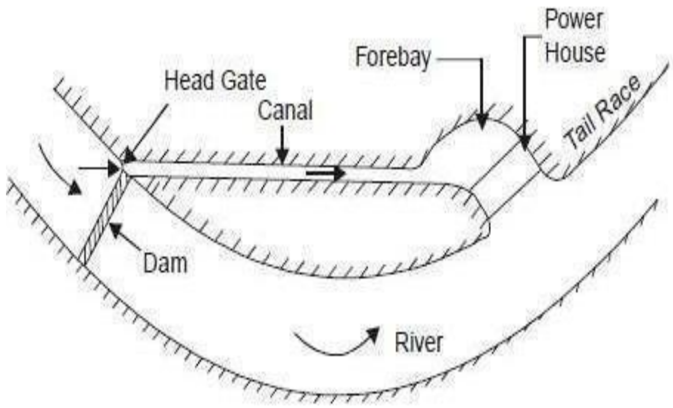
1. Baseloadplants
2. Peakloadplants
3. Pumpedstorageplants

According to head:

1. Highheadplants(>100m)
2. Mediumheadplants(30-100m)
3. Lowheadplants(<30m)

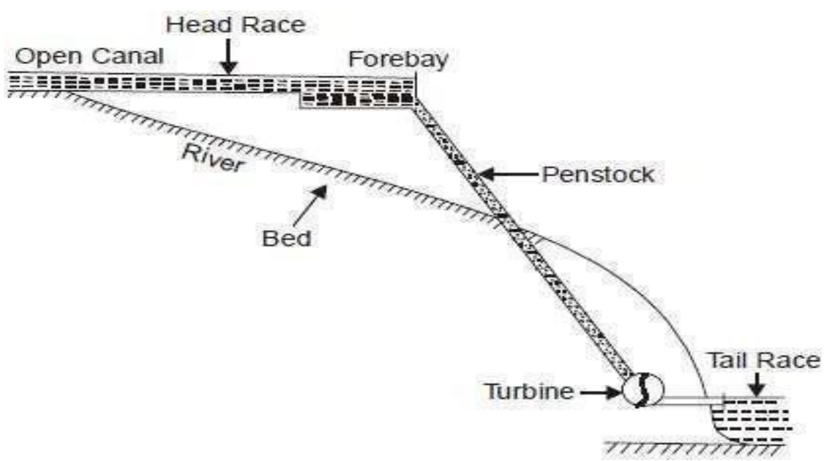
Lowheadplant

- Operatingheadislessthan15m.
- VerticalshaftFrancisturbineorKaplanturbine.
- Smalldamisrequired.



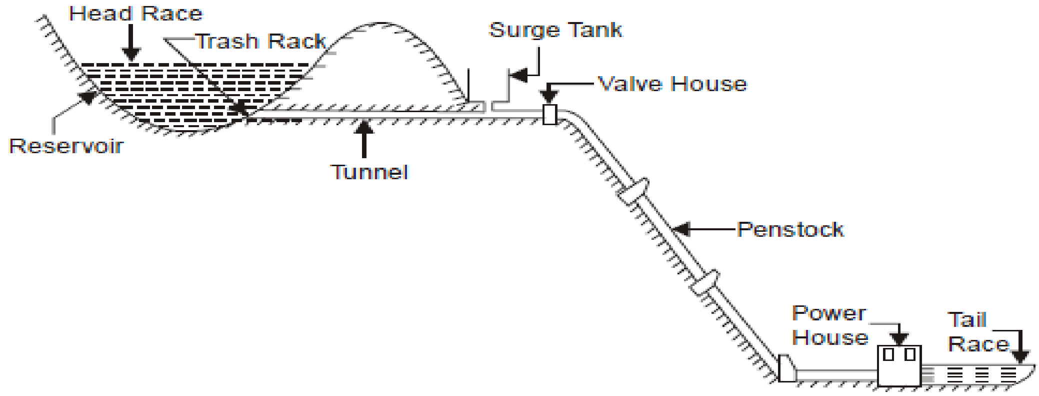
Mediumheadplant

- Operatingheadislessthan15to50m.
- Francisturbines.
- Forebayisprovidedatthebeginningofthepenstock.



Highheadplant

- Operatingheadexceed50m.
- Peltonturbines.
- Surgetankisattachedtothepenstocktoreducewaterhammereffectonthepenstock.



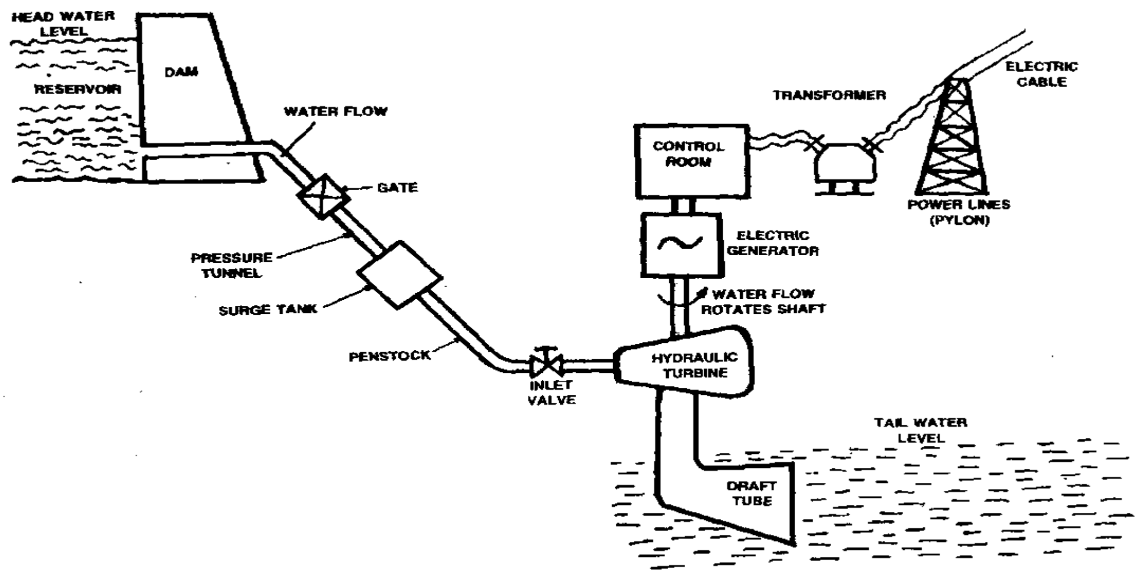


FIG. 3.6: LAYOUT OF HYDRO-ELECTRIC POWER PLANT

Componentsofa HPP

SchematicofaHydropowerPlant

ThevariouscomponentsofHPP areasfollows:

1. Catchmentarea
2. Reservoir
3. Dam
4. Spillways
5. Conduits
6. Surgetanks

7. Drafttubes
8. Powerhouse
9. Switchyardforpowerevacuation

Dam

- Developsareservoirtostorewater
- Buildsupheadforpowergeneration

Spillway

- Tosafeguardthedamwhenwaterlevelinthereservoirrises

Intake

- Containstrashrackstofilteroutdebriswhichmaydamagetheturbine

Forebay

- Enlargedbodyofwaterjustabovetheintake

ForebayConduits

- Headraceisachannelwhichleadthewatertotheturbine
- Tailraceisachannelwhichcarrieswaterfromtheturbine
- Acanalisanopenwaterwayexcavatedinnaturalgroundfollowingitscontour.
- Aflumeisanopenchannelerectedonasurfaceaboveground.
- Atunnelisaclosedchannelexcavatedthroughanobstruction.
- Apipelineisaclosedconduitsupportedontheground.
- **Penstocks**areclosedconduitsforsupplyingwater“underpressure”fromheadpondtothe turbines.

SurgeTank

- Asurgetankisasmallreservoirinwhichthewaterlevelrisesorfallstoreducethepressureswings so that they are not transmitted to the penstock.
- WaterHammer
    - Loadontheturbineissuddenlyreduced
    - Governorclosesturbinegates
    - Suddenincreaseofpressureinthepenstock
- NegativePressure
    - Loadonthegeneratorissuddenlyincreased
    - Governoropenstheturbinegates
    - Tendstocauseavacuuminthepenstock
- Whenthegatesareclosed,waterlevelrisesinthesurgetankandwhenthegatesaresuddenlyopened, surge tank provides the initial water supply.

SurgeTankDraftTubes

Thefunctionofthedrafttubeisto

- Toreducethevelocityheadlossesofthewater
- Toallowtheturbinetobesetabovethetailracetofacilitateinspectionandmaintenance

Tailrace:

- Atailraceisrequiredtodischargethewaterleavingtheturbineintotheriver.
- Thedesignofthetailraceshouldbesuchthatwaterhasafreeexit.

PowerHouse

1. Hydraulicturbines
2. Electricgenerators
3. Governors
4. Gatevalves
5. Reliefvalves
6. Watercirculationpumps
7. Airducts
8. Switchboardandinstruments
9. Storagebatteries
10. Cranes

Switchyard

1. Stepuptransformers
2. Instrumenttransformers
3. Transmissionlines

Advantagesofhydropowerplant:

- Waterisarenewableenergysource.
- Maintenanceandoperationchargesareverylow.
- Theefficiencyoftheplantdoesnotchangewithage.
- Inadditiontopowergeneration,hydro-electricpowerplantsarealsousefulforflood control, irrigation purposes, fishery and recreation.
- Havealongerlife(100to125years)astheyoperateatatmospherictemperature.
- Waterstoredinthehydro-electricpowerplantscanalsobeusedfordomesticwatersupply.
- Since hydro-electricpowerplantsrunatlowspeeds(300to400rpm)thereisno requirementofspecialalloysteelconstructionmaterialsorspecialisedmechanical maintenance.

Disadvantagesofhydropowerplant:

- o Theinitialcostoftheplantisveryhigh.
- o Sincetheyarelocatedfarawayfromtheloadcentre,costoftransmissionlinesand transmission losses will be more.
- o Duringdroughtseasonthepowerproductionmaybereducedorevenstoppeddueto insufficient water in the reservoir.
- o Waterinthereservoirislostbyevaporation.

PUMPSTORAGESCHEME

Principle

The basic principle ofpumped storage is to convert the surplus electrical energyavailable in a system in off-peak periods, to hydraulic potential energy, in order to generate power in periods whenthe peak demand onthe systemexceeds the totalavailable capacityofthegenerating stations.

By using the surplus scheme electrical energy available in the network during low-demand periods,waterispumped fromalowerpondtoanupperpond.Inperiodsofpeakdemand,thepower station is operated in the generating mode i.e. water from the upper pond is drawn through the same water conduit system to the turbine for generating power.

Therearetwomaintypesofpumpedstorageplants:

Pumped-storage plants and

Mixedpumped-storageplants.

Pump-storage plants: In this type only pumped storage operation is envisaged without any scope forconventionalgenerationofpower.Thesearprovidedinplaceswheretherun-offispoor.Further,theyare designed only for operation on a day-to-day basis without room for flexibilityin operation.

Mixed pumped-storage plants: In this type, in addition to the pumped storage operation, some amount of extra energy can be generated by utilizing the additional natural run-off during a year. Thesecanbedesigned foroperationonaweeklycycleorotherformofa longerperiodbyproviding for additional storage and afford some amount of flexibility in operation.

PumpedStoragePlant

Waterisutilizedforgenerationofpowerduringpeakdemand,whilesamewaterispumpedbackin the reservoir during offpeak demand period, when excess power is available for this purpose.

Ifturbineisreversible,itcanbeusedasapumptosupplywaterbacktoreservoir,otherwiseseparatepump can be used.

Basedonoperatingcycleitcanbeclassifiedas:

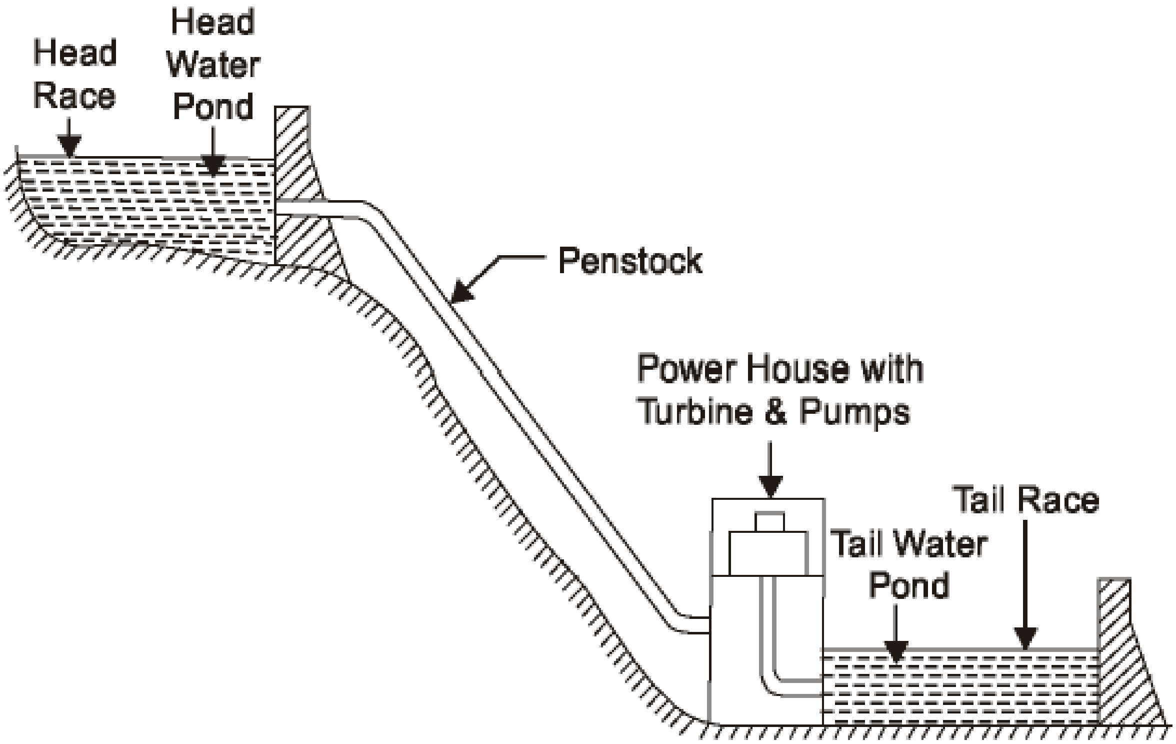
Plantwithadailycycle:waterispumpedupfrommidnighttoearlymorningaswellasnearlunchtime.

Plantwithaweeklycycle:waterispumpedupduringweekend.

Plantwithaseasonalcycle:waterispumpedupinthewintercontinuouslyforseveraldaystobe utilized for a continuous power generation in the high demand summer period.

PUMPEDSTORAGEPOWERPLANTS

These plants supply the peak load for the base load power plants and pump all or a portion of their ownwatersupply.Theusualconstructionwouldbeatailwaterpondandaheadwaterpondconnectedthrough a penstock. The generating pumping plant is at the lower end. During off peak hours, some of the surplus electric energy being generated bythe base load plant is utilized topump the water fromtail water pond into the head water pond and this energy will be stored there. During times of peakload,thisenergywillbereleasedbyallowingthewatertoflowfromtheheadwaterpondthrough the water turbine of the pumped storage plant. These plants can be used with hydro, steam and i.e. engine plants. This plant is nothing but a hydraulic accumulator system and is shown. These plants can have either vertical shaft arrangement or horizontal shaft arrangement. Inthe older plants, there were separate motor driven pumps and turbine driven generators. Theimprovement was the pump and turbine on the same shaft with the electrical element acting aseither generator or motor. The latest designisto useaFrancisturbinewhichis justthereverseofcentrifugalpump. Whenthewater flows through it from the head water pond it will act as a turbine and rotate the generator. When rotatedinthereversedirectionbymeansofanelectric motor,it will act asapumpto shunt thewater from the tail water pond to the head water pond



PumpedStoragePlant

PowerEstimation

Thepotentialelectricpowerofthewaterintermsofflowandheadcanbecalculatedfromthefollowing equation.

$$KW=9.81 x Q x H x \eta$$

Where,

kW=electricpowerinkW

Q = quantity of water flowing through the hydraulic turbine in cubic meters per second. Discharge (quantity of water) flowing in a stream and available for power generationhasdailyandseasonalvariation.Optimumdischargeforpowergeneration is determined on the basis of energy generationcost.

H=Netavailableheadinmeters(grosshead–losses)

=overallefficiencyofthehydropowerplant.Forgeneralestimationpurposes,ηisnormally taken as 0.85

Hydrology

- Firstrequirement–Q(discharge)
- Hydrologydealswithoccurrenceanddistributionofwateroverandunderearth'ssurface.
  - SurfaceWaterHydrology
  - GroundWaterHydrology
- **Watershed,catchmentareaordrainagearea:**lengthoftheriver,sizeandshapeoftheareait affects, tributaries, lakes, reservoirsetc.
- Investigationof**run-off**forpastfewyearsisrequiredforpowerpotentialstudiesofaHPP.

ObjectivesofHydrology

- Toobtaindataregardingthestreamflowofwaterthatwouldbeavailable,
- Topredicttheyearlypossibleflow
- Tocalculatethemeanannualrainfallintheareaunderconsiderationfromarecordoftheannual rainfall for a number of years, say25 to30
- Tonotethefrequencyofdryyears
- Tofindmaximumrainfallandfloodfrequency

VarioustermsrelatedtoHydrology

- Rainfallisalsoknownasprecipitationandcanbemeasuredbyraingauges.
- Somepartofprecipitationislostduetoevaporation,interceptionandtranspiration.
- **Transpiration:**Plantsabsorbingmoistureandgivingitofftotheatmosphere
- Streamflow=precipitation–losses
- Streamflow=surfaceflow+percolationtoground
- Surfaceflowisalsoknownas**run-off.**
- **Hydrograph:**
  - Showsthevariationofstreamflowinm^3/swithtimeforaparticularriversite.The time may be hour, week, month or a year.
  - Theareaunderhydrographgivesthetotalvolumeofflow

- **Flowdurationcurve:**
  - Showsthepercentageoftimeduringtheperiodwhentheflowwasequaltogreaterthan the given flow.
  - TheareaunderFDCgivesthetotalquantityofrun-offduringaperiod

- **Masscurve**
  - Indicatesthetotalvolumeofrun-offincubicmetersuptoacertaintime.
  - theslopeofthecurveatanypointshowstherateofflowatthattime
  - Usedforestimatingthecapacityofstoragereservoir
- **Storage:**
  - toensurewateravailabilityduringdeficientflowandthusincreasingthefirmcapacity

  - Storagealsoresultsinmoreenergyproduction
- **Pondage:**
  - Storingwaterinsmallpondsnearthepowerplantasthestoragereservoir isaway fromplant
  - Tomeetthepowerdemandfluctuationsoverashortperiodoftimee.g.24hours

- **PrimaryPower:**powerthatwillbeavailable90%ofthetime
- **SecondaryPower:**powerthatwillbeavailable75%ofthetime
- **DumpPower:**powerthatwillbeavailable50%ofthetime.
- **Maximumflowestimation:**givesestimationoffloodsandhelpsindesignofdamand spillway.

HYDROGRAPH&FLOWDURATIONCURVE:-

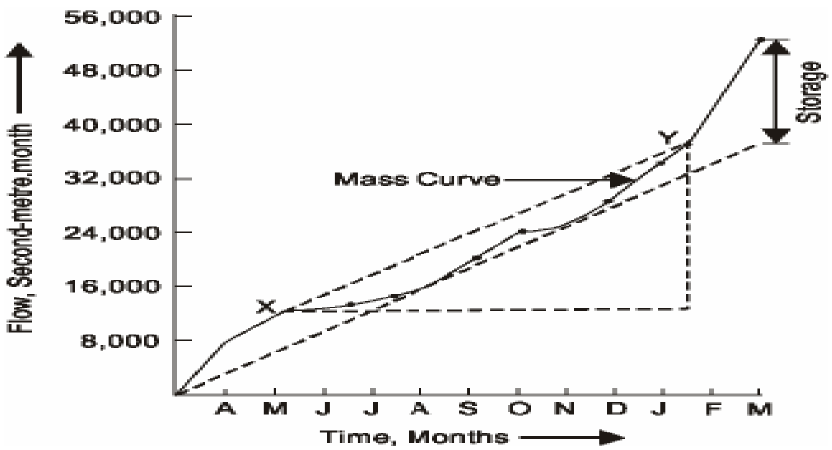
- A hydrograph indicates the variation of discharge or flow with time. It is plotted with flows as ordinates and time intervals as abscissas. The flow is in m^3/sec and the time may be in hours, days, weeks or months.

- A flow duration curve shows the relation between flows and lengths of time during whichtheyare available. The flows are plotted as the ordinates and lengths oftime as abscissas. The flow duration curve canbe plotted from ahydrograph.

THEMASSCURVE:-

The use of the mass curve is to compute the capacity of the reservoir for a hydro site. The mass curve indicates the total volume of run-off in second meter-months or other convenient units, duringagivenperiod.Themasscurveisobtainedbyplottingcumulativevolumeofflowasordinateandtime (days, weeks bymonths)asabscissa. Fig. 11.2showsa masscurve foratypicalriver forwhichflow data is given in Table 11.2. The monthly flow is only the mean flow and is correct only at the beginning and end of the months. The variation of flow during each month is not considered. Cumulative daily flows, instead of monthly flows, will give a more accurate mass curve, but this involves an excessive amount of work. The slope of the curve at any point gives the flow rate in second- meter. Let us join two points X and Y on the curve. The slope ofthis line gives the average rate of flow during the period between X and Y. This will be = (Flow at Y-Flow at X)/Time Span Lettheflowdemandbe,3000sec-meter.ThenthelineX-Ymaybecalledas `demand line'or „Useline‟. If duringa particular period, the slope of the mass Curveis greater than thatofthedemandline, itmeansmorewaterisflowingintothereservoirthanisbeingutilized,so the level of water in the reservoirwill beincreasing duringthat period and viceversa. Upto point X and beyond point Y the reservoir will be overflowing. Being full at both X andY.

The capacityof the reservoir is given bythe maximum ordinate between the mass curve and the demand line. Forthe portion ofmass curve between point X and Y, the storage capacityis about 4600 sec-meter-month. However, considering the entire mass curve, storage capacity will be about 15,400sec-meter-months.



UNITII

ECONOMICSOFPOWERGENERATION

ECONOMICASPECTSOFPOWERGENERATION

TOPICS

Loadcurve,loaddurationcurve,integratedloaddurationcurve,masscurve,numberandsize of generatorunits,demandfactor,Diversityfactor,Plantcapacityfactor,utilizationfactor,cost of Generation and their division in to fixed, semi fixed and running cost.
TariffMethods:objectivesofTariff,Tariffmethods.

ECONOMICASPECTSOFPOWERGENERATION

The capacity of power station mainly depends on **load demand**. The load on the power station**is notconstant**,butvaryingtimeto time.Before fixingthesizeand numberofunits generatedinapowerstation,itisnecessarytostudythetechnicalandeconomicfeasibilityof the power station.

- **Natureofload.**
- **Futureloadconditions.**
- **Locationofload.**
- **Reliabilityofsupply.**
- **Reservecapacity.**
- **Minimumcapitalandoperating(Running)cost.**

TYPESOFLOADS

ADevicewhichtapsElectricalEnergyfromtheElectricalPowerSystemiscalledaLoadon the system.

The loadcanberesistive (eg.Electric lamp),Inductive(e.gInduction motor),Capacitive orsome combination of them.

- **Domesticload**
- **Commercialload**
- **Industrialload**
- **Municipalload**
- **Irrigationload**
- **Tractionload**

LOADCURVE

Thecurveshowingthevariations ofLoadonthePowerstationwithrespecttotimeis known as a "load curve".

- Theloadonthepowerstationisnotconstant,butvaryingtimetotime.Thecurveobtained by plotting Time in hours (day, monthor year) onX-axis and Load (kW or MW) onY- axis is known as load curve.
- Ifthedailyvariationsinloadonthepowerstationisdrawn,suchacurveisknownasdaily load curve.
- Fromthedailyload curvesof aparticularmonth,themonthlyload curvecanbe obtained by calculating the average values of power at a particular hour on each day.
- The yearly/annual load curve can be obtained by considering all monthly load curves of a particular year.

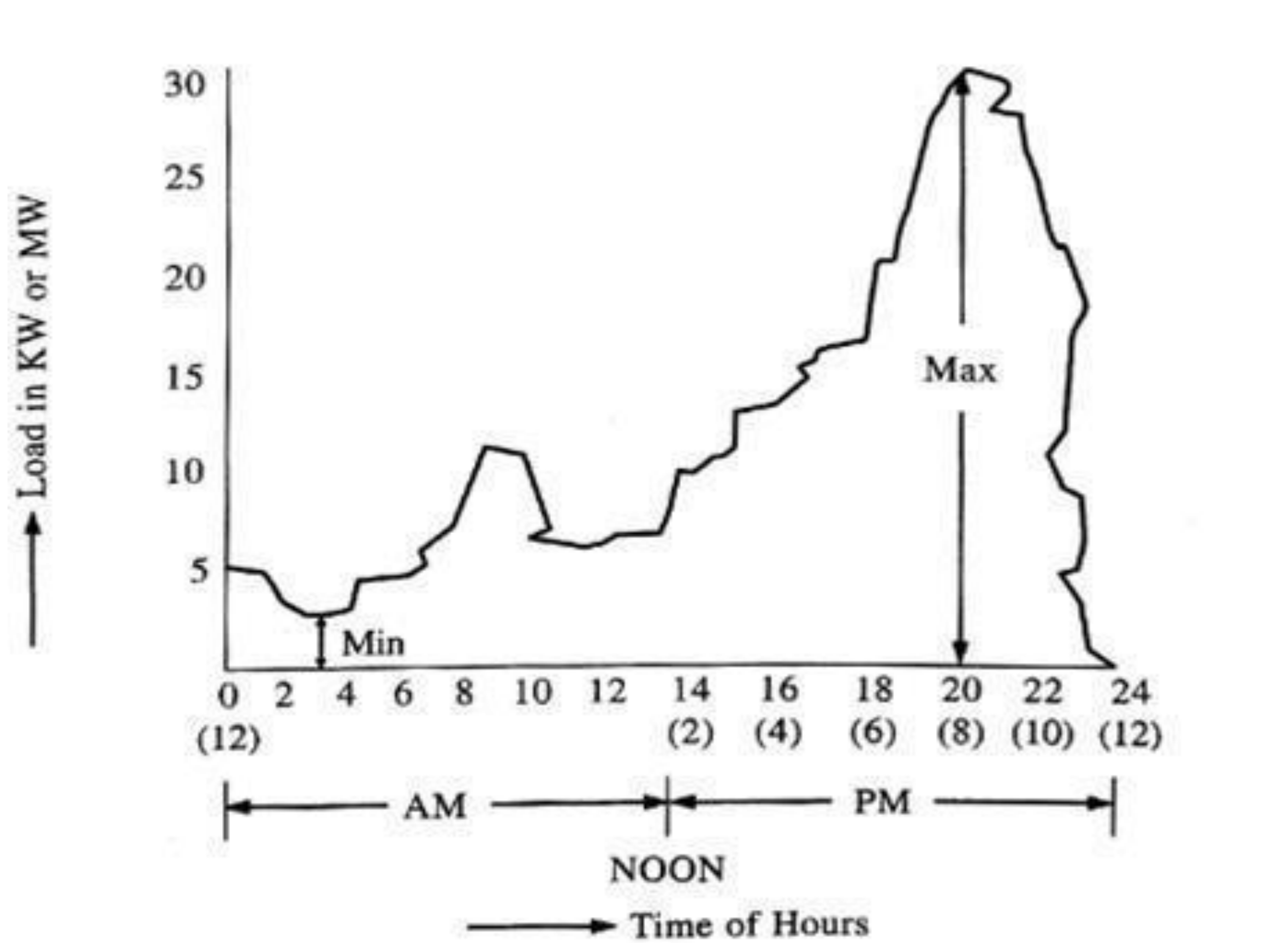
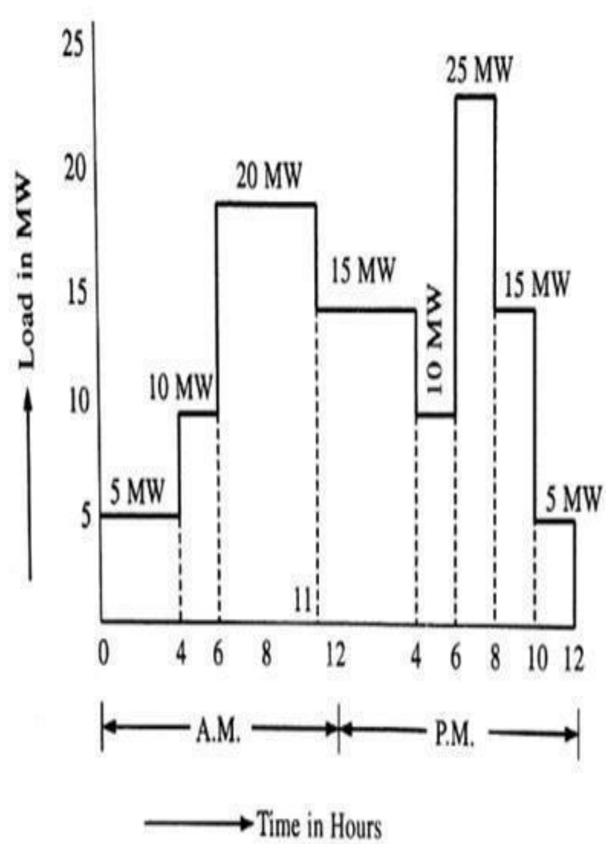


Figure 6.2 Daily Load Curve

Fromtheloadcurvewecanknowthefollowing information.



- Thevariationinloadduringdifferent hours of a day.
- Theareaunderloadcurverepresentsthe totalnumberofunitsgenerated(inkWh)in a day.
- Themaximum andminimum load in a day.
- The area under load curve (in kWh) divided by number of hours (24 hours) gives the average load on the power station.

Average load= Area under daily load curve(Kwh) / 24 hours

- Theareaunderloadcurvedividedby areaofrectangleinwhichitiscontained gives load factor.
- TheLoadcurvehelpsinselectingthe size and number of generatingunits.
- Theloadcurvehelpsinpreparingtheoperationscheduleofthestation.

LOADDURATIONCURVE

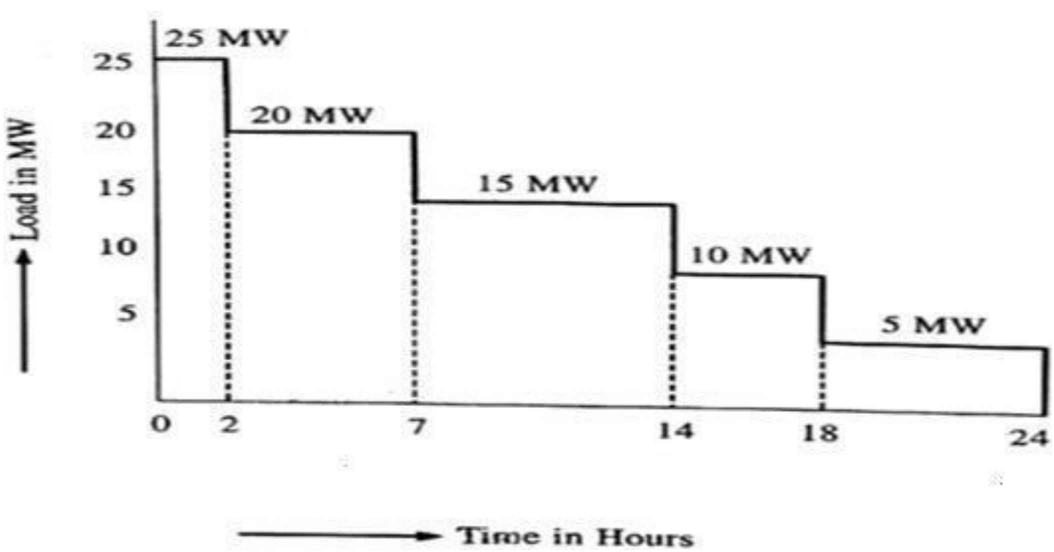
WhentheLoadelementsofaloadcurvearearrangedintheorderofdescending magnitudes, the curve thus obtained is called a “Load Duration curve”.

- **The** LoadDurationCurveisobtainedfromthesamedataasthe LoadCurvebutthe ordinates are arranged in the order of descending magnitudes.

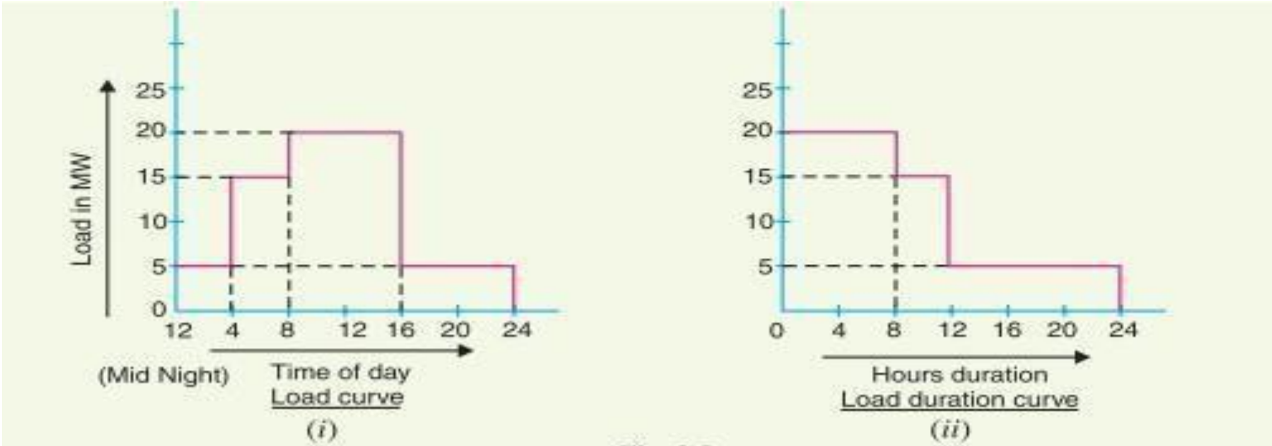
- Inotherwords,themaximumLoadisrepresentedtotheleftanddecreasingloadsare represented to the right in the descending order.

- LoadDurationCurve givesthenumberofhoursforwhichaparticularloadisonthe Power station.

- TheareaundertheLoaddurationcurveisequaltothatofthecorrespondingloadcurve.The area under this curve gives the number of units generated.



LOADANDLOADDURATIONCURVE



INTEGRATEDLOADDURATIONCURVE(ENERGYLOADDURATIONCURVE)

Thiscurvegivesthetotalnumberofunitsgenerated(KWh)forthegivendemand.

Integrated load duration curve is drawn between the MW demand and the total energy generated (KWh or MWh) at a given demand.

In Integrated load duration curve on Y-axis, load demand in kW or MW is plotted while on x-axis correspondingnumberofunits generated are obtained.Such acurvecorresponding to load duration curve shown in Fig.

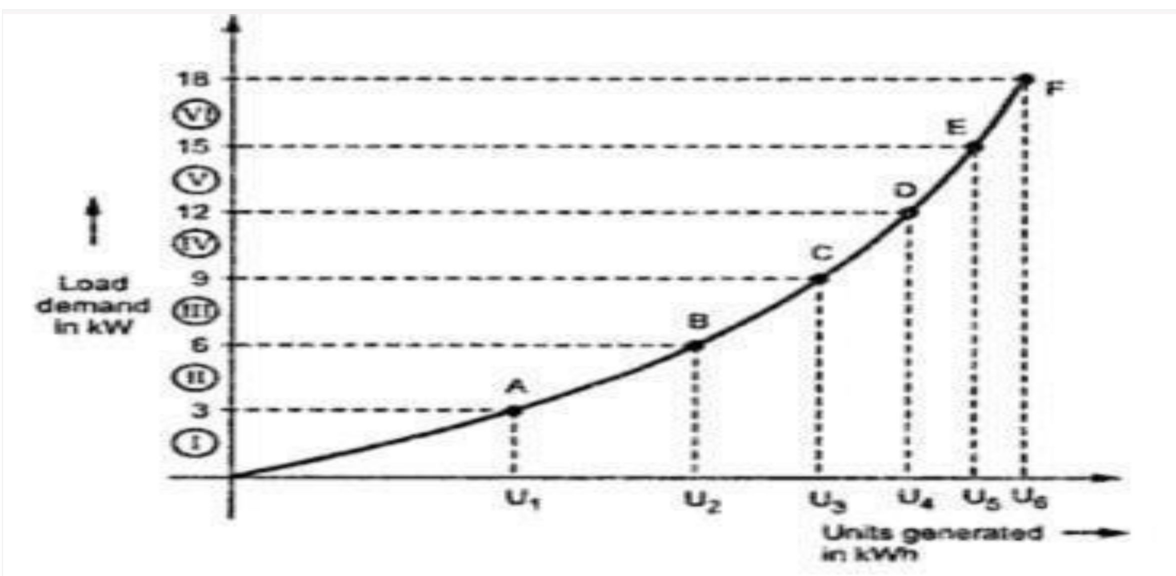


Fig.1IntegratedLoadDurationCurve

Thiscurveisobtainedfromloaddurationcurve.Lettheloaddemandbe3kWfromthe loaddurationcurveinsectionI.Thenumberofunitsgeneratedcorrespondingtothisdemand willbeareaundersectionIwhichisshownasU_1inintegratedloaddurationcurve.Similarlythe other points are also obtained to get a total curve.

Thenumberofunitsconsumedbyaloaduptoaparticulartimeofadaycanalsobeshownonacurve which is called as mass curve.

IMPORTANTTERMSANDFACTORS

CONNECTEDLOAD:Itisthesumofcontinuousratingsofalltheequipmentsconnectedto supply system.

Itisdefinedasthesumofthecontinuousratingsofallload-consumingapparatusconnectedto the system.

Ifaconsumerhas5incandescentlamps of60watteachand2fansof80watteach,thenthe total connected load

= 5 X60+2X80

=460watt

MAXIMUMDEMAND(FORPEAKLOAD)

TheMaximumofalldemands(loads)onapowerstationduringagivenperiodisknown as Maximum Demand.

Generallyalltheconsumersneverswitchedonallthedevicesatfullloadsimultaneously.Ifall consumers switched on simultaneously, then the load is equal to **connected load.**

Hence,MaximumDemandisalways**lessthanorequaltoconnectedload**.Maximumdemandhelpsin determining the **size and cost of the installation**.

DEMANDFACTOR.

Demandfactorisdefinedastheratioof Maximumdemandonthepowerstationtothe connected load.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

Thevalueofdemandfactorisusually**lessthan1**.Itisexpectedbecausemaximumdemandon the power station is generally less than the connected load.

Demandfactorisusedtodeterminethe**capacityoftheplantequipment**.

AVERAGELOAD.

Theaverageofloadsoccurringonthepowerstationinagivenperiod(dayormonthor

year)isknownas**averageload*****or*****averagedemand.**

$$\text{Daily average load} = \frac{\text{No. of units (kWh) generated in a day}}{\text{24 hours}}$$

$$\text{Monthly average load} = \frac{\text{No. of units (kWh) generated in a month}}{\text{No. of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{\text{365 X 24 hours}}$$

LOADFACTOR.

The ratio of average load to the maximum demand during a given period is known as load factor.

$$\text{Load Factor} = \frac{\text{Average Load}}{\text{Max. Demand}}$$

IftheplantisinoperationforThours,

$$\text{Load Factor} = \frac{\text{Average Load X T}}{\text{Max. Demand X T}}$$

$$\text{Load Factor} = \frac{\text{No. of units generated in T hours}}{\text{Max. Demand X T hours}}$$

Theloadfactormaybedailyloadfactor,monthlyloadfactororannualloadfactorifthetime period considered is a day or month or year.

Load factor is always less than 1 because average load is smaller than the maximum demand. The load factorplays keyrole in determining **theoverall cost per unit generated**. **Higher the load factor of the power station, lesser will be the cost per unit generated.**

DIVERSITYFACTOR.

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. Demand on Power station}}$$

Thesumofindividualmaximumdemands isalwaysgreaterthanthe maximumdemandof the power station.

Hence,**thediversityfactorisalwaysgreaterthanunity(>1).**Thediversityfactorreducesthe capital cost of the station and rate of generation of electricity.

PLANTCAPACITYFACTOR.

Itistheratioofactualenergyproducedtothemaximumpossibleenergythatcouldhave been produced during a given period i.e.,

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced(KWh)}}{\text{Max. energy that could have been produced}}$$

$$\text{Plant capacity factor} = \frac{\text{Average load X T}}{\text{Plant capacity X T}}$$

$$\text{Plant capacity factor} = \frac{\text{Average load}}{\text{Plant capacity}}$$

Thusiftheconsideredperiodisoneyear,

$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity X 8760}}$$

Theplantcapacityfactorisanindicationofthereservecapacityoftheplant. Apowerstation is so designed that it has some reserve capacity for meeting the increased load demand in future. Therefore, the installed capacity ofthe plant is always somewhat greater than the maximum demand on the plant.

Reservecapacity=Plantcapacity-Max.demand

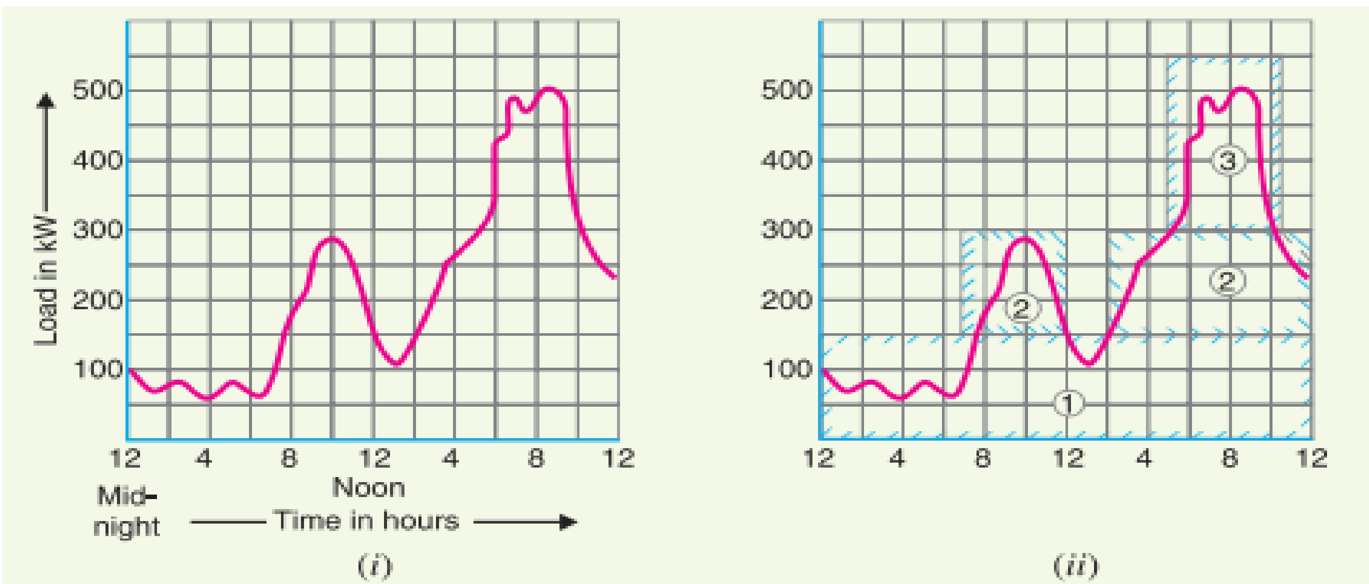
PLANTUSEFACTOR.

It isratioof kWhgenerated tothe product of plant capacity and the number of hours for which the plant was in operation *i.e.*

$$\text{Plant use factor} = \frac{\text{power Station output in kWh}}{\text{Plant capacity X Hours of use}}$$

Suppose a plant having installed capacity of 20 MW produces annual output of $7{\cdot}35 \times 10^6$ kWh and remains in operation for 2190 hours in a year. Then, Plant use factor =0·167 = 16·7%.

SELECTION OF GENERATING UNITS (NUMBER AND SIZEOFGENERATING UNITS)



1. Theloadonapowerstationisseldomconstant;itvariesfromtimetotime.Obviously, asinglegeneratingunit(*i.e.*,alternator)willnotbeaneconomicalpropositiontomeet this varying load.

2. It is because a single unit will have very poor efficiency during the periods of light loads on the power station. Therefore, in actualpractice, a number of generating units of different sizes are installed in a power station.

3. Theselectionofthenumberandsizesoftheunitsisdecidedfromtheannualloadcurve of the station. *The number and size of the units are selected in such a way that theycorrectly fit the station load curve.*

Once this underlying principle is adhered to, it becomes possible to operate the generating units at or near the point of maximum efficiency.

Illustration. Theprincipleofselectionofnumberandsizesofgeneratingunitswiththehelp of load curve is illustrated in Fig. The annual load curve of the station is shown in fig.It is clearfrom the curve that load on the station has wide variations; the minimum load being somewhatnear**50kW**andmaximumloadreachingthevalueof**500kW**.Ithardlyneedsany mention that use of a single unit to meet this varying load willbe highly uneconomical.

As discussed earlier, the total plant capacity is divided into several generating units of differentsizestofittheloadcurve.ThisisillustratedinFig.Heretheplantcapacityisdivided into three units numbered as 1, 2 and 3. The cyan colour outline shows the units capacity being used.Thethreeunits employed havedifferent capacities and areused accordingtothe demand on the station. In this case, the operating schedule can be as under:

Time	Unitsinoperation
From12midnightto7A.M.	Onlyunitno.1isputinoperation.
From7A.M.to12.00noon	Unitno.2isalsostartedsothatbothunits1 and 2 are in operation.
From12.00noonto2P.M.	Unitno.2isstoppedandonlyunit1operates.
From2P.M.to5P.M.	Unitno.2isagainstarted.Nowunits1and2 are in operation.
From5P.M.to10.30P.M.	Units1,2and3areputinoperation.
From10.30P.M.to12.00 midnight	Units1and2areputinoperation.

Thus by selecting the proper number and sizes of units, the generating units can be made to operate near maximum efficiency. This results in the overall reduction in the cost of production of electrical energy.

ImportantPointsintheSelectionofUnits

Whilemakingtheselectionofnumberandsizesofthegeneratingunits,thefollowingpoints should be kept in view:

(i) The number and sizes of the units should be so selected that they approximately**fit theannual load curve of the station.**

(ii) Theunitsshouldbe*preferably*of**differentcapacities**tomeettheloadrequirements. Althoughuseofidenticalunits(*i.e.*,havingsamecapacity)ensuressavingincost,theyoftendonot meet the load requirement.

(iii) Thecapacityoftheplantshouldbemade**15%to20%**morethanthe**maximumdemand** tomeetthefutureloadrequirements.

(iv) Thereshouldbea**sparegeneratingunit**sothatrepairsandoverhaulingoftheworkingunits can be carried out.

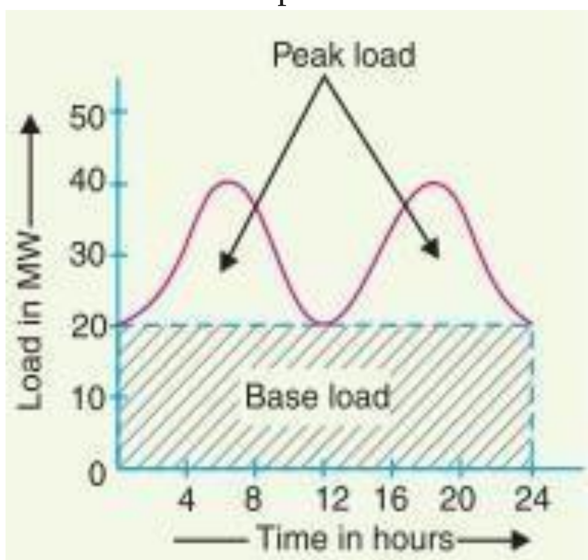
(v) The tendency to select a **large number of units of smaller capacity** in order to fit the load curve very accurately should be **avoided.** It is because the investment cost per kW of capacity increases as the size of the units decreases.

BASELOADANDPEAKLOADONPOWERSTATION

The changing load on the power station makes its load curve of variable nature. Fig shows thetypicalloadcurveofapowerstation.Itisclearthatloadonthepowerstationvaries from time to time. However, a close look at the load curve reveals that load on the power station can be considered in two parts, namely;

(i) Baseload

(ii) Peakload



(i) Baseload.

***Theunvaryingloadwhichoccursalmostthewholeday on the station is known as* base load.** Referring to the load curve ofFig it is clear that **20 MW** of load has to be supplied by the station at all timesofdayandnight*i.e.*throughout24hours. Therefore,20MWisthebaseloadofthestation.As baseloadonthestationisalmostofconstantnature, therefore,itcanbesuitablysuppliedwithoutfacingthe problems of variable load.

(ii) Peakload.*Thevariouspeakdemandsofloadoverandabovethebaseloadofthestati onisknownas* peakload.
Referringtotheloadcurveof Figitisclearthattherearepeakdemandsofloadexcluding baseload.Thesepeakdemandsofthestationgenerallyformasmallpartofthetotal loadand may occur throughout the day.

MethodofMeetingtheLoad

Thetotalload on apowerstation consistsof twoparts *viz*.,baseloadandpeak load.In order to achieve overall economy, *the best method to meet load is to* ***interconnect two different power stations*.**

The **more efficient plant** is used to supply the base load and is known *as* ***base load power station***. The **less efficient plant** is used to supply the peak loads and is known as ***peak load power station***.

There is no hard and fast rule for selection of base load and peak load stations as it would depend upon the particular situation. For example, both hydro-electric and steam power stationsarequiteefficientandcanbeusedasbaseloadaswellaspeakloadstationto meetaparticular load requirement.

Illustration. Theinterconnectionofsteamand hydroplantsisabeautifulillustrationto meet the load. When water is available in sufficient quantity as in summer and rainy season, the **hydroelectric plant** is used to carry the **base load** and the **steam plant** supplies the **peak load.**

However,whenthewaterisnotavailable insufficientquantityasinwinter, **thesteamplant** carries the **base load**, whereas **the hydro-electric plant carries the peakload** as shown in fig.

ECONOMICSOFPOWERGENERATION

***Theartofdeterminingtheperunit(i.e.,onekWh)costofproductionofelectricalenergy is known as* economics of power generation.**

(i) Interest.

***Thecostofuseofmoneyisknownas*interest.**

Apowerstationisconstructedbyinvestingahugecapital.Thismoneyisgenerallyborrowed from banks or other financial institutions and the supply company has to pay the annual intereston this amount.

Therefore, while calculating the cost of production of electrical energy, the interest payable onthecapitalinvestmentmustbeincluded.Therateofinterestdependsuponmarketposition and other factors, and may vary **from 4% to 8%** per annum.

(ii) Depreciation.

***The decrease in the value of the power plant equipment and building due to constant use is known as* depreciation.**

If the power station equipment were to last forever, then interest on the capital investment wouldhavebeentheonlychargetobemade.However,inactualpractice,everypowerstation has a useful life ranging from **fifty to sixty years**.

Fromthetimethepowerstationisinstalled,itsequipmentsteadilydeteriorates dueto **wear and tear** so that there is a gradual reduction in the value of the plant. This reduction in the valueofplanteveryyearisknownas*annualdepreciation.*Duetodepreciation,theplanthas to be replaced by the new one after its useful life. Therefore, suitable amount must be set aside every year so that by the time the plant retires, the collected amount by way of depreciation equals the cost of replacement.

COSTOFELECTRICALENERGY

Thetotalcostofelectricalenergygeneratedcanbedividedintothreeparts,namely;

(i) Fixedcost;**(*ii*)**Semi-fixedcost;**(*iii*)**Runningoroperatingcost.

(i)* Fixedcost.*Itisthecostwhichisindependentofmaximumdemandandnumberofunits generated.

Thefixedcostisdueto

- **the*annualcostofcentralorganisation,***
- ***interestoncapitalcostofland***
- ***salariesofhighofficials*.**

Theannualexpenditureonthecentralorganisationandsalariesofhighofficials is fixed sinceithastobe metwhethertheplanthashighorlowmaximumdemandoritgenerates less or more units. Further, thecapital investmentonthe land is fixedand hencetheamountof interest is also fixed.

(ii) **Semi-fixedcost.** ***Itisthecostwhichdependsuponmaximumdemandbutis independent of units generated.***

Thesemi-fixedcostisdirectlyproportionaltothemaximumdemandonpowerstationand isonaccountof

- ***annualinterestanddepreciationoncapitalinvestmentofbuildingandequipment,***
- ***taxes,***
- ***salariesofmanagementandclericalstaff*.**

Themaximumdemandonthepowerstationdeterminesits sizeand costof installation.The greaterthemaximumdemandonapowerstation,thegreaterisitssizeandcostofinstallation.Further,thetaxesandclericalstaffdependuponthesizeoftheplantandhenceuponmaximum demand.

(iii) **Runningcost.*Itisthecostwhichdependsonlyuponthenumberofunitsgenerated*.**

Therunningcostisonaccountof

- ***annualcostoffuel,***
- ***lubricatingoil,***
- ***maintenance,repairs*and**
- ***salariesofoperatingstaff*.**

Sincethesechargesdepend upontheenergyoutput,therunningcostisdirectlyproportional tothenumberofunitsgeneratedbythestation.Inotherwords,ifthepowerstationgenerates more units, it will have higher running cost and *vice-versa*.

ExpressionsforCostofElectricalEnergyTheoverallannualcostofelectricalenergygeneratedbyapowerstationcanbeexpressed in two forms *ie*. three part form and two part form.

(i) Threepartform. Inthismethod,theoverallannualcostofelectricalenergygeneratedis divided into three parts *ie*. **fixed cost, semi-fixed cost and running cost**

Totalannualcostofenergy=Fixedcost+ Semi-fixedcost+Runningcost

=Constant+Proportionaltomax.demand+ProportionaltokWh generated.

=Rs(a+bkW+ckWh)

where

a=annualfixedcostindependentofmaximumdemandandenergyoutput.Itisonaccount of the costs mentioned.

b=constantwhichwhenmultipliedbymaximumkWdemandonthestationgivestheannualsemi-fixed cost.
c=aconstantwhichwhenmultipliedbykWhoutputperannumgivestheannual runningcost.

(ii) **Twopartform.**Itissometimesconvenienttogivetheannualcostofenergyintwopartform.In this case, the annual cost of energy is divided into two parts *i.e.* **afixedsumperkWofmaximumdemand*plus*arunningchargeperunitofenergy**.The expression for the annual cost of energy then becomes:

Totalannualcostofenergy=Rs.(*A*kW +*B*kWh)

where*A*=aconstantwhichwhenmultipliedbymaximumkWdemandonthestationgives the annual cost of the first part.
B=aconstantwhichwhenmultipliedbytheannualkWhgeneratedgivestheannualrunning cost.
Itisinterestingtoseeherethattwo-partformisasimplificationofthree-partform.

TARIFF

The rate or charge at which electrical energy is supplied to a consumer is known as "Tariff".

Theelectricsupplierproduces electricalenergyinapowerstationandisdeliveredtovarious consumers. These suppliers invest capital cost on equipment, land, building etc. and they derive income from consumers through electricity bills.

The different methods of charging consumers are known* as *Tariff. Tariff should be such that, it not only recovers the total cost of producing electrical energy, but also earns profit on the capital investment.

OBJECTIVESOFTARIFF

Themain objectiveof Tariffisto recovervariousinvestmentson production of electrical energy. Tariff should fulfill the following items.

- **Recoveryofcostofcapitalinvestmentingeneration,Transmissionanddistributionof equipment.**

- **Recoveryofcostofoperation,supplies,maintenanceandlosses.**
- **Recoveryofcostofmetering,billingcollectionandmiscellaneousservices.**
- **Asatisfactorynetreturnsonthecapitalinvestment**.

FACTORSAFFECTINGTHEDESIGNOFTARIFF(OR)BASICCHARACTERISTICSOFTARIFF

Theelectricenergysupplyisdifferent fromotherformsofbusiness.Hence,the following factors will be taken into account while fixing the Tariff.

- Itis notpossibletostoreelectricityinhugeamounts.Hence,thetariffshouldbesuchthat,it ensures proper returns from each consumer.
- Electricalenergymustbeavailable wheneverneeded.Hence,Tariffshouldearnsufficient money to meet the instant demand.
- Thevariousconsumersareencouragedtomakeeffectiveandefficientuseofelectricity.
- Thesuppliershaveacontroluptotheelectricitymeter.Hence,theuseofelectricitybyconsumer cannot be controlled.
- TheTariffshouldbedesignedinsimplesuchthatanordinaryconsumercaneasilyunderstand it.
- Thetariffshouldbefairinordertosatisfythedifferenttypesofconsumers.
- Itshouldhaveaprovisionofchargingapenaltyforconsumersatlowpowerfactor.
- Thetariffshouldbeuniformoverlargepopulation.
- Itshouldprovideincentiveforusingelectricalenergyduringoff-peakhours.
- Abigconsumershouldbechargedatalowerratethansmallerconsumer,becauseincreaseinuse of electricity decreases the cost of generation per unit.

TYPESOFTARIFFS

Large numberofTariffshavebeenproposedtimetotime,butthe followingaresomeoftheTariffs which are in common use.

1. **simpleTariff(or)UniformTariff**
2. **FlatRateTariff**
3. **BlockRateTariff**
4. **Two-partTariff**
5. **MaximumDemandTariff**
6. **PowerFactorTariff**

1. SimpleTariff(or)UniformTariff **Iftherateorchargeperunitofelectricalenergyconsumedisfixed,suchatariffis known as Simple or Uniform Tariff.**

Thisisthesimplesttypeoftariffinwhichthecostofenergyconsumedischargedonthebasisof **numberofunitsconsumed**.Thecostperunitischargedas follows.

$$\text{Cost per unit} = \frac{\text{Annual fixed charges} + \text{Annual running charges}}{\textit{Total number of units supplied to the consumer annualy}}$$

Advantages:

(a) ItissimplesttypeofTariffandeasytounderstand

(b) Calculationiseasy.

Disadvantages:

(a) Thecostperunitdeliveredwillbehigher.

(b) Nodiscriminationbetweendomestic(small)consumerandbulkconsumers,hence allconsumers have to pay equitably for the fixed charges.

(c) Itdoesnotencouragetheuseofelectricity.

2.FlatRateTariff:

If the different types of consumers are charged at different rates per unit energy consumed, such a tariff is known as Flat rate Tariff.

In this type, the consumers are classified into different classes (such as domestic, industrial, public etc) and each class of consumer is charged at different rates. The different class of consumer is made by taking into account their **load factors and diversity factors**. If the consumer has two types of loads, say

(1) Lightingloads(lightandfanetc)and

(2) Powerloads,

thentwometersaretobeinstalledathispremises,oneforlightingloadandanotherforpower load.TheFlatrateperkWh(unit)forlightingloadmaybeslightlyhigherthanthepower

load.SupposetherateperkWhforlightingloadandpowerloadbe60paiseand55paiseandmeterrent maybeRs.2.50/-per meterpermonth,thenthe monthlybillcalculationwillbeas follows.

Type of Load	No.of units Consumed	Rate/Unit	Cost	MeterRent	TotalBill
Lighting Load	Say50	60paise	50X60=3000paise =Rs30/-	Rs2.50/-	Rs32.50/-
Power	Say80	55paise	80X55=4400paise =Rs44/-	Rs2.50/-	Rs46.50/-
	ThetotalbillofaconsumerpermonthRs79/-				

***Advantages*:**

(a) Tariffisfaireranditcanbeunderstoodbydifferenttypesofconsumers.
(b) Simpleincalculation.

Disadvantages:

(a) Itisdifficulttoclassifytheconsumersbasedon**loadfactoranddiversityfactor.**

(b) Separatemetersarerequiredforlightingandpowerload,willmake thesystem**complex and expensive.**

(c) Doesnotencouragetheuseofelectricity.

3. BlockRateTariff:

Ifoneblockofenergyischargedataspecified rateandnextblockofenergyischarged at reduced rates, such a tariff is known as Block Rate Tariff.

In this type of tariff, the energyconsumption is divided into blocks. The cost perunitin first block is **high** and the cost per unit in next blocks is progressively reduced. Hence, the consumer who consumes large units has to pay less as compared to the consumer, who consumes fewer units.

Forexampleinadomesticthetotalnumberofunitsis100,thenThe first

30 units may be charged @ 60 paise per unit,

Thenext50unitsmaybecharged @50paiseperunitand

Theremaining20units maybecharged @30paiseperunit.

Then,thetotalbillwillbe$30x60+50x50+20x30=4900$paise=Rs.49/-.

Advantages:

(a) Theconsumergetsanincentiveforconsumingmoreunits.

(b) Thistariffincreasestheloadfactor,therebydecreasesthecostofunitgenerated.

Disadvantages:

(a) Dividingtheunitsintoblocksisproblem.

(b) Calculatingthebill.

4. Two-partTariff:

If the consumers are charged on the basis of maximum demand and units consumed, such a tariff is knows as Two part Tariff.

In this type of Tariff, the total charges are split into two parts namely **fixed charges and running charges. Fixed charges are proportional to maximum demand *(kW)* and running charges are proportional to number of units consumed *(kWh)*.**

Generally this tariff is expressed as

Totalcharges=Rs(a*kW+b *kWh)

Wherea=Chargeper*KW*ofmaximumdemandb= Charge

per *Kwh* of energy consumed.

Advantages:

(a) Itcanbeeasilyunderstandbytheconsumers.

(b) Itrecoversthe fixedchargeswhichdependonmaximumdemand,suchasinterest anddepreciation on capital cost of building and equipment, taxes and insurance etc.

Disadvantages:

(a) Theconsumerhas **topayhisfixedcharges**,whetherhe hasconsumedelectricalenergy or not.

(b) Theremaybeerrorincalculating**themaximumdemand**oftheconsumer

5. MaximumDemandTariff:

This Tariff is similar to two-part tariff except that, in this case the maximum demand is actually measured by using a **maximum demand meter** installed at the premises of the consumer.

Ifaconsumerdoesnotconsumeenergyforamonththemaximumdemandmeterreads zero, hence, the drawback of two-part tariff can be eliminated.

This tariff is mainly applicable to **large industrial consumers**, but not suitable for small consumer (domestic) as it requires a separate maximum demand meter.

6. PowerFactorTariff:

If the power factor of the consumer's load is taken into consideration such a tariff is known as power factor Tariff.

The efficiency ofplant and equipment depends on power factor. Hence, in order to increase theutilityofplant and equipment to maximumpossibleextent,theplant must beoperated at a most economical power factor. So, the supplier has to encourage the consumer to operatethe load at high power factor. The following are some types of power factor tariff.

kVA Maximum Demand Tariff: It is similar to two-part tariffexcept that the fixed charges are measured in KVA instead of KW. As KVA is inversely proportional to power factor, at high power factor the fixed charges will be less.

$$kVA = \frac{kW}{Power\ factor}$$

Hence,thistariffencouragestheconsumerstoworkathighpowerfactor.

kWhandkVARhTariff:Inthistypeboth*kWh*andKVARhsuppliedarechargedseparately. As *kVARh* isinverselyproportionaltopower factor.

$$kVARh = \frac{kW}{Power\ factor}\ X\ Sin\ \theta$$

athighpowerfactorthechargewillbe less.Hence,it isneedto improvethepowerfactorof a consumer load.

Sliding Scale* or *Average* Power *Factor Tariff: In this case an average power factori.e. 0.8 lagging is taken as reference. If the power factor of the consumer is less than this value, additional charges are made and ifthe power factor ismore than this value, a discount may

beallowed.Hence,thisresultsinimprovethepowerfactoroftheconsumerload.

2013

1. (a)Explainaboutcharacteristicsandtypesoftariffs.

   (b) Thefollowingtwotariffsareoffered

   (i) Rs100plus15paiseperunit

   (ii) Aflatrateof30paiseperunit

   Atwhatconsumptionisfirsttariffiseconomical?

2. (a)Explainaboutchoiceofnumberandsizeofgenerationunits.

   (b) Calculateannualbillofaconsumerwhosemaximumdemandis100kw,p.f=0.8laggingAnd load factor=60%.Thetariff usedisRs.75perkvAofmaximumdemandplus15paise per kwh consumed.

2014

3. (a)writeashortnotesonloadcurve,loaddurationandintegratedloaddurationcurve.

   (b) Definedemandfactor,Diversityfactor,plantusefactor.

4. (a)Whatdoyouunderstandbyelectricaltariff?

   (b) Discusstwoparttariff,threeparttariffandpowerfactortariff.

2015

5. (a)Explainthefollowingtermsasappliedtopowersystem

   (i) Diversityfactor

   (ii) Plantusefactor

   (iii) Demandfactor.

   (b)Writeashortnotesonintegratedloaddurationcurve.

6. (a)Namedifferenttypesoftariffs,explainthembriefly.

(b) Explainaboutcostofgenerationandtheirdivisionintofixed,semifixedandrunningcost.

2016

7. (a)ExplainLoadcurveandwhataretheinformationprovidedbythiscurve?

(b) A1000MWpowerstationdelivers1000MWfor2hours,500MWfor6hoursandisshut-down for the rest of each day. It is also shut-down for maintenance for 50 days annually. Calculate its annual load factor.

8. (a)AConsumerneedsonemillionunitsperyearandhisannualloadfactoris50%.Thetariff is Rs 1,200/- per KW. Estimate theSavinginhisenergycost,whichwouldresultifhe improves hisloadfactorto95%?

(b) Defineloadfactor,utilizationfactorandPlantusefactor?

UNITIII

OVERHEAD TRANSMISSIONLINES

Parameters of single and three phase transmission lines with single and double circuits - Resistance, inductanceandcapacitanceof solid,strandedandbundledconductors, Symmetrical andunsymmetrical spacingand transposition -application of self and mutual GMD; skin and proximity effects -interference with neighboring communication circuits - Typical configurations, conductor types and electrical parameters of EHV lines, corona discharges.

TYPESOFCONDUCTORS

Conductorsusedforelectricalsystemarethosehavinglessresistance,lowweight,high tensilestrength,lowcostandlowcoefficientofexpansion.Normallyaluminumandcopperareusedas conductors. The main advantages of aluminum conductors over copper conductors are:

- Lowweight
- Lowconductivity(lessresistance)andlesscoronaloss
- Lowcost

Themainproblemswithaluminumconductorsare:

- Lowtensilestrength
- Highcoefficientofexpansion
- Largearea

TYPESOFCONDUCTOR

1. Copper

Copperisanidealmaterialforoverhead linesowingtoitshighelectricalconductivityand greatertensilestrength. Itisalwaysused intheharddrawnformasstranded conductor.Althoughhard drawingdecreasestheelectricalconductivityslightlyyetitincreasesthetensilestrength considerably.Copperhas highcurrent density*i.e.*, thecurrent carryingcapacityofcopperperunit of X sectionalareaisquitelarge.Thisleadstotwoadvantages.Firstly,smallerX-sectionalarea ofconductorisrequired andsecondly,theareaoffered bytheconductortowindloadsisreduced. Moreover,thismetalisquitehomogeneous,durableandhashighscrapvalue.Thereishardlyany doubtthatcopperisanidealmaterialfortransmissionanddistributionofelectricpower.However, duetoitshighercostandnon-availability,itisrarelyusedforthesepurposes.Nowadaysthetrend is to use aluminum in place of copper.

2. Aluminum

Aluminumis cheap and light ascompared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below:

(i) The conductivity of aluminum is 60% that of copper. The smaller conductivity of aluminum means that for anyparticular transmission efficiency, the X-sectional area ofconductor mustbe larger in aluminum than in copper. For the same resistance, the diameter of aluminum conductor is about 1·26 times the diameter of copper conductor. The increased X-section of aluminum exposesagreatersurface towindpressureand,therefore,supportingtowersmust bedesignedfor greatertransversestrength.Thisoftenrequirestheuseofhighertowerswithconsequenceof greatersag.

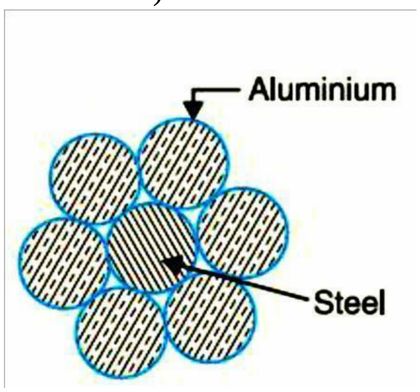
(ii) The specific gravity of aluminum (2·71 gm/cc) is lower than that of copper (8·9 gm/cc).Therefore, an aluminum conductor has almost one-half the weight of equivalent copper conductor. Forthisreason, the supporting structures for aluminumneed not be made so strong as that of copper conductor.

(iii) Aluminum conductor being light is liable to greater swings and hence larger cross-arms are required.

(iv) Duetolowertensilestrengthandhigherco-efficientoflinearexpansionofaluminum,thesag is greaterinaluminumconductors.Consideringthecombinedpropertiesofcost,conductivity, tensilestrength,weightetc.,aluminumhasanedgeovercopper.Therefore,itis beingwidelyused asaconductormaterial.Itisparticularlyprofitabletousealuminumforheavy-currenttransmission wheretheconductorsizeislargeanditscostformsamajorproportionofthetotalcostofcompleteinstallation.

3. Steelcoredaluminum

Duetolowtensilestrength,aluminumconductorsproducegreatersag.Thisprohibitstheir useforlargerspansandmakesthemunsuitableforlongdistancetransmission.Inorderto increase the tensile strength, the aluminum conductor is reinforced with a coreof galvanized steel wires. The composite conductor thus obtainedis known as*steel cored aluminum*andis abbreviated as A.C.S.R.(aluminumconductorsteelreinforced).



Steel-cored aluminum conductor consists of central core of galvanized steel wires surrounded by a number of aluminum strands. Usually, diameter of both steel and aluminum wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor. Fig. shows steel cored aluminum conductor havingonesteelwiresurroundedbysixwiresofaluminum.Theresult ofthiscompositeconductor isthat steelcoretakesgreaterpercentageofmechanicalstrengthwhilealuminum strandscarrythe bulk of current. The steel cored aluminum conductors have the following

Advantages:

(i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steelcored aluminum conductors will produce smaller sag and hence longer spans can be used.

(ii) Duetosmallersagwithsteelcoredaluminumconductors,towersofsmallerheightscanbeused.

4. Galvanisedsteel

Steel hasvery high tensilestrength.Therefore,galvanisedsteel conductorscan beusedfor extremely long spans or forshort line sections exposed to abnormally high stresses due to climaticconditions.Theyhavebeenfoundverysuitableinruralareaswherecheapnessisthemain consideration. Due to poor conductivityand high resistance ofsteel, such conductors are not suitable fortransmittinglargepoweroveralongdistance.However,theycanbeusedtoadvantagefor transmittingasmallpoweroverasmalldistancewherethesizeofthecopperconductordesirablefromeconomic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

5. Cadmiumcopper

Theconductormaterialnowbeingemployedin certaincasesiscopperalloyed withcadmium. An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivityisonlyreducedby15%belowthatofpurecopper.Therefore,cadmiumcopperconductor can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section i.e., where the cost of conductor material is comparatively small compared with the cost of supports.

STRANDEDCONDUCTORS

For transmission lines operating at high voltages normally stranded conductors are used. These conductors are known as composite conductors as they compose of two or more elements or strands electricallyinparallel.Theconductorsusedfortransmissionlinesarestrandedcopperconductors,hollowcopper conductors, ACSR conductors and copper weld conductors.

Inmodernoverheadtransmissionsystemsbarealuminumconductorsareusedwhichareclassified as:

AAC : all-aluminum conductor
AAAC :all-aluminumalloyconductor
ACSR :aluminumconductorsteelreinforced
ACAR :aluminumconductoralloyreinforced

Inordertoincreasethetensilestrengthaluminumconductorisreinforcedwithacoreofgalvanized steel wire, which is aluminum conductor steel reinforced. ACSR composite conductors are widely used for long distance transmission due to

- Steelcoredaluminumconductorsarecheaper than copper conductorsofequalresistanceand this economy is obtained without sacrificing efficiency.
- Theseconductorsarecorrosionresistantandareusefulunderunfavorableconditions.
- Thesuperior mechanicalstrengthofACSRcanbeutilizedbyusingspansoflarger lengthresults in smaller number of supports.
- Coronalossesarereducedbecauseoflargerdiameteroftheconductors.

BUNDLEDCONDUCTORS

Forvoltages in excess of230KVit isin fact not possibleto usearoundsingleconductor. Instead of going in for a hollow conductor it is preferable to use more than one conductor per phase which isknown as bundling of conductors. A bundle conductor is a conductor made up of two or more sub conductors and is used as one phase conductor.

ADVANTAGESINUSINGBUNDLECONDUCTORS

- Reducedreactance
- Reducedvoltagegradient
- Reducedcoronaloss
- Reducedradiointerference
- Reducedsurgeimpedance

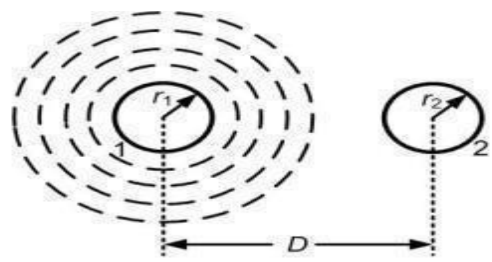
The basic difference between a stranded conductor and bundled conductor is that the sub conductors ofbundled conductorsareseparated fromeachother byadistanceofalmost 30cmsormoreand thewires of composite conductors touch each other.

LINEPARAMETERS

An AC transmission line has resistance, inductance and capacitance uniformly distributed along its length. These areknownas constants or parametersofa line. The performance ofa transmission line dependsupontheseconstants.

INDUCTANCEOFASINGLE-PHASELINE

Consider two solid round conductors with radii of r_1 and r_2 as shown in Fig. 1. One conductor is the return circuit for the other. This implies that if the current in conductor 1 is I then the current in conductor2 is $-I$. First let us consider conductor1. Thecurrent flowing in theconductor will set up flux lines. However, the fluxbeyond a distance $D + r_2$ fromthe center ofthe conductor links a net currentof zero andthereforedoesnotcontributetothefluxlinkageofthecircuit.Also at adistance lessthan$D-r_2$fromthecenterofconductor1thecurrentflowingthroughthisconductorlinkstheflux.Moreoversince $D >> r_2$wecanmakethe following approximations



Asingle-phaselinewithtwoconductors.

$$D + r_1 \approx D \;\; and \;\; D - r_1 \approx D$$

Wecanspecifytheinductanceofconductor1duetointernalandexternalfluxas

$$L_{int} = \frac{1}{2} \times 10^{-7} \text{ H/m}$$

$$L_{ext} = 2 \times 10^{-7} \ln \frac{D_2}{D_1} \text{ H/m}$$

$$L_1 = \left(\frac{1}{2} + 2 \ln \frac{D}{r_1} \right) \times 10^{-7} \text{ H/m} \qquad (1)$$

WecanrearrangeL_1givenin(1)asfollows

$$L_1 = 2 \times 10^{-7} \left(\frac{1}{4} + \ln \frac{D}{r_1} \right) = 2 \times 10^{-7} \left(\ln e^{1/4} + \ln \frac{D}{r_1} \right) = 2 \times 10^{-7} \left(\ln \frac{D}{r_1 e^{-1/4}} \right)$$

Substituting$r_1' = r_1 e^{-1/4}$intheaboveexpressionweget

$$L_1 = 2 \times 10^{-7} \left(\ln \frac{D}{r_1'} \right) \text{ H/m} \qquad (2)$$

Theradiusr_1'canbeassumedtobethatofafictitiousconductorthathasnointernalfluxbutwiththesame inductance as that of a conductor with radius r_1 .

Inasimilarwaytheinductanceduecurrentintheconductor2isgivenby

$$L_2 = 2 \times 10^{-7} \left(\ln \frac{D}{r_2'} \right) \text{ H/m} \qquad (3)$$

Thereforetheinductanceofthecompletecircuitis

$$\begin{aligned} L = L_1 + L_2 &= 2 \times 10^{-7} \left(\ln \frac{D}{r_1'} \right) + 2 \times 10^{-7} \left(\ln \frac{D}{r_2'} \right) \\ &= 2 \times 10^{-7} \left(\ln \frac{D^2}{r_1' r_2'} \right) = 4 \times 10^{-7} \left(\ln \frac{D}{\sqrt{r_1' r_2'}} \right) \text{ H/m} \end{aligned} \qquad (4)$$

Ifweassume$r_1'=r_2'=r'$,thenthetotalinductancebecomes

$$L = 4\times10^{-7}\left(\ln\frac{D}{r'}\right) \text{ H/m} \quad (5)$$

Where$r'=re^{-1/4}$.

INDUCTANCEOFTHREE-PHASELINESWITHSYMMETRICALSPACING

Consider the three-phase line shown in Fig.2. Each of the conductors has a radius of r and their centers formanequilateraltrianglewithadistance$D$betweenthem. Assumingthatthecurrentsarebalanced, we have

$$I_a + I_b + I_c = 0 \quad (1)$$

ConsiderapointPexternaltotheconductors.Thedistanceofthepointfromthephasesa,bandcare denoted by D_{pa}, $D_{pb}$and D_{pc}respectively.

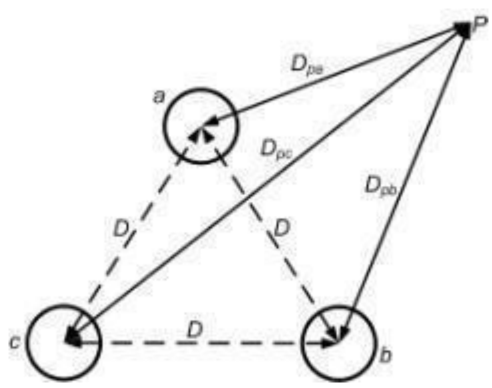


Fig.2Three-phasesymmetricallyspacedconductorsandanexternalpointP.

Letusassumethatthefluxlinkedbytheconductorofphase-aduetoacurrent$I_a$includestheinternalflux linkages but excludes the flux linkages beyond the point P . Then from

$$L_1 = 2\times10^{-7}\left(\ln\frac{D}{r_1'}\right)$$

Weget

$$\lambda_{apa} = \left(\frac{1}{2} + 2\ln\frac{D_{pa}}{r}\right)I_a = 2\times10^{-7} I_a \ln\frac{D_{pa}}{r'} \quad (2)$$

Thefluxlinkagewiththeconductorofphase-aduetothecurrentI_b,excludingallfluxbeyondthepoint$P$

,isgivenbyas

$$\lambda_{apb} = 2\times10^{-7} I_b \ln\frac{D_{pb}}{D} \quad (3)$$

Similarlythefluxduetothecurrent$I_c$is

$$\lambda_{apc} = 2\times10^{-7} I_c \ln\frac{D_{pc}}{D} \quad (4)$$

Thereforethetotalfluxinthephase-aconductoris

$$\lambda_a = \lambda_{apa} + \lambda_{apb} + \lambda_{apc} = 2\times10^{-7}\left(I_a \ln\frac{D_{pa}}{r'} + I_b \ln\frac{D_{pb}}{D} + I_c \ln\frac{D_{pc}}{D}\right)$$

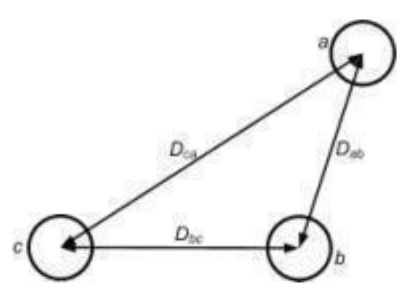
$$\lambda_a = 2\times10^{-7}\left(I_a \ln\frac{1}{r'} + I_b \ln\frac{1}{D} + I_c \ln\frac{1}{D} + I_a \ln D_{pa} + I_b \ln D_{pb} + I_c \ln D_{pc}\right)$$

$$I_b + I_c = -I_a$$

$$\lambda_a = 2\times10^{-7}\left(I_a \ln\frac{1}{r'} - I_a \ln\frac{1}{D} + I_b \ln\frac{D_{pb}}{D_{pa}} + I_c \ln\frac{D_{pc}}{D_{pa}}\right)$$

$$\lambda_a = 2\times10^{-7}\left(I_a \ln\frac{1}{r'} - I_a \ln\frac{1}{D}\right) = 2\times10^{-7} I_a \ln\frac{D}{r'}$$

$$L_a = 2\times10^{-7} \ln\frac{D}{r'}$$

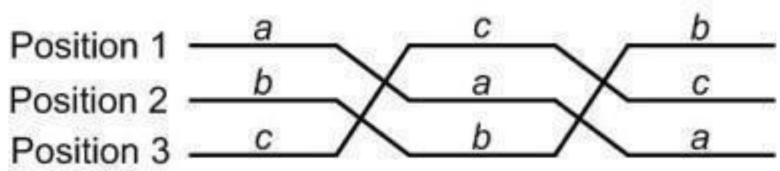


$$L_a = 2\times10^{-7}\left(\ln\frac{1}{r'} + a^2 \ln\frac{1}{D_{ab}} + a \ln\frac{1}{D_{ca}}\right)$$
$$L_b = 2\times10^{-7}\left(\ln\frac{1}{r'} + a \ln\frac{1}{D_{ab}} + a^2 \ln\frac{1}{D_{bc}}\right)$$
$$L_c = 2\times10^{-7}\left(\ln\frac{1}{r'} + a^2 \ln\frac{1}{D_{ca}} + a \ln\frac{1}{D_{bc}}\right)$$

Theinductancesthataregivenin(1)to(3)areundesirableastheyresult inanunbalancedcircuit configuration. One wayofrestoring the balanced natureofthe circuit is to exchange the positions ofthe conductors at regular intervals. This is called transposition of line and is shown.

In this each segment ofthe line is divided into three equal sub-segments. The conductors ofeach ofthephasesa,bandcareexchangedaftereverysub-segmentsuchthateachofthemisplacedineachofthethree positions once in the entire segment.

For example, the conductor of the phase-a occupies positions in the sequence 1, 2 and 3 in the threesub-segmentswhilethatofthephase-boccupies2,3and1.Thetransmissionlineconsistsofseveral such segments.



Asegmentofatransposedline**.**

Inatransposedline,eachphasetakesallthethreepositions.Theperphaseinductanceistheaveragevalueofthe three inductances calculated in (1) to (3). We therefore have

$$L = \frac{L_a + L_b + L_c}{3} \tag{4}$$

Thisimplies

$$L = \frac{2\times10^{-7}}{3}\left[\ln\frac{3}{r'} + (a + a^2)\left(\ln\frac{1}{D_{ab}} + \ln\frac{1}{D_{bc}} + \ln\frac{1}{D_{bc}}\right)\right]$$

Weknow

$$a^2 = e^{j240^0} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \text{ and } 1 + a + a^2 = 0$$

wehave$a+a^2$=-1.Substitutingthisintheaboveequationweget

$$L = \frac{2\times10^{-7}}{3}\left(3\ln\frac{1}{r'} - \ln\frac{1}{D_{ab}} - \ln\frac{1}{D_{bc}} - \frac{1}{D_{ca}}\right) \tag{5}$$

Theaboveequationcanbesimplifiedas

$$L = 2\times10^{-7}\left(\ln\frac{1}{r'} - \ln\frac{1}{(D_{ab}D_{bc}D_{ca})^{1/3}}\right) = 2\times10^{-7}\ln\frac{(D_{ab}D_{bc}D_{ca})^{1/3}}{r'} \tag{6}$$

Definingthegeometricmeandistance(GMD)as

$$GMD = \sqrt[3]{D_{ab}D_{bc}D_{ca}} \qquad (7)$$

equation(7)canberewrittenas

$$L = 2\times10^{-7}\ln\frac{GMD}{r'} \text{ H/m} \qquad (8)$$

Notice that (8) is of the same form as for symmetrically spaced conductors. Comparing these two equationswecanconcludethat *GMD*canbeconstruedastheequivalentconductorspacing.The*GMD* isthe cube root of the product of conductor spacing.

CAPACITANCEOFASINGLE-PHASELINE

Consider the single-phase line consisting of two round conductors as shown in Fig.5. The separation betweenthe conductors is *D*. Let us assume that conductor 1 carries a charge of q_1 C/mwhile conductor 2 carries a charge q_2 C/m. The presence of the second conductor and the ground will disturb field of the first conductor.

However we assume that the distance of separation between the conductors is much larger compared to the radius of the conductor and the height of the conductor is much larger than *D* for the groundto disturbtheflux.Thereforethedistortionissmallandthecharge isuniformlydistributedonthe surface of the conductor.

Assumingthattheconductor1alonehasthechargeq_1,thevoltagebetweentheconductorsis

$$V_{12}(q_1) = \frac{q_1}{2\pi\varepsilon_0}\ln\frac{D_2}{r_1} \text{ V} \qquad (1)$$

Similarlyiftheconductor2alonehasthechargeq_2,thevoltagebetweentheconductorsis

$$V_{21}(q_2) = \frac{q_2}{2\pi\varepsilon_0}\ln\frac{D}{r_2}$$

Theaboveequationimpliesthat

$$V_{12}(q_2) = \frac{q_2}{2\pi\varepsilon_0}\ln\frac{r_2}{D} \text{ V} \qquad (2)$$

Fromtheprincipleofsuperpositionwecanwrite

$$V_{12} = V_{12}(q_1) + V_{12}(q_2) = \frac{q_1}{2\pi\varepsilon_0}\ln\frac{D}{r_1} + \frac{q_2}{2\pi\varepsilon_0}\ln\frac{r_2}{D} \text{ V} \qquad (3)$$

Forasingle-phaselineletusassumethatq_1(=-q_2)isequalto*q*.Wethereforehave

$$V_{12} = \frac{q}{2\pi\varepsilon_0}\ln\frac{D}{r_1} - \frac{q}{2\pi\varepsilon_0}\ln\frac{r_2}{D} = \frac{q}{2\pi\varepsilon_0}\ln\frac{D^2}{r_1r_2} \text{ V}$$

Assuming$r_1=r_2=r_3$,wecanrewrite(4)as

(4)

$$V_{12} = \frac{q}{\pi \varepsilon_0} \ln \frac{D}{r} \quad \text{V}$$

(5)

Thecapacitancebetweentheconductorsisgivenby

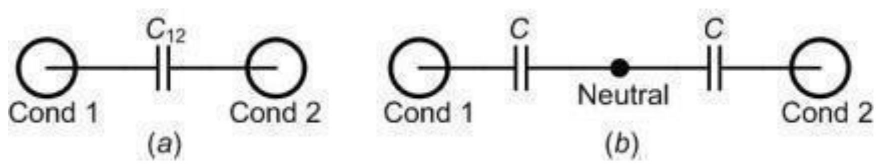
$$C_{12} = \frac{\pi \varepsilon_0}{\ln(D/r)} \text{F/m}$$

(6)

The above equationgives the capacitance between two conductors. For the purpose of transmission line modeling, the capacitance is defined between the conductor and neutral.

ThereforethevalueofthecapacitanceisgivenfromFig.5as

$$C = 2C_{12} = \frac{2\pi \varepsilon_0}{\ln(D/r)}$$



Capacitancebetweentwoconductorsand(b)equivalentcapacitancetoground.

CAPACITANCEOFATHREE-PHASETRANSPOSEDLINE

Considerthethree-phasetransposedlineshowninFig.6.Inthisthechargesonconductorsofphasesa,band c are q_a, $q_b$and q_c espectively. Since the system is assumed to be balanced we have

$$q_a + q_b + q_c = 0 \tag{1}$$

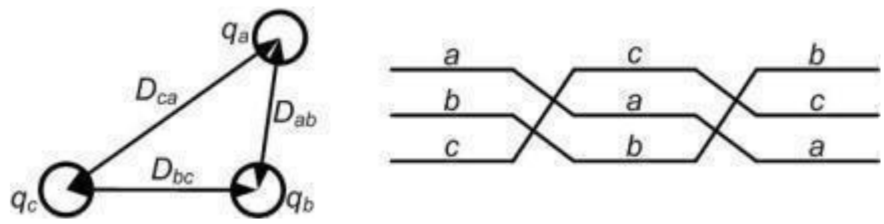


Fig.6Chargeonathree-phasetransposedline.

Usingsuperposition,thevoltageV_{ab}forthefirst,secondandthirdsectionsofthetranspositionaregiven respectively as

$$V_{ab}(1) = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{ab}}{r} + q_b \ln\frac{r}{D_{ab}} + q_c \ln\frac{D_{bc}}{D_{ca}}\right) \text{ V} \tag{2}$$

$$V_{ab}(2) = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{bc}}{r} + q_b \ln\frac{r}{D_{bc}} + q_c \ln\frac{D_{ca}}{D_{ca}}\right) \text{ V} \tag{3}$$

$$V_{ab}(3) = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{ca}}{r} + q_b \ln\frac{r}{D_{ca}} + q_c \ln\frac{D_{ab}}{D_{bc}}\right) \text{ V} \tag{4}$$

Thentheaveragevalueofthevoltageis

$$V_{ab} = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{ab}D_{bc}D_{ca}}{r^3} + q_b \ln\frac{r^3}{D_{ab}D_{bc}D_{ca}} + q_c \ln\frac{D_{ab}D_{bc}D_{ca}}{D_{ab}D_{bc}D_{ca}}\right) \text{ V} \tag{5}$$

Thisimplies

$$V_{ab} = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{\sqrt[3]{D_{ab}D_{bc}D_{ca}}}{r} + q_b \ln\frac{r}{\sqrt[3]{D_{ab}D_{bc}D_{ca}}}\right) \text{ V} \tag{6}$$

From*GMD*oftheconductors.Wecanthereforewrite

$$V_{ab} = \frac{1}{2\pi\,\varepsilon_0}\left(q_a \ln\frac{GMD}{r} + q_b \ln\frac{r}{GMD}\right) \text{ V} \quad (7)$$

SimilarlythevoltageV_{ac}isgivenas

$$V_{ac} = \frac{1}{2\pi\,\varepsilon_0}\left(q_a \ln\frac{GMD}{r} + q_c \ln\frac{r}{GMD}\right) \quad (8)$$

Adding(7)and(8)andusing(1)weget

$$\begin{aligned} V_{ab} + V_{ac} &= \frac{1}{2\pi\,\varepsilon_0}\left[2q_a \ln\frac{GMD}{r} + (q_b + q_c)\ln\frac{r}{GMD}\right] \\ &= \frac{1}{2\pi\,\varepsilon_0}\left[2q_a \ln\frac{GMD}{r} - q_a \ln\frac{r}{GMD}\right] = \frac{3}{2\pi\,\varepsilon_0} q_a \ln\frac{GMD}{r} \end{aligned} \quad (9)$$

Forasetofbalancedthree-phasevoltages

$$\begin{aligned} V_{ab} &= V_{an}\angle 0° - V_{an}\angle -120° \\ V_{ac} &= V_{an}\angle 0° - V_{an}\angle -240° \end{aligned}$$

Thereforewecanwrite

$$V_{ab} + V_{ac} = 2V_{an}\angle 0° - V_{an}\angle -120° - V_{an}\angle -240° = 2V_{an}\angle 0° \text{ V} \quad (10)$$

Combining(9)and(10)weget

$$V_{an} = \frac{1}{2\pi\,\varepsilon_0} q_a \ln\frac{GMD}{r} \text{ V} \quad (11)$$

Thereforethecapacitancetoneutralisgivenby

$$C = \frac{q_a}{V_{an}} = \frac{2\pi\,\varepsilon_0}{\ln(GMD/r)} \text{ F/m} \quad (12)$$

Forbundlesconductor

$$C = \frac{2\pi\,\varepsilon_0}{\ln(GMD/r)}$$

where

$$\begin{aligned} D_b &= \sqrt{\pi d} \text{ for 2 bundle} \\ &= \sqrt[3]{\pi d^2} \text{ for 3 bundle} \\ &= 1.094\sqrt[4]{\pi d^3} \text{ for 4 bundle conductors} \end{aligned}$$

EFFECTOFEARTHONCAPACITANCE

Incalculatingthecapacitanceoftransmissionlines,thepresenceofearthwasignored,sofar. Theeffect ofearthon capacitance can be convenientlytaken into account bythe method of images.

METHODOFIMAGES

- Theelectricfieldoftransmissionlineconductorsmustconformtothepresenceoftheearthbelow.
- Theearthforthispurposemaybeassumedtobeaperfectlyconductinghorizontalsheetof infinite extent which therefore acts like an equipotential surface.
- Theelectricfieldoftwolong,parallelconductorscharged+qand–qperunitissuchthatithasazero potential plane midway between the conductors as shown in Fig. 7.

- If a conductingsheet of infinitedimensions is placed at thezeropotential plane, the electricfield remains undisturbed.
- Further,iftheconductorcarryingcharge-qisnowremoved,theelectricfieldabovetheconducting sheet stays intact, while that below itvanishes.
- Using these well-known results in reverse, we may equivalently replace the presence of ground belowachargedconductorbyafictitiousconductorhavingequalandoppositechargeandlocated as far below the surface ofground as the overhead conductor above it-such a fictitious conductor is the mirror image of the overhead conductor.
- Thismethodofcreatingthesameelectricfield asinthepresenceofearthis knownasthemethod ofimages originally suggested by Lord Kelvin.

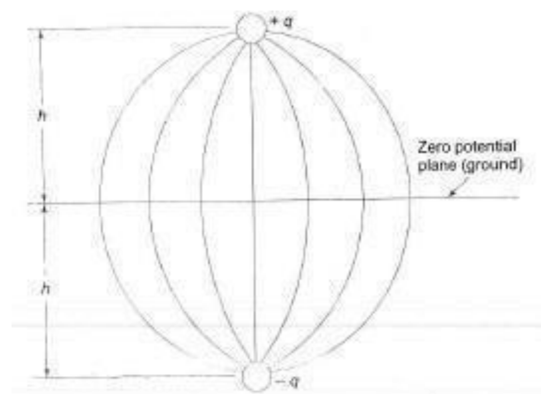
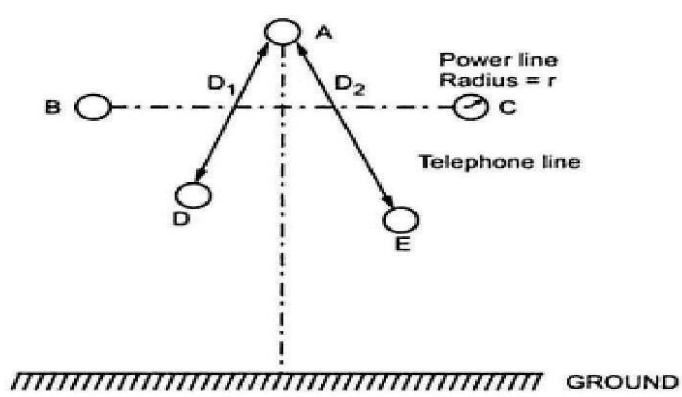


Fig.7Electricfieldoftwolong,parallel,oppositelychargedconductors

EXPRESSIONFORTHEVOLTAGEINDUCEDINCOMMUNICATIONLINESDUETOTHECURRENT IN POWER LINES



Theinductanceofthisloopisgivenby,

$$L_{AD}=2x10^{-7}\ln[D_1/r]H/m.$$

TheinductanceoftheloopAEisgivenby,

$$L_{AE}=2x10^{-7}\ln[D_2/r]H/m$$

ThemutualinductancebetweenconductorAandtheloopDEisgivenby,

$$M_A=L_{AE}-L_{AD}=2x10^{-7}[\ln[D_2/r]\ln[D_1/r]$$

Theneteffectofthemagneticfieldwillbe,

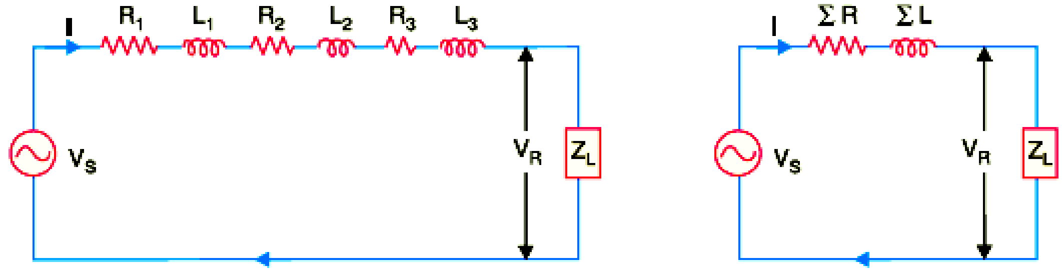
$$M=M_A+M_B+M_C$$

$$V=2\Pi fIM volts/m.$$

PARAMETERSOFSINGLEANDTHREEPHASETRANSMISSIONLINESWITHSINGLE AND DOUBLE CIRCUITS

CONSTANTSOFATRANSMISSIONLINE

Atransmissionlinehasresistance,inductanceandcapacitanceuniformlydistributedalong the whole length of the line. Before we pass on to the methods of finding these constants for a transmission line, it is profitable to understand themthoroughly.



(*i*) Resistance. It is the opposition of line conductors to current flow. The resistance is distributed uniformly along the whole length of the line as shown in Fig. However, the performance of a transmission line can be analysed conveniently if distributed resistance is considered as lumped as shown in Fig.

(*ii*) Inductance. Whenanalternating current flows througha conductor, a changing flux issetupwhichlinkstheconductor.Duetothesefluxlinkages,theconductorpossessesinductance. Mathematically,inductanceisdefinedasthefluxlinkagesperampere*i.e.*,

$$\text{Inductance, } L = \frac{\psi}{I} \text{ henry}$$

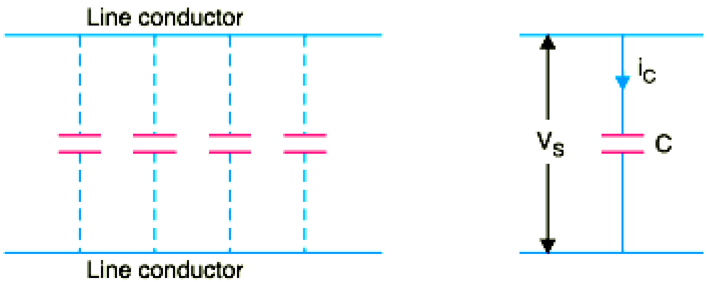
where ψ = flux linkages in weber-turns

I = current in amperes

Theinductanceisalsouniformlydistributedalongthelengthofthe*lineasshowinFig.Againforthe convenience of analysis, it can be taken to be lumped as shown in Fig

(*iii*)Capacitance.Weknowthatanytwoconductorsseparatedbyaninsulatingmaterialconsti-tute acapacitor.Asanytwoconductorsofanoverheadtransmissionlineareseparatedbyairwhichacts as an insulation,therefore,capacitanceexistsbetweenanytwooverheadlineconductors.Thecapacitance between the conductors is the charge per unit potential difference

(*iii*) Capacitance. We know that anytwo conductors separated byan insulating materialconsti-tuteacapacitor.Asanytwoconductorsofanoverheadtransmissionlineareseparatedbyairwhich actsasaninsulation,therefore, capacitanceexistsbetweenanytwooverhead lineconductors.The capacitance between the conductors is the charge per unit potential difference *i.e.*, Capacitance, $C = \frac{q}{v}$ farad



where

q=chargeonthe lineincoulomb

v=p.d.betweentheconductorsinvolts

Thecapacitanceisuniformlydistributedalongthewholelengthofthelineandmaybe regarded as auniform series of capacitors connected between the conductors as shown in Fig. 9.2(*i*). When an alternating voltage is impressed on a transmission line, the charge on the conductors at any point increases and decreases with the increase and decrease of the instantaneousvalueofthevoltagebetweenconductorsatthatpoint.Theresult isthat acurrent (known as *charging current*) flows between the conductors [See Fig. 9.2(*ii*)]. This charging current flowsinthe lineevenwhenit isopen-circuited*i.e.*,supplying no load.Itaffectsthevoltagedrop along the line as well as the efficiency and power factor of the line.

ResistanceofaTransmissionLine

Theresistanceoftransmissionlineconductorsisthemostimportantcause ofpowerlossin a transmission line. The resistance *R* of a line conductor having resistivity ρ, length *l* and area of cross-section *a* is given by ;

$R=\rho l/a$

The variation of resistance of metallic conductors with temperature is practically linear over the normal range of operation. Suppose R_1 and R_2 are the resistances of a conductor at t_1 °C and t_2 °C ($t_2>t_1$)respectively.If$\alpha_1$isthetemperaturecoefficientatt_1°C,then,

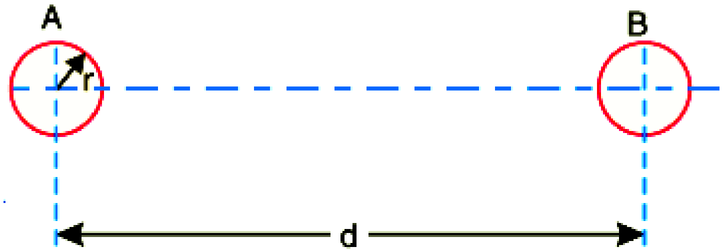
$$R_2 = R_1 [1 + \alpha_1 (t_2 - t_1)]$$

where
$$\alpha_1 = \frac{\alpha_0}{1+\alpha_0 t_1}$$
$$\alpha_0 = \text{temperature coefficient at } 0^\circ \text{ C}$$

INDUCTANCEOFASINGLEPHASETWO-WIRELINE

A single phase line consists oftwo parallel conductors which form a rectangular loop of one turn.

Whenanalternatingcurrentflowsthroughsuchaloop,achangingmagneticfluxissetup. Thechangingfluxlinkstheloopandhencetheloop(orsinglephaseline)possessesinductance. It mayappear that inductance ofa single phase line is negligible because it consistsofa loopofone turn andtheflux path is through airof high reluctance.Butas theX -sectional areaoftheloopisvery**large,evenforasmallfluxdensity,thetotalfluxlinkingtheloopisquitelarge and hence the line has appreciable inductance.



Considerasinglephaseoverhead lineconsistingoftwo parallelconductorsAandBspacedd metresapartasshowninFig.9.7.ConductorsAandBcarrythesameamountofcurrent(i.e.I_A =I_B),butintheoppositedirectionbecauseoneformsthereturncircuitoftheother.

$$I_A+I_B=0$$

InordertofindtheinductanceofconductorA(orconductorB),weshallhaveto considerthe flux linkageswithit.Therewillbe fluxlinkageswithconductorAduetoitsowncurrent $I_A$andalso A due to the mutualinductance effect ofcurrent I_B inthe conductor B Flux linkages with conductor Adue to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right)$$

FluxlinkageswithconductorAduetocurrentI_B

$$= \frac{\mu_0 I_B}{2\pi}\int_d^\infty \frac{dx}{x}$$

TotalfluxlinkageswithconductorAis

$$\psi_A = \exp.\ (i) + \exp\ (ii)$$

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_d^\infty \frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right) I_A + I_B \int_d^\infty \frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}+\log_e \infty - \log_e r\right) I_A + \left(\log_e \infty - \log_e d\right) I_B\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{I_A}{4}+\log_e \infty\left(I_A+I_B\right) - I_A \log_e r - I_B \log_e d\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} - I_A \log_e r - I_B \log_e d\right] \quad (\because I_A + I_B = 0)$$

Now. $$I_A + I_B = 0 \quad \text{or} \quad -I_B = I_A$$

$$\therefore \quad -I_B \log_e d = I_A \log_e d$$

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e d - I_A \log_e r\right] \text{ wb-turns/m}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e \frac{d}{r}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ wb-turns/m}$$

Inductance of conductor $A, L_A = \dfrac{\psi_A}{I_A}$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m} = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m}$$

$$L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{d}{r}\right] \text{H/m}$$

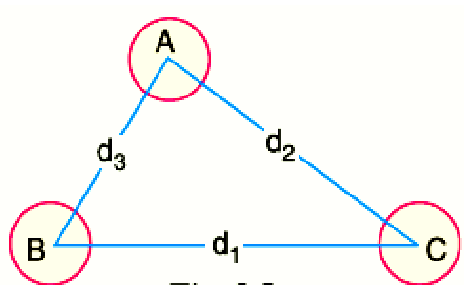
$$\text{Loop inductance} = 2\,L_A \text{ H/m} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

$$\text{Loop inductance} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

Notethat eq. (ii) is the inductance ofthe two-wire line and is sometimes called loop inductance. However,inductancegivenbyeq.(i)istheinductanceperconductorandisequaltohalftheloopinductance.

INDUCTANCEOFA3-PHASEOVERHEADLINE

shows the three conductors A, B and C of a 3-phase line carrying currents I_A , I_B and $I_C$respectively. Let d_1 , d_2 and d_3 be the spacings betweenthe conductorsas shown. Let us further assume that the loads are balanced i.e. $I_A + I_B + I_C = 0$. Consider the flux linkages withconductor There will be flux linkages with conductor A due to its own current and also due to the mutual inductance effects of I_B and I_C



FluxlinkageswithconductorAduetoitsowncurrent

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right) \quad ...(i)$$

FluxlinkageswithconductorAduetocurrentI_B

$$= \frac{\mu_0 I_B}{2\pi}\int_{d_3}^\infty \frac{dx}{x}$$

FluxlinkageswithconductorAduetocurrentI_C

$$= \frac{\mu_0 I_C}{2\pi}\int_{d_2}^\infty \frac{dx}{x}$$

TotalfluxlinkageswithconductorAis

$$\begin{aligned}
\psi_A &= (i)+(ii)+(iii) \\
&= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right)+\frac{\mu_0 I_B}{2\pi}\int_{d_3}^\infty \frac{dx}{x}+\frac{\mu_0 I_C}{2\pi}\int_{d_2}^\infty \frac{dx}{x} \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}+\int_r^\infty \frac{dx}{x}\right)I_A+I_B\int_{d_3}^\infty \frac{dx}{x}+I_C\int_{d_2}^\infty \frac{dx}{x}\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A-I_B\log_e d_3-I_C\log_e d_2+\log_e\infty\left(I_A+I_B+I_C\right)\right]
\end{aligned}$$

As $I_A+I_B+I_C = 0,$

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A-I_B\log_e d_3-I_C\log_e d_2\right]$$

SYMMETRICALSPACING

IfthethreeconductorsA,BandCareplacedsymmetricallyatthecornersofanequilateraltriangle of side d, then, d1 = d2 = d3 = d. Under such conditions, the flux Derivedin a similar way, the expressions for inductance are the same for conductors B andC**.**

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d - I_C\log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - (I_B+I_C)\log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A + I_A\log_e d\right] \qquad (\because I_B + I_C = -I_A)$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4}+\log_e\frac{d}{r}\right] \text{ weber-turns/m}$$

$$L_A = \frac{\psi_A}{I_A}\text{ H / m} = \frac{\mu_0}{2\pi}\left[\frac{1}{4}+\log_e\frac{d}{r}\right]\text{ H/m}$$

$$= \frac{4\pi\times10^{-7}}{2\pi}\left[\frac{1}{4}+\log_e\frac{d}{r}\right]\text{ H/m}$$

$$L_A = 10^{-7}\left[0\cdot5 + 2\log_e\frac{d}{r}\right]\text{ H/m}$$

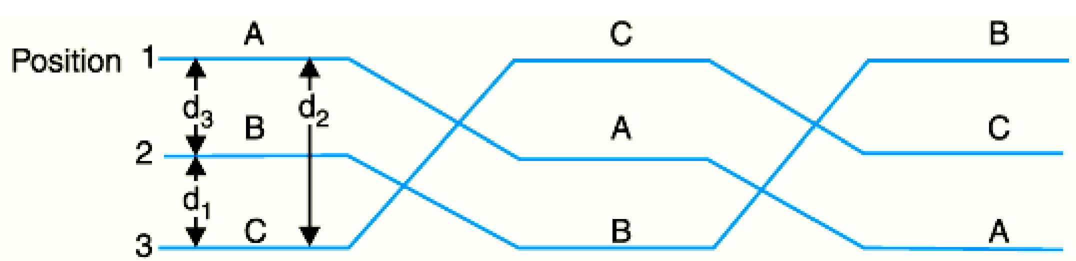
UNSYMMETRICALSPACING

When3-phaselineconductorsarenot equidistant fromeachother,theconductorspacing is saidtobeunsymmetrical.Undersuchconditions,the fluxlinkagesand inductanceofeachphase are not the same. A different inductance in each phase results in unequal voltage drops in thethreephasesevenifthecurrentsintheconductorsarebalanced.Therefore,thevoltageatthereceiving end will not be the same for allphases. In order that voltage drops are equal in all conductors, we generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over an equaldistance. Such an exchange of positions is known as transposition. The transposed line. Thephaseconductorsaredesignatedas A,B and C and the positions occupied are numbered 1,2 and 3. Theeffect of transposition is that each conductor has the same average inductance.

Fig.showsa3-phasetransposedlinehavingunsymmetricalspacing.Letusassumethateach ofthe three sections is 1 m in length. Let us further assume balanced conditions i.e.,

$$I_A + I_B + I_C = 0$$

Letthelinecurrentsbe:



$$I_A = I(1 + j\,0)$$
$$I_B = I(-0\cdot5 - j\,0\cdot866)$$
$$I_C = I(-0\cdot5 + j\,0\cdot866)$$

Asprovedabove,thetotalfluxlinkagespermetrelengthofconductorAis

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d_3 - I_C\log_e d_2\right]$$

Putting the values of I_A, I_B and I_C, we get,

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I - I(-0\cdot5-j\,0\cdot866)\log_e d_3 - I(-0\cdot5+j\,0\cdot866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0\cdot5\,I\log_e d_3 + j\,0\cdot866\log_e d_3 + 0\cdot5\,I\log_e d_2 - j\,0\cdot866\,I\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0\cdot5\,I(\log_e d_3 + \log_e d_2) + j\,0\cdot866\,I(\log_e d_3 - \log_e d_2)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + I^*\log_e\sqrt{d_2 d_3} + j\,0\cdot866\,I\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I + I\log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\,I\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2 d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]$$

∴ Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A} = \frac{\psi_A}{I}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{4\pi\times10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]\ \text{H/m}$$

$$= 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,1\cdot732\log_e\frac{d_3}{d_2}\right]\ \text{H/m}$$

SimilarlyinductanceofconductorsBandCwillbe:

$$L_B = 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_3\,d_1}}{r} + j\,1\cdot732\log_e\frac{d_1}{d_3}\right]\ \text{H/m}$$

$$L_C = 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_1\,d_2}}{r} + j\,1\cdot732\log_e\frac{d_2}{d_1}\right]\ \text{H/m}$$

Inductanceofeachlineconductor

$$= \frac{1}{3}(L_A + L_B + L_C)$$

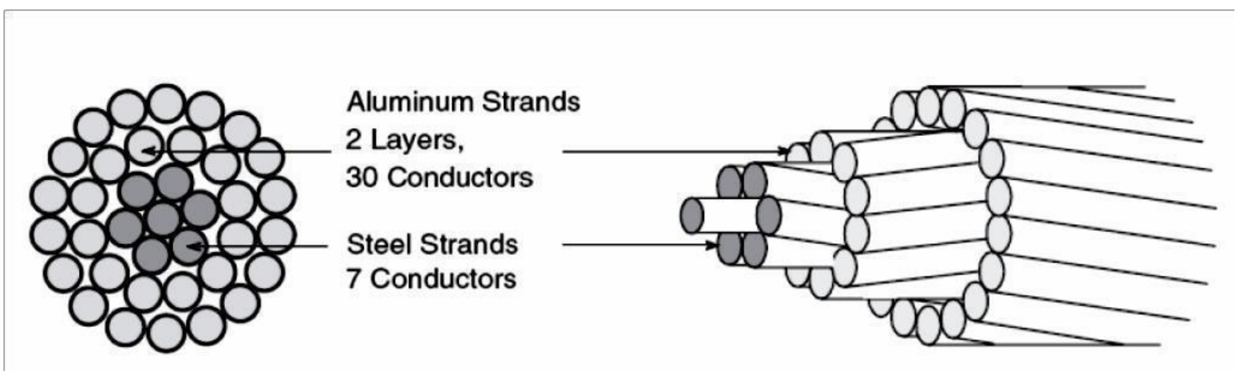
$$= ^{*}\left[\frac{1}{2} + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

$$= \left[0\cdot5 + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

Ifwecomparetheformulaofinductanceofanun symmetricallyspacedtransposedlinewiththat ofsymmetricallyspacedline,wefindthatinductanceofeachlineconductorinthetwocaseswill be equal if $d = \sqrt[3]{d_1 d_2 d_3}$ The distance d isknownasequivalentequilateralspacingforun symmetrically transposed line

SPIRALINGANDBUNDLECONDUCTOREFFECT

Therearetwotypesoftransmissionlineconductors:overheadandunderground.Overhead conductors, made of naked metal and suspended on insulators, are preferred over undergroundconductorsbecauseofthelowercostandeasymaintenance.Also,overheadtransmissionlines use aluminumconductors,becauseofthelowercostandlighterweightcomparedtocopperconductors, althoughmorecross-sectionareaisneededtoconductthesameamountofcurrent.Thereare differenttypesofcommerciallyavailablealuminumconductors:aluminum-conductor-steel-reinforced(ACSR),aluminum-conductor-alloy-reinforced(ACAR),all-aluminum-conductor (AAC), and all-aluminumalloy- conductor (AAAC).



ACSRisoneof themostusedconductors intransmissionlines.Itconsists of alternate layersofstrandedconductors,spiraledinoppositedirectionstoholdthestrandstogether,surrounding a core ofsteelstrands. Figure 13.4 shows an example ofaluminum and steel strands combination. The purposeof introducing a steel coreinside the stranded aluminumconductors is to obtain a high strength-to-weight ratio. A stranded conductor offers more flexibility and easier tomanufacturethanasolidlargeconductor.However,thetotalresistanceisincreasedbecausethe outsidestrandsarelargerthantheinsidestrandsonaccountofthespiraling.Theresistanceofeachwound conductor at anylayer, per unit length, is based on its total length as follows:

$$R_{cond} = \frac{\rho}{A}\sqrt{1+\left(\pi\frac{1}{P}\right)^2}\ \ \Omega/m$$

CONCEPTOFSELF-GMDANDMUTUAL-GMD

The use of self geometrical mean distance (abbreviated as self-GMD) and mutual geometrical mean distance (mutual-GMD) simplifies the inductance calculations, particularly relatingtomulticonductorarrangements.ThesymbolsusedforthesearerespectivelyDsand Dm. We shall briefly discuss these terms.

(i) Self-GMD(Ds)

In order to have concept of self-GMD (also sometimes called Geometrical mean radius; GMR), consider the expression for inductance per conductor per metre already derived in Art. Inductance/conductor/m

$$= 2\times 10^{-7}\left(\frac{1}{4}+\log_e\frac{d}{r}\right)$$

$$= 2\times 10^{-7}\times\frac{1}{4}+2\times 10^{-7}\log_e\frac{d}{r}$$

Inthisexpression,theterm$2\times10^{-7}\times(1/4)$istheinductanceduetofluxwithinthesolidconductor. For many purposes, it is desirable to eliminate this term by the introduction of a concept called self-GMD or GMR. If we replace the original solid conductor by an equivalent hollow cylinder with extremelythin walls, the current is confined to the conductor surface and internal conductor flux linkage would be almost zero. Consequently, inductance due to internal flux would be zero and the term $2\times10^{-7}\times(1/4)$ shall be eliminated. The radius of this equivalent hollow cylinder must be sufficiently smaller than the physical radius of the conductor to allow room for enough additional flux to compensate for the absence of internal flux linkage. It can be proved mathematically that for a solid round conductor of radius r, the self-GMD or GMR = 0·7788 r. Using self-GMD, the eq. (i) becomes:

Inductance/conductor/m=$2\times10\text{-}7\log_e d/Ds$*

Where

Ds=GMRorself-GMD=0·7788r

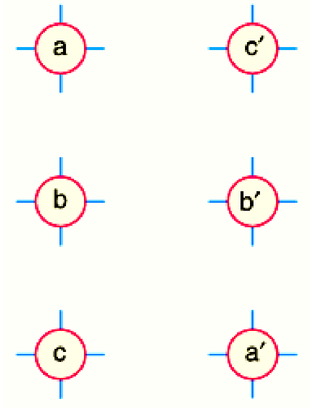
Itmaybenotedthatself-GMDofaconductordependsuponthesizeandshapeoftheconductorandis independent of the spacing between the conductors.

(i) Mutual-GMD

Themutual-GMDisthegeometricalmeanofthedistancesformoneconductortotheother and, therefore, must be between the largest and smallest such distance. In fact, mutual- GMD simply represents the equivalent geometrical spacing.

(a) The mutual-GMD between two conductors (assuming that spacing between conductors is large compared to the diameter ofeach conductor) is equalto the distance between their centres i.e. Dm = spacing between conductors = d

(b) For a single circuit 3-φ line, the mutual-GMD is equal to the equivalent equilateral spacing i.e., $(d_1 d_2 d_3)^{1/3}$.



(c) The principle of geometrical mean distances can be most profitably employed to 3-φ double circuit lines. Consider the conductor arrangement of the double circuit shown in Fig. Suppose the radius of each conductor is r.

Self-GMDofconductor=0·7788r

Self-GMDofcombinationaa'is

$$D_{s1} = (**D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a})^{1/4}$$

Self-GMDofcombinationbb'is

$$D_{s2} = (D_{bb} \times D_{bb'} \times D_{b'b'} \times D_{b'b})^{1/4}$$

Self-GMDofcombinationcc'is

$$D_{s3} = (D_{cc} \times D_{cc'} \times D_{c'c'} \times D_{c'c})^{1/4}$$

Equivalentself-GMDofonephase

$$D_s = (D_{s1} \times D_{s2} \times D_{s3})^{1/3}$$

ThevalueofDsisthesameforallthephasesaseachconductorhasthesameradius.

Mutual-GMD between phases A and B is

$$D_{AB} = (D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'})^{1/4}$$

Mutual-GMDbetweenphasesBandCis

$$D_{BC} = (D_{bc} \times D_{bc'} \times D_{b'c} \times D_{b'c'})^{1/4}$$

Mutual-GMDbetweenphasesCandAis

$$D_{CA} = (D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'})^{1/4}$$

Equivalent mutual-GMD, $D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$

ItisworthwhiletonotethatmutualGMDdependsonlyuponthespacingandissubstantially independent of the exact size, shape and orientation of the conductor.

InductanceFormulasinTermsofGMD

Theinductanceformulasdevelopedinthepreviousarticlescanbeconvenientlyexpressedin terms of geometrical mean distances.

(i) *Single phase line*

$$\text{Inductance/conductor/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

where $D_s = 0{\cdot}7788\, r$ and D_m = Spacing between conductors = d

(ii) *Single circuit 3-φ line*

$$\text{Inductance/phase/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

where $D_s = 0{\cdot}7788\, r$ and $D_m = (d_1\, d_2\, d_3)^{1/3}$

(iii) *Double circuit 3-φ line*

$$\text{Inductance/phase/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

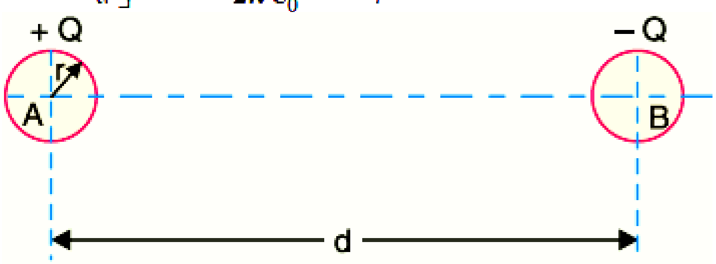
where $D_s = (D_{s1}\, D_{s2}\, D_{s3})^{1/3}$ and $D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$

CAPACITANCEOFASINGLEPHASETWO-WIRELINE

Consider a single phase overhead transmission line consisting of two parallel conductors Aand B spaced d metres apart in air. Supposethat radius ofeach conductor is r metres. Let their respective charge be + Q and − Q coulombs per metre length.The total p.d.between conductorA and neutral "infinite" plane is

$$V_A = \int_r^\infty \frac{Q}{2\pi\, x\, \varepsilon_0}\, dx + \int_d^\infty \frac{-Q}{2\pi\, x\, \varepsilon_0}\, dx$$

$$= \frac{Q}{2\pi\, \varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] \text{volts} = \frac{Q}{2\pi\, \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$



Similarly,p.d.betweenconductorBandneutral"infinite"planeis

$$V_B = \int_r^\infty \frac{-Q}{2\pi x\, \varepsilon_0}\, dx + \int_d^\infty \frac{Q}{2\pi x\, \varepsilon_0}\, dx$$

$$= \frac{-Q}{2\pi\, \varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] = \frac{-Q}{2\pi\, \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$

Boththesepotentialsarew.r.t.thesameneutralplane.Sincetheunlikechargesattracteach other, the potential difference between the conductors is

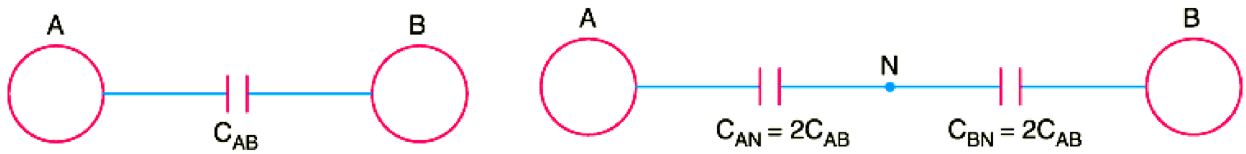
$$V_{AB} = 2V_A = \frac{2Q}{2\pi\varepsilon_0}\log_e\frac{d}{r}\text{ volts}$$

Capacitance, $$C_{AB} = Q/V_{AB} = \frac{Q}{\frac{2Q}{2\pi\varepsilon_0}\log_e\frac{d}{r}}\text{ F/m}$$

$$C_{AB} = \frac{\pi\varepsilon_0}{\log_e\frac{d}{r}}\text{ F / m}$$

Capacitancetoneutral

Equation (i) gives the capacitance between the conductors of a two-wire line Often it is desiredtoknowthecapacitancebetweenoneoftheconductorsandaneutralpointbetweenthem. Sincepotentialofthemid-pointbetweentheconductorsiszero,thepotentialdifference between each conductor and the ground or neutral is half the potential difference between the conductors.Thusthecapacitancetogroundorcapacitanceto neutralforthetwo-wireline istwice the line-to-line capacitance



$$\text{Capacitance to neutral, } C_N = C_{AN} = C_{BN} = 2C_{AB}$$

$$C_N = \frac{2\pi\varepsilon_0}{\log_e\frac{d}{r}}\text{ F / m}$$

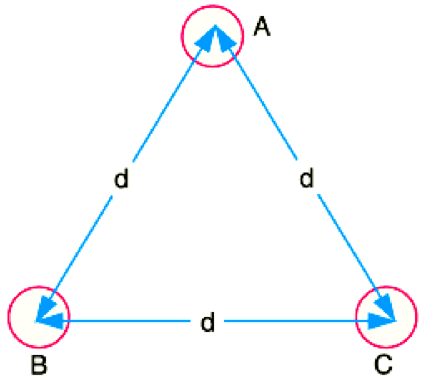
Thereadermaycompare eq. (ii)to theoneforinductance. Onedifference between theequations for capacitance and inductance should be noted carefully. The radius in the equation for capacitance is the actual outside radius of the conductor and not the GMR of the conductor as in the inductance formula. Note that eq. (ii) applies onlyto a solid round conductor.

2.7.1CAPACITANCEOFA3-PHASEOVERHEADLINE

Ina 3-phase transmission line, the capacitance of eachconductor is considered instead of capacitance from conductor to conductor. Here, again two cases arise viz., symmetrical spacing and unsymmetrical spacing.

(i) SymmetricalSpacing

Fig shows the three conductors A, B and C of the 3-phase overhead transmission line havingchargesQ$_A$,Q$_B$ andQ$_C$ permeterlengthrespectively. Lettheconductorsbeequidistant (dmeters) from each other. We shall find the capacitance from line conductor to neutral in this symmetrically spaced line. Referring toFig,



Overallpotentialdifferencebetweenconductor Aandinfiniteneutralplaneisgivenby

$$V_A = \int_r^{\infty} \frac{Q_A}{2\,\pi x \varepsilon_0}\,dx + \int_d^{\infty} \frac{Q_B}{2\,\pi x \varepsilon_0}\,dx + \int_d^{\infty} \frac{Q_C}{2\,\pi x \varepsilon_0}\,dx$$

$$= \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d} + Q_C \log_e \frac{1}{d}\right]$$

$$= \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + (Q_B + Q_C) \log_e \frac{1}{d}\right]$$

Assuming balanced supply, we have, $Q_A + Q_B + Q_C = 0$

$$\therefore \quad Q_B + Q_C = -Q_A$$

$$\therefore \quad V_A = \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} - Q_A \log_e \frac{1}{d}\right] = \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$

∴CapacitanceofconductorAw.r.tneutral,

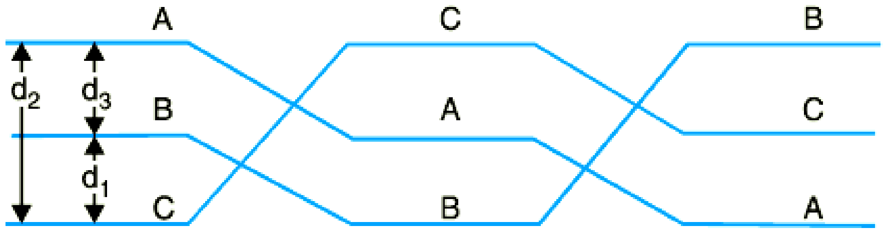
$$C_A = \frac{Q_A}{V_A} = \frac{Q_A}{\frac{Q_A}{2\pi\,\varepsilon_0}\log_e \frac{d}{r}} \text{ F/m} = \frac{2\pi\,\varepsilon_0}{\log_e \frac{d}{r}} \text{ F/m}$$

$$C_A = \frac{2\pi\,\varepsilon_0}{\log_e \frac{d}{r}} \text{ F/m}$$

Notethatthisequationisidenticaltocapacitancetoneutralfortwo-wireline.Derivedinasimilar manner, the expressions for capacitance are the same for conductors B and C.

(ii) Unsymmetricalspacing.

Fig.showsa3-phasetransposedlinehavingunsymmetricalspacing.Letusassume balanced conditions i.e. $Q_A + Q_B + Q_C = 0$.



ConsideringallthethreesectionsofthetransposedlineforphaseA,

Potential of 1st position, $$V_1 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_3} + Q_C \log_e \frac{1}{d_2}\right)$$

Potential of 2nd position, $$V_2 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_1} + Q_C \log_e \frac{1}{d_3}\right)$$

Potential of 3rd position, $$V_3 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_2} + Q_C \log_e \frac{1}{d_1}\right)$$

AveragevoltageonconductorAis

$$V_A = \frac{1}{3}(V_1 + V_2 + V_3)$$

$$= \frac{1}{3 \times 2\pi\varepsilon_0} * \left[Q_A \log_e \frac{1}{r^3} + (Q_B + Q_C) \log_e \frac{1}{d_1 d_2 d_3} \right]$$

As $Q_A + Q_B + Q_C = 0$, therefore, $Q_B + Q_C = -Q_A$

$$\therefore \quad V_A = \frac{1}{6\pi\varepsilon_0} \left[Q_A \log_e \frac{1}{r^3} - Q_A \log_e \frac{1}{d_1 d_2 d_3} \right]$$

$$= \frac{Q_A}{6\pi\varepsilon_0} \log_e \frac{d_1 d_2 d_3}{r^3}$$

$$= \frac{1}{3} \times \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{d_1 d_2 d_3}{r^3}$$

$$= \frac{Q_A}{2\pi\varepsilon_0} \log_e \left(\frac{d_1 d_2 d_3}{r^3} \right)^{1/3}$$

$$= \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{(d_1 d_2 d_3)^{1/3}}{r}$$

Capacitancefromconductortoneutralis

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \; F/m$$

INDUCTIVEINTERFERENCEWITHNEIGHBOURINGCOMMUNICATIONCIRCUITS

It is usual practice to run telephone lines along the same route as the power lines. The transmission lines transmit bulk power at relatively high voltages and, therefore, these lines give rise to electro-magnetic and electrostatic fields of sufficient magnitude which induce are superposed on the true speech currents in the neighboring telephone wires and set up distortion whilethevoltagesoinducedraisethepotentialofthecommunicationcircuitasawhole.Inextreme cases the effect of these maymakeit impossible to transmit anymessage faithfullyand mayraise the potential of the telephone receiver above the ground to such an extent to render the handling ofthetelephonereceiverextremelydangerousandinsuchcaseselaborateprecautionsarerequired to be observed to avoid this danger.

In practice it is observed that the power lines and the communication lines run along the same path. Sometimes it can also be seen that both these lines run on same supports along the same route. The transmission lines transmit bulk power with relatively high voltage. Electromagnetic and electrostatic fields are produced bythese lines havingsufficient magnitude. Because of these fields, voltages and currents are induced in the neighbouring communication lines. Thus it gives rise to interference of power line with communication circuit.

Duetoelectromagneticeffect,currentsareinducedwhichissuperimposedonspeechcurrentofthe neighbouringcommunicationline whichresultsinto distortion.Thepotentialofthe communicationcircuit asa whole israised because ofelectrostatic effect and the communication apparatusandtheequipmentsmaygetdamagedduetoextraneousvoltages.Intheworstsituation,the faithfultransmissionofmessagebecomesimpossibleduetoeffectofthesefields.Alsothe potentialoftheapparatusisraisedabovethegroundtosuchanextentthatthehandlingoftelephonereceiver becomes extremely dangerous.

The electromagnetic and the electrostatic effects mainly depend on what is the distance betweenpowerandcommunicationcircuitsandthelengthoftherouteoverwhichtheyareparallel. Thusit can be noted that if the distortion effect and potential rise effect are within permissible limits then the communication will be proper. The unacceptable disturbance which isproduced in the telephone communication because of power lines is called Telephone Interference.

Therearevariousfactorsinfluencingthetelephoneinterference.Thesefactorsareasfollows

1) Becauseofharmonicsinpowercircuit,theirfrequencyrangeandmagnitudes.
2) Electromagneticcouplingbetweenpowerandtelephoneconductor.

The electric coupling is in the form of capacitive coupling between power and telephone conductor whereas the magnetic couplingis through space and is generallyexpressed in terms of mutual inductance at harmonic frequencies.

3) Duetounbalanceinpowercircuitsandintelephonecircuits.
4) Typeofreturntelephonecircuiti.e.eithermetallicorgroundreturn.
5) Screeningeffects.

StepsforReducingTelephoneInterference

Therearevariouswaysthatcanreducethetelephoneinterference.Someofthemareaslisted below

i) TheharmonicsatthesourcecanbereducedwiththeuseofA.C.harmonic filters,D.C. harmonic filters and smoothing rectors.
ii) Usegreaterspacingbetweenpowerandtelephonelines.
iii) Theparallelrunbetweentelephonelineandpowerlineisavoided.
iv) Insteadofusingoverheadtelephonewires,undergroundtelephonecablesmaybeused.
v) Ifthetelephonecircuitisgroundreturnthenreplaceitwithmetallicreturn.
vi) Usemicrowaveorcarriercommunicationinsteadoftelephonecommunication.
vii) The balance of AC power line is improved by using transposition. Transposition of lines reducesthe induced voltagesto a considerable extent. The capacitance ofthe lines is balanced by transposition leading to balance in electro statically induced voltages. Using transposition the fluxes due to positive and negative phase sequence currents cancelout sothe electromagnetically inducede.m.f'sarediminished.Forzerosequencecurrentsthetelephonelinesarealsotransposed which is shown in the Fig.

INDUCTIVEINTERFERENCEWITHNEIGHBOURINGCIRCUITS

Thefactorsinfluencingthetelephoneinterferenceare:

- Becauseofharmonicsinpowercircuit,theirfrequencyrangeandmagnitudes
- Electromagneticcoupling
- Duetounbalanceinpowercircuitsandintelephonecircuits
- Typeofreturntelephonecircuit
- Screeningeffects

STEPSFORREDUCINGTELEPHONEINTERFERENCE

- HarmonicscanbereducedwiththeuseofACharmonicfilters,DCharmonic filtersand smoothening reactors
- Usegreaterspacingbetweenpowerandtelephonelines
- Parallelrunbetweentelephoneandpowerlineisavoided
- Iftelephonecircuitisgroundreturn,replacewithmetallicreturn.

UNIT IV
PERFORMANCEOFLINES:
SHORT,MEDIUMANDLONGTRANSMISSIONLINES

CLASSIFICATIONOFLINES-INTRODUCTION

Theimportantconsiderationsin thedesign andoperation of atransmissionlineare the determinationofvoltagedrop,linelossesandefficiencyoftransmission.Thesevaluesaregreatly influencedbythelineconstants*R*,*L*and*C*ofthetransmissionline.Forinstancethevoltagedropin thelinedependsuponthevaluesofabovethreelineconstants.Similarly,theresistanceof transmission line conductorsis the most important cause ofpowerloss inthe line and determines the transmission efficiency. In this chapter, we shalldevelop formulas bywhich we can calculate voltage regulation, line losses and efficiency oftransmission lines. These formulas are important fortwoprincipalreasons.Firstly,theyprovideanopportunitytounderstandtheeffectsof the parameters of the line on bus voltages and the flow of power. Secondly, they help in developing an overall understanding of what is occurring on electric power system.

CLASSIFICATIONOFOVERHEADTRANSMISSIONLINES

Atransmissionlinehas*threeconstants*R*,*L*and*C*distributeduniformlyalongthewhole length of the line. The resistance and inductance form the series impedance. The capacitance existing between conductors for 1-phase line or from a conductor to neutral for a 3- phase line forms a shunt path throughout the length of the line. Therefore, capacitance effects introduce complicationsintransmissionlinecalculations.Dependinguponthemanner inwhichcapacitance is taken into account, the overhead transmission lines are classified as :

(i) Short transmission lines. When the length of an overhead transmission line is up to about50kmandthelinevoltageiscomparativelylow(<20kV),itisusuallyconsideredasashort transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken intoaccount.

(ii) Medium transmission lines. When the length of an overhead transmission line is about 50-150 km and thelinevoltageis moderatelyhigh (>20 kV<100 kV), it isconsidered as a mediumtransmissionline.Duetosufficientlengthandvoltageoftheline,thecapacitance effects are taken into account. For purposes ofcalculations, the distributed capacitance ofthe line is divided and lumped inthe formof condensers shunted across the line at one or more points.

(iii) Long transmission lines. When the length ofan overhead transmission line is more than150kmand linevoltageisveryhigh(>100 kV),itisconsidered asa longtransmissionline. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.

It may be emphasized here that exact solution ofany transmission line must consider the factthattheconstantsofthelinearenotlumpedbutaredistributeduniformlythroughoutthelength of the line.

However,reasonableaccuracycanbeobtainedbyconsideringtheseconstantsaslumped for short and medium transmission lines.

ImportantTerms

Whilestudyingtheperformanceofatransmissionline,itisdesirabletodetermineitsvoltage regulation and transmission efficiency. We shall explain these two terms in turn.

(i) Voltage regulation. Whena transmission line is carrying current,there is a voltage dropin thelinedueto resistanceand inductanceoftheline.Theresult isthat receivingend voltage(V_R) ofthe line isgenerally lessthanthesending end voltage(V_S). Thisvoltagedrop(V_s−V_R) inthe line is expressed as a percentage ofreceiving end voltage V and is called voltage regulation. The difference involtageatthereceivingendofatransmissionline**betweenconditionsofno load and full load is called **voltage regulation** and is expressed as apercentage ofthereceivingendvoltage.

(ii) Transmissionefficiency. Thepowerobtainedatthereceivingendofatransmissionlineis generally less than the sending end power due to losses in the line resistance.

Theratioofreceivingendpowertothesendingendpowerofatransmissionlineisknownasthe **transmissionefficiency**oftheline

PERFORMANCEOFSINGLEPHASESHORTTRANSMISSIONLINES

Asstatedearlier,theeffectsoflinecapacitanceareneglectedforashorttransmissionline. Therefore, while studying the performance of such aline, only resistance and inductance of the linearetakenintoaccount.Theequivalentcircuitofasinglephaseshorttransmissionlineisshown in Fig.

Here,thetotallineresistanceandinductanceareshownasconcentratedorlumpedinsteadof being distributed. The circuit isa simple a.c. series circuit.

Let

I=loadcurrent

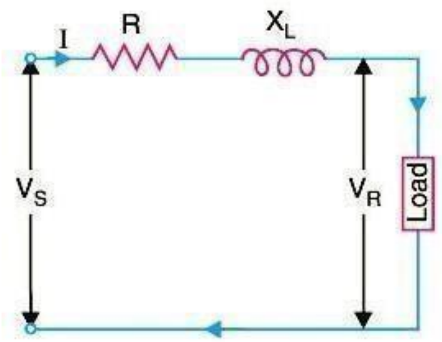
R=loopresistancei.e.,resistanceofbothconductorsX_L= loop reactance

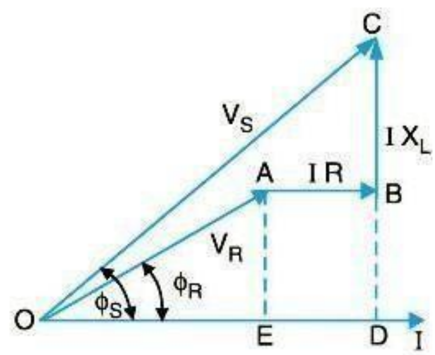
V_R=receivingendvoltage

cosφ_R=receivingendpowerfactor(lagging)

V_S=sendingendvoltage

cosφ_S=sendingendpowerfactor





The*phasordiagramofthelineforlaggingloadpowerfactorisshowninFig.Fromtherightangled traingle ODC, we get,

$$(OC)^2 = (OD)^2 + (DC)^2$$

or

$$V_S^2 = (OE + ED)^2 + (DB + BC)^2$$

$$= (V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2$$

$$\therefore \quad V_S = \sqrt{(V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2}$$

(*i*) %age Voltage regulation $= \dfrac{V_S - V_R}{V_R} \times 100$

(*ii*) Sending end *p.f.*, $\cos\phi_S = \dfrac{OD}{OC} = \dfrac{V_R \cos\phi_R + IR}{V_S}$

(*iii*) Power delivered $= V_R I_R \cos\phi_R$

Line losses $= I^2R$

Power sent out $= V_R I_R \cos\phi_R + I^2R$

%age Transmission efficiency $= \dfrac{\text{Power delivered}}{\text{Power sent out}} \times 100$

$$= \frac{V_R\, I_R \cos\phi_R}{V_R\, I_R \cos\phi_R + I^2 R} \times 100$$

AnapproximateexpressionforthesendingendvoltageVscanbeobtainedasfollows.DrawS perpendicular fromBandConOAproducedasshowninFig.ThenOCisnearlyequaltoOF

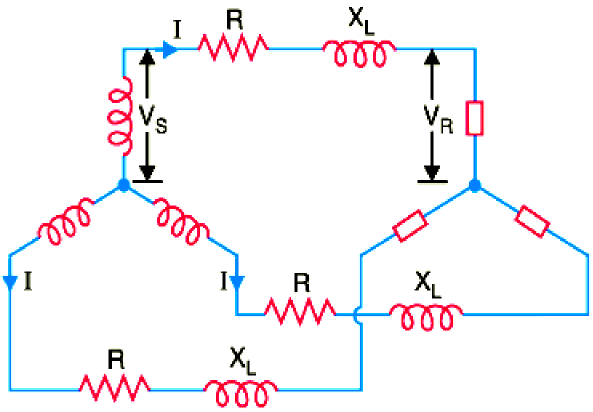
OC=OF=OA+AF=OA+AG+GF

=OA+AG+BH

$V_s=V_R+IR\cos\varphi_R+IX_L\sin\varphi_R$

THREE-PHASESHORTTRANSMISSIONLINES

For reasons associated with economy, transmission of electric power is done by 3-phase system. This system may be regarded as consisting of three single phase units, each wire transmitting one-third of the total power. As a matter of convenience, we generally analyze 3-phase systembyconsidering one phase only. Therefore, expression for regulation, efficiencyetc. derived for a single phase line can also be applied to a 3-phase system. Since only one phase is considered, phase values of 3-phase system should be taken. Thus, Vs and V_R are the phase voltages, whereas R and X_L are the resistance S and inductive reactance per phase respectively.



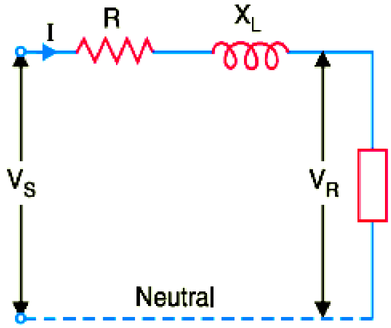


Fig (*i*) shows a *Y*-connected generator supplying a balanced *Y*-connected load through a transmissionline.Eachconductorhasaresistanceof*R*Ωandinductivereactanceof*X*Ω.Fig.(ii)shows one phase separately. The calculationscan now be made inthe same wayas for a single phase line.

EffectofLoadp.f.OnRegulationandEfficiency

Theregulationandefficiencyofatransmissionlinedependtoaconsiderableextentuponthe power factor of the load.

1. **Effecton regulation.**
Theexpressionforvoltageregulationofashorttransmissionlineisgivenby:

$$\%\text{age Voltage regulation} = \frac{I R \cos\phi_R + I X_L \sin\phi_R}{V_R} \times 100 \qquad (\textit{for lagging p.f.})$$

$$\%\text{age Voltage regulation} = \frac{I R \cos\phi_R - I X_L \sin\phi_R}{V_R} \times 100 \qquad (\textit{for leading p.f.})$$

Thefollowingconclusionscanbedrawnfromtheaboveexpressions:

(i) Whentheloadp.f.islaggingorunityorsuchleadingthat$IR\cos\varphi_R > IX_L\sin\varphi_R$,thenvoltageregulation is positive *i.e.* , receiving end voltage $V_R$will be less thanthe sending end voltage V_S.
(i) Foragiven$V_R$and*I*,thevoltageregulationofthelineincreaseswiththedecreaseinp.f.forlagging loads.
(i) Whenthe loadp.f. is leadingtothisextentthat $IX_L\sin\varphi_R > I\cos\varphi_R$,thenvoltage regulationisnegative*i.e.*thereceivingendvoltage V_R*is*morethanthesendingendvoltageV_S.
(iv)Foragiven$V_R$and*I*,thevoltageregulationofthelinedecreaseswiththedecreaseinp.f. for leading loads.

2. Effectontransmissionefficiency.

Thepowerdeliveredtotheloaddependsuponthepowerfactor.

$$P = V_R * I \cos\phi_R \quad \text{(For 1-phase line)}$$

$$I = \frac{P}{V_R \cos\phi_R}$$

$$P = 3\, V_R I \cos\phi_R \quad \text{(For 3-phase line)}$$

$$I = \frac{P}{3V_R \cos\phi_R}$$

It is clear that in each case, for a given amount ofpowerto be transmitted (P) and receiving end voltagePower FactorMeter(V_R),theload currentIisinverselyproportionaltotheload p.f.cosφ_R. Consequently, with the decrease in load p.f., the load current and hence the line losses are increased. This leads to the conclusion that transmission efficiency of a line decreases with the decrease in load Power Factor Regulator p.f. and vice-versa,

ABCDPARAMETERS

A major section of power system engineering deals in the transmission of electrical power from one particular place (eg. Generating station) to another like substations or distribution units with maximumefficiency. So its of substantial importance for power systemengineers to be thorough with its mathematical modeling. Thus the entire transmission system can be simplified to a **two port network** for the sake of easier calculations.

The circuit of a 2 port network is shown in the diagram below. As the name suggests, a 2 port network consists of an input port PQ and an output port RS.Eachport has 2 terminals to

Connectitselftotheexternalcircuit.Thusitisessentiallya2portora4terminalcircuit,havingSupplyend

voltage = VS and Supplyend current = IS given to the input port P Q.

AndthereistheReceivingendVoltage=VRandReceivingendcurrent=IRGivento the

output port R S. As shown in the diagram below.

Nowthe**ABCDparameters**orthetransmissionlineparametersprovidethelinkbetweenthesupply and receiving end voltages and currents, considering the circuit elements to be linear in nature.

Thustherelationbetweenthesendingandreceivingendspecificationsaregivenusing

ABCDparametersbytheequationsbelow.VS

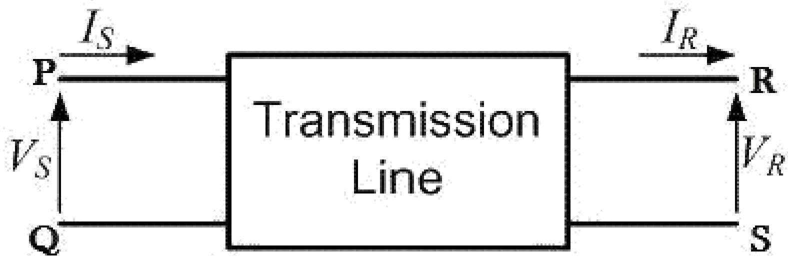
=AVR+BIR ———————-(1)

IS=CVR+DIR———————-(2)

NowinordertodeterminetheABCDparametersoftransmissionlineletusimposetherequired circuit conditions in different cases.

ABCDparameters,whenreceivingendisopencircuited

ThereceivingendisopencircuitedmeaningreceivingendcurrentIR=0.Applyingthisconditionto



equation(1)weget.

$$V_S = A\,V_R + B\,0 \Rightarrow V_S = A\,V_R + 0$$

$$A = \left.\frac{V_S}{V_R}\right|_{I_R = 0}$$

Thus its implies that onapplyingopen circuit condition to ABCD parameters,we get parameter A as theratioofsendingendvoltagetotheopencircuitreceivingend voltage.SincedimensionwiseAisa ratio of voltage to voltage, A is a dimension less parameter.

Applyingthesameopencircuitconditioni.eIR=0toequation(2)

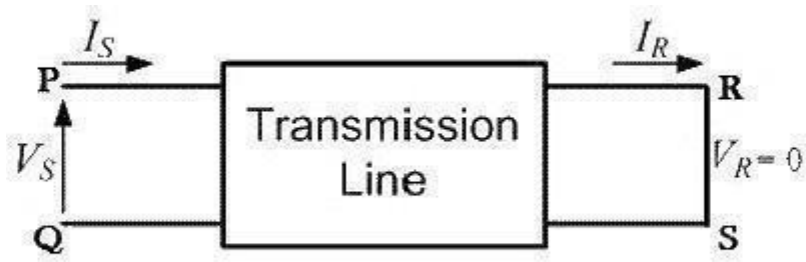
$$I_S = C\,V_R + D\,0 \Rightarrow I_S = C\,V_R + 0$$

$$C = \left.\frac{I_S}{V_R}\right|_{I_R = 0}$$

Thusitsimpliesthat onapplyingopen circuit condition to ABCDparametersoftransmissionline, we get parameter C as the ratio of sending end current to the open circuit receiving end voltage. Since dimension wise C is a ratio of current to voltage, its unit is mho.

ThusCistheopencircuitconductanceandisgivenbyC=IS⁄VRmho.

ABCDparameterswhenreceivingendisshortcircuited



ReceivingendisshortcircuitedmeaningreceivingendvoltageVR=0Applyingthisconditiontoequation (1) weget

$$V_S = A\,0 + B\,I_R \Rightarrow V_S = 0 + B\,I_R$$
$$B = \left.\frac{V_S}{I_R}\right|_{V_R = 0}$$

Thus its implies that onapplying short circuit conditiontoABCD parameters, we get parameter B as theratioofsendingendvoltagetotheshortcircuitreceivingendcurrent.SincedimensionwiseBisa ratio of voltage tocurrent, its unit is Ω. Thus B is the short circuit resistance and is

givenby

B=VS⁄IRΩ.

Applyingthesameshortcircuitconditioni.eVR=0toequation(2)weget

$$I_S = C\,0 + D\,I_R \Rightarrow I_S = 0 + D\,I_R$$
$$D = \left.\frac{I_S}{I_R}\right|_{V_R = 0}$$

Thus its implies that on applying short circuit condition to ABCD parameters, we get parameter D as the ratio ofsendingend current tothe shortcircuit receivingend current. Since dimension wise D isa ratioofcurrenttocurrent,it’sadimensionlessparameter.∴theABCDparametersoftransmissionline can be tabulated as:-

Parameter **Specification**

UnitA=VS/VRVoltageratio

UnitlessB=VS/IRShortcircuit

resistance Ω

C=IS/VROpencircuitconductancemho

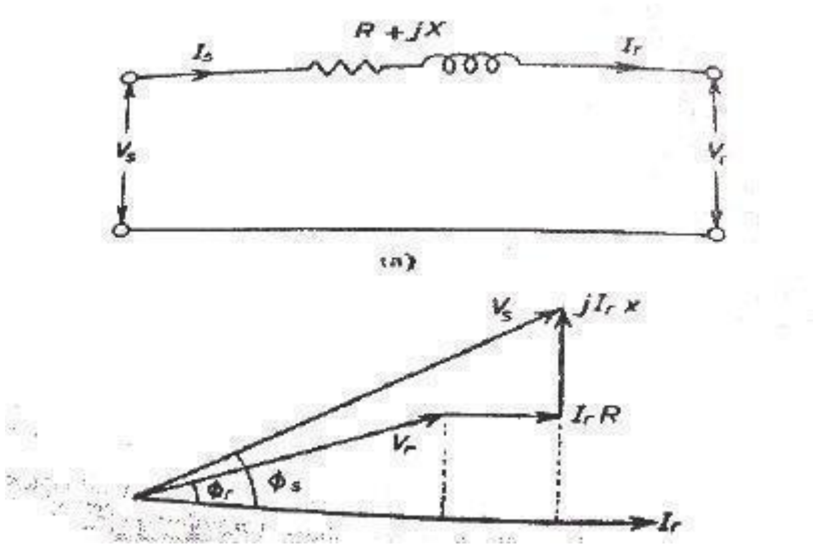
D=IS/IRCurrentratio Unitless

SHORTTRANSMISSIONLINE

Thetransmissionlineswhichhavelengthlessthan80kmaregenerallyreferredasshorttransmissionlines.

For short length, the shunt capacitance of this type of line is neglected and other parameters like resistanceandinductanceoftheseshortlinesarelumped,hencetheequivalentcircuitisrepresented as given below,

Let's draw the vector diagram for this equivalent circuit, taking receiving end current Ir as reference. The sending end and receiving end voltages make angle with that reference receiving end current, of φs and φr, respectively.



Astheshuntcapacitance ofthe lineis neglected, hencesendingendcurrentandreceivingendcurrent is same, i.e. Is = Ir.

Nowifweobservethevectordiagramcarefully,wewillget,VsisapproximatelyequaltoVr+

Ir.R.cosφr + Ir.X.sinφr that means,

Vs≅Vr+Ir.R.cosφr+Ir.X.sinφrastheitisassumedthatφs≅φr

Asthereisnocapacitance,duringnoloadconditionthecurrentthroughthelineisconsideredaszero,henceat noload condition,receivingend voltage is thesameas sendingend voltageAs perdentitionofvoltage regulation,

$$\% \text{ regulation} = \frac{V_s - V_r}{V_r} X\ 100\ \%$$

$$= \frac{I_r.R.\cos\varphi_r + I_r.X.\sin\varphi_r}{V_r} X\ 100\ \%$$

$$\text{per unit regulation} = \frac{I_r.R}{V_r}\cos\varphi_r + \frac{I_r.X}{V_r}\sin\varphi_r = v_r\cos\varphi_r + v_x\sin\varphi_r$$

$$A = \left.\frac{V_s}{V_r}\right| I_r = 0$$

Here,vrandvxaretheperunitresistanceandreactanceoftheshorttransmissionline.

Anyelectricalnetworkgenerallyhastwoinputterminalsandtwooutputterminals.Ifweconsider any complex electrical network in a blackbox, it will have two input terminals and output terminals. This network is called two – port network. Two port model of a network simplifies the network solving technique. Mathematicallya two port network can be solved by2 by2matrixes.

Atransmission as it is alsoan electrical network; line can be represented as twoport network. Hence twoportnetworkoftransmissionlinecanberepresentedas2by2matrixes.HeretheconceptofABCD parameters comes. Voltage and currents of the network can represented as ,

Vs=AVr+BIr… (1)

Is=CVr+DIr… (2)

WhereA,B,CandDaredifferentconstantofthenetwork.IfweputIr=0atequation(1),weget

Hence,Aisthevoltageimpressedatthesendingendpervoltatthereceivingendwhenreceivingendisopen.It is dimension less.

IfweputVr=0atequation(1),weget

$$B = \left.\frac{V_s}{I_r}\right| V_r = 0$$

Thatindicatesitisimpedanceofthetransmissionlinewhenthereceivingterminalsareshortcircuited.Thisparameteris referred as transfer impedance.

$$C = \left.\frac{I_s}{V_r}\right| I_r = 0$$

Cisthecurrentinamperesintothesendingendpervoltonopencircuitedreceivingend.Ithasthedimension of admittance.

$$D = \left.\frac{I_s}{I_r}\right| V_r = 0$$

Disthecurrentinamperesintothesendingendperamponshortcircuitedreceivingend.Itisdimensionless.

Nowfromequivalentcircuit,itisfoundthat,

Vs=Vr+IrZandIs=IrComparingtheseequationswithequation1and2weget,

A=1,B=Z,C=0andD=1.AsweknowthattheconstantA,B,CandDarerelatedforpassivenetworkas

Here,A=1,B=Z,C=0andD=1AD− BC

= 1.

⇒1.1−Z.0=1

Sothevaluescalculatedarecorrectforshorttransmissionline.Fromaboveequation(1),

$$V_s = AV_r + BI_r$$

WhenIr=0thatmeansreceivingendterminalsisopencircuitedandthenfromtheequation1,weget receiving end voltage at no load

$$V_r' = \frac{V_s}{A}$$

andasperdefinitionofvoltageregulation,

$$\%\ \text{voltage regulation} = \frac{V_s / A - V_r}{V_r} X100\ \%$$

EfficiencyofShortTransmissionLine

Theefficiencyofshortlineassimpleasefficiencyequationofanyotherelectricalequipment,thatmeans

$$\%\ \text{efficiency}\ (\mu) = \frac{\text{Power received at receiving end}}{\text{Power delivered at sending end}} X\ 100\ \%$$

$$\%\ \mu = \frac{\text{Power received at receiving end}}{\text{Power received at receiving end} + 3I_r^2.R} X\ 100\ \%$$

MEDIUMTRANSMISSIONLINES

Inshorttransmissionlinecalculations,theeffectsofthelinecapacitanceareneglectedbecause such lines have smaller lengths and transmit power at relativelylow voltages (< 20 kV). However, as the length and voltage of the line increase, the capacitance graduallybecomes of greater importance.

Since medium transmission lineshave sufficient length (50-150 km) and usually operate atvoltagesgreaterthan20kV,theeffectsofcapacitancecannotbeneglected.Therefore,inordertoobtain reasonable accuracyin medium transmission line calculations, the linecapacitance must betaken into consideration.

The capacitance is uniformly distributed over the entire length of the line. However, in order to make the calculations simple, the line capacitance is assumed to be lumped or concentrated in the form ofcapacitors shunted across the line at one ormore points. Sucha treatment of localising the linecapacitancegivesreasonablyaccurateresults.Themostcommonlyusedmethods(knownas localised capacitance methods) for the solution of medium transmissions lines are:

(i) Endcondensermethod

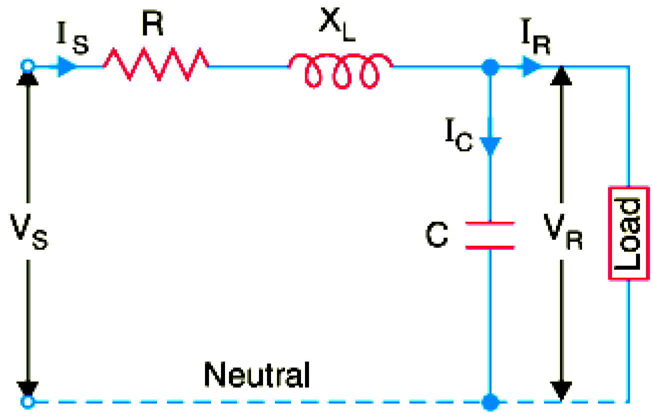
(ii) NominalTmethod

(iii) Nominalπmethod.

Although the above methods are used for obtaining the performance calculations of medium lines, theycanalsobe used for short lines iftheir line capacitance is given inaparticular problem.

i) EndCondenserMethod

In this method, the capacitance of the line is lumped or concentrated at the receiving or load end as shown in Fig. This method of localising the line capacitance at the load end overestimates the effects of capacitance. In Fig, one phase of the 3-phase transmission line is shown as it is more convenient to work in phase instead of line-to-line values.



Let

I_R=loadcurrentperphaseR
= resistance per phase
X_L=inductivereactanceperphaseC
= capacitance per phase
cosφ_R=receivingendpowerfactor(lagging)V_S=
sending end voltage per phase

The*phasordiagramforthecircuitisshowninFigTakingthereceivingendvoltageVRasthereference phasor,

we have, $\vec{V_R} = V_R + j\,0$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

Capacitive current, $\vec{I_C} = j\,\vec{V_R}\,\omega C = j\,2\,\pi f C\,\vec{V_R}$

Thesendingendcurrent$I_s$isthephasorsumofloadcurrent$I_R$andcapacitivecurrentI_Ci.e.

$$\vec{I_S} = \vec{I_R} + \vec{I_C}$$
$$= I_R(\cos\phi_R - j\sin\phi_R) + j\,2\pi f C\,V_R$$
$$= I_R\cos\phi_R + j(-I_R\sin\phi_R + 2\pi f C V_R)$$
$$= \vec{I_S}\,\vec{Z} = \vec{I_S}\,(R + jX_L)$$
$$\vec{V_S} = \vec{V_R} + \vec{I_S}\,\vec{Z} = \vec{V_R} + \vec{I_S}\,(R + jX_L)$$

Thus,themagnitudeofsendingendvoltage$V_S$canbecalculated.

$$\%\text{ Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

$$\%\text{ Voltage transmission efficiency} = \frac{\text{Power delivered / phase}}{\text{Power delivered / phase + losses / phase}} \times 100$$
$$= \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I_S^2 R} \times 100$$

Limitations

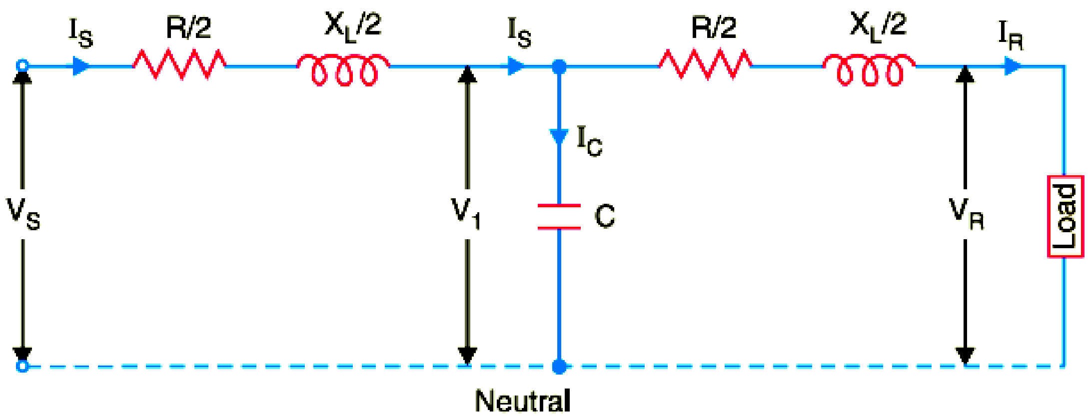
Althoughendcondensermethodforthesolutionofmediumlinesissimpletoworkout calculations, yet it has the following drawbacks:

(i) Thereisaconsiderableerror(about10%)incalculationsbecausethedistributed capacitance has been assumed to be lumped or concentrated.

(ii) Thismethodoverestimatestheeffectsoflinecapacitance.

ii) NominalTMethod

Inthis method, thewhole line capacitanceisassumed tobeconcentratedatthe middlepoint of the line and half the line resistance and reactance are lumped on its either side as shown in Fig. Therefore, in this arrangement, full charging current flows over half the line. In Fig. one phase of 3-phase transmission line isshown as it isadvantageous towork inphase instead of line-to-line values.



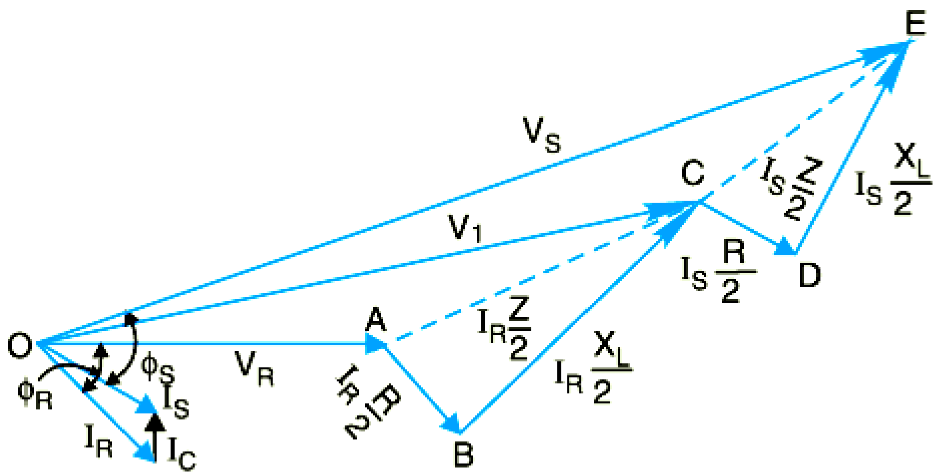
Let

I_R=loadcurrentperphase;R=
resistance per phase
X_L=inductivereactanceperphase;
C=capacitanceperphase
cosφ$_R$=receivingendpowerfactor(lagging);V_S=
sending end voltage/phase
V_1=voltageacrosscapacitorC

The*phasordiagramforthecircuitisshowninFig.TakingthereceivingendvoltageV$_R$asthereference phasor, we have,

Receiving end voltage, $\vec{V_R} = V_R + j\,0$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$



Voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\vec{Z}/2$

$$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\frac{X_L}{2}\right)$$

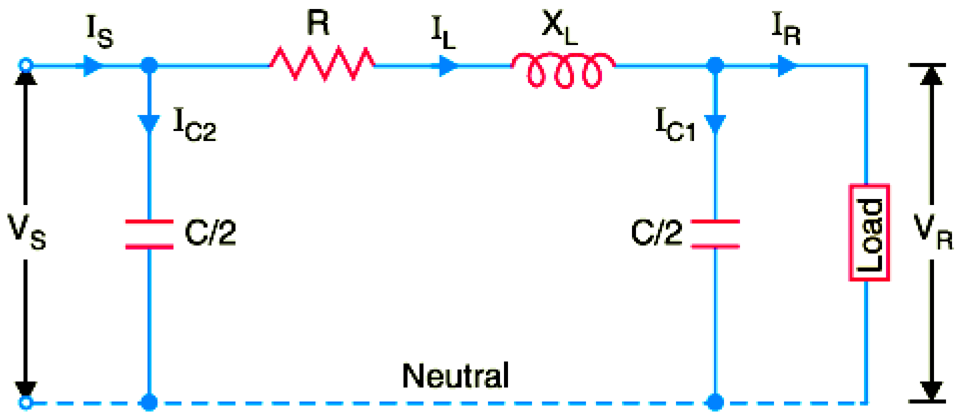
Capacitive current, $\vec{I_C} = j\,\omega\,C\,\vec{V_1} = j\,2\pi f\,C\,\vec{V_1}$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

Sending end voltage, $\vec{V_S} = \vec{V_1} + \vec{I_S}\,\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

iii) NominalπMethod

In thismethod,capacitance ofeachconductor(i.e.,linetoneutral) isdividedinto twohalves; one half being lumped at the sending end and the other half at the receiving end as shown in Fig. It is obviousthatcapacitanceatthesendingendhasnoeffectonthelinedrop.However,itschargingcurrentmustbe added to line current in order to obtain the total sending end current.



Let

I_R= loadcurrentperphaseR=resistanceperphase

X_L=inductivereactanceperphaseC=capacitanceperphase

cosφ_R=receivingendpowerfactor(lagging)V_S=sendingendvoltageperphase

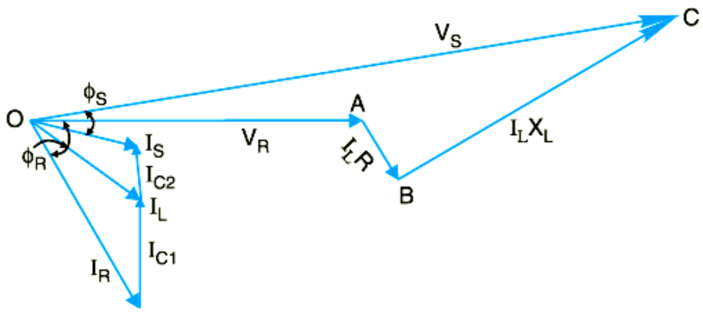
The*phasordiagramforthecircuitisshowninFig.Takingthereceivingendvoltageasthereference phasor, we have,

$$\vec{V_R} = V_R + j\,0$$

Load current, $$\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$$

Charging current at load end is

$$\vec{I_{C1}} = j\,\omega\,(C/2)\,\vec{V_R} = j\,\pi\,f\,C\,\vec{V_R}$$



Line current, $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$

Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I_L}\,\vec{Z} = \vec{V_R} + \vec{I_L}\,(R + jX_L)$

Charging current at the sending end is

$$\vec{I_{C2}} = j\,\omega\,(C/2)\,\vec{V_S} = j\,\pi\,f\,C\,\vec{V_S}$$

∴ Sending end current, $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$

MEDIUMTRANSMISSIONLINE

Thetransmissionlinehaving itseffectivelengthmorethan80 kmbutlessthan250 kmisgenerally referred to as a **medium transmission line**. Due to the line length being considerably high, admittanceY ofthe networkdoesplaya role incalculatingtheeffectivecircuitparameters,unlike in thecaseofshorttransmissionlines.Forthisreasonthemodellingofa **mediumlengthtransmission line** isdoneusinglumpedshuntadmittancealongwiththelumpedimpedanceinseriestothecircuit. These lumped parameters of a medium length transmission line can be represented using two different models, namely.

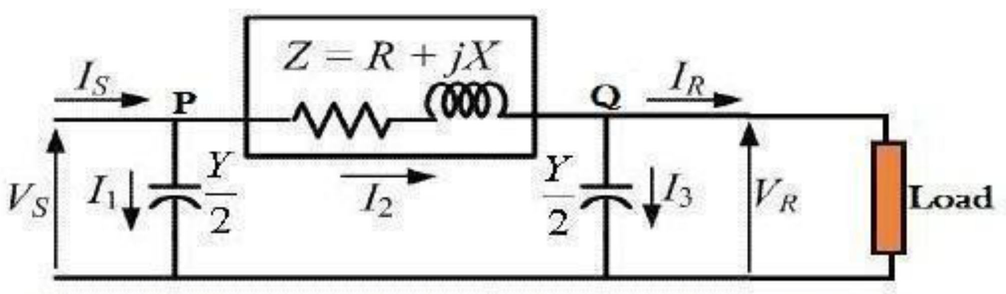
(i) Nominal**Π**representation.

(ii) Nominal**T**representation.

Let'snowgointothedetaileddiscussionoftheseabovementionedmodels.

NominalΠrepresentationofamediumtransmissionline

Incaseofanominal**Π**representation,thelumpedseriesimpedanceisplacedatthemiddleofthe circuitwhereastheshuntadmittancesareattheends.AswecanseefromthediagramoftheΠnetwork below,thetotallumpedshuntadmittance isdividedinto2equalhalves,andeachhalfwithvalueY⁄2isplaced at both the sending and the receiving end while the entire circuit impedance is between the two. The shapeofthecircuitsoformedresemblesthatofasymbol**Π**,andforthisreasonitisknownasthe nominalΠrepresentationofamediumtransmissionline.Itismainlyusedfordeterminingthe general circuit parameters and performing load flow analysis.



Nominal Π network of medium transmission line.

Aswecanseehere,VSandVRisthesupplyandreceivingendvoltagesrespectively,andIsisthe current flowing through the supply end.
IRisthecurrentflowingthroughthereceivingendofthecircuit.

I1andI3arethevaluesofcurrentsflowingthroughtheadmittances.AndI2isthecurrentthroughthe impedance Z.

NowapplyingKCL,atnodeP,weget.IS=I1+I2—————(1)

SimilarlyapplyingKCL,tonodeQ.I2=I3+IR—————(2)Now substituting equation (2) to equation(1)

IS=I1+I3+IR

$$= \frac{Y}{2}V_S + \frac{Y}{2}V_R + I_R \text{--------}(3)$$

NowbyapplyingKVLtothecircuit,VS=VR+ZI2

$$= V_R + Z(V_R\frac{Y}{2} + I_R)$$

$$= (Z\frac{Y}{2} + 1)\, V_R + ZI_R \text{ ----------}(4)$$

Now substituting equation (4) to equation (3), we get.

$$I_s = \frac{Y}{2}[(\frac{Y}{2}Z + 1)V_R + ZI_R] + \frac{Y}{2}V_R + I_R$$

$$= Y(\frac{Y}{4}Z + 1)V_R + (\frac{Y}{2}Z + 1)I_R \text{ -----------}(5)$$

Comparingequation(4)and(5)withthestandardABCDparameterequationsVS=A VR + B IR

IS=CVR+DIR

Wederivetheparametersofamediumtransmissionlineas:

$$A = (\frac{Y}{2}Z + 1)$$

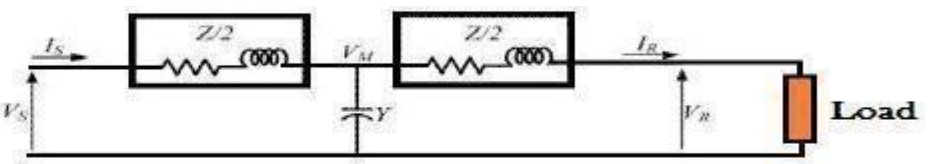
$$B = Z\ \Omega$$

$$C = Y(\frac{Y}{4}Z + 1)$$

$$D = (\frac{Y}{2}Z + 1)$$

NOMINALTREPRESENTATIONOFAMEDIUMTRANSMISSIONLINE

In the **nominal T** model of a medium transmission line the lumped shunt admittance is placed in themiddle,whilethenetseries impedance is divided intotwoequal halvesandandplaced oneitherside of the shunt admittance. The circuit so formed resembles the symbol of a capital **T**, and hence is known as the nominal T network ofa medium length transmission line and is shown in the diagram below.



Nominal T representation of a medium transmission line.

Here also Vs and Vr is the supplyand receivingend voltages respectively, andIs is the current flowing through the supply end. Ir is the current flowing through the receiving end of the circuit. Let M be a node at the midpoint of the circuit, and the drop at M, be given by Vm.ApplyingKVLtotheabovenetworkweget

$$\frac{V_S - V_M}{Z/2} = Y V_M + \frac{V_m - V_R}{Z/2}$$

$$\text{Or } V_M = \frac{2(V_S + V_R)}{YZ + 4} \text{------------(6)}$$

And the receiving end current

$$\text{Or } I_R = \frac{2(V_M - V_R)}{Z/2} \text{------------(7)}$$

Now substituting V_M from equation (6) to (7) we get,

$$\text{Or } I_R = \frac{[(2V_S + V_R)/YZ+4] - V_R}{Z/2}$$

Rearranging the above equation:

$$V_S = (\frac{Y}{2}Z + 1)V_R + Z(\frac{Y}{4}Z + 1)I_R \text{------------(8)}$$

Nowthesendingendcurrentis

Is=YVM+IR——————(9)

SubstitutingthevalueofVMtoequation(9)weget,

$$\text{Or } I_S = Y V_R + (\frac{Y}{2}Z + 1)I_R \text{------------(10)}$$

AgaincomparingComparingequation(8)and(10)withthestandardABCDparameter equations

VS=AVR+BIR IS =

CVR + DIR

TheparametersoftheTnetworkofamediumtransmissionlineare

$$A = (\frac{Y}{2}Z + 1)$$

$$B = Z(\frac{Y}{4}Z + 1)\ \Omega$$

$$C = Y \text{ mho}$$

$$D = (\frac{Y}{2}Z + 1)$$

LONGTRANSMISSIONLINES

It is well known that line constants of the transmission line are uniformlydistributed over the entire length of the line. However, reasonable accuracy can be obtained in line calculations for short andmediumlinesbyconsideringtheseconstantsaslumped.Ifsuchanassumptionoflumpedconstants is applied to long transmission lines (having length excess of about 150 km), it is found that serious errors are introduced in the performance calculations. Therefore, in order to obtain fair degree of accuracyin the performance calculations of long lines, the line constants are considered as uniformly distributed throughout the length of the line. Rigorous mathematical treatment is required for the solution ofsuch lines. Fig shows the equivalent circuit ofa 3-phase longtransmission line ona phase-neutralbasis. The whole line length is divided into n sections, each section having line constants 1 /n th of those for the whole line. The following points mayby noted :

(i) Thelineconstantsareuniformlydistributedovertheentirelengthoflineasisactuallythecase.

(ii) Theresistanceandinductivereactancearetheserieselements.

(ii) Theleakagesusceptance(B)andleakageconductance(G)areshuntelements.

(iii) Theleakagesusceptanceisduetothefactthatcapacitanceexistsbetweenlineandneutral.Theleakage conductance takes into account the energy losses occurring through leakage over the

$$= \sqrt{G^2 + B^2} .$$

insulatorsorduetocoronaeffectbetweenconductors.Admittance

(iv) Theleakagecurrentthroughshuntadmittanceismaximumatthesendingendofthelineand decreasescontinuouslyasthereceivingendofthecircuitisapproachedatwhichpointitsvalueiszero.

ANALYSISOFLONGTRANSMISSIONLINE(RIGOROUSMETHOD)

Fig. shows one phase and neutral connection of a 3-phase line with impedance and shunt admittance of the line uniformly distributed.

Considerasmallelementinthelineoflengthdxsituatedatadistancexfromthereceiving end.

Let

z=series impedanceofthelineperunitlengthy

=shuntadmittanceofthelineperunit length

V=voltageattheendofelementtowardsreceivingend

V+dV=voltageattheendofelementtowardssendingendI

+dI=currententeringtheelementdx

I=currentleavingtheelementdxThen
for the small element dx,
zdx=seriesimpedancey dx
=shuntadmittance
Obviously,dV=Iz dx

$$\frac{dV}{dx} = I z$$

Now,thecurrententeringtheelementisI+dIwhereasthecurrentleavingtheelementisI.The difference in the currents flows through shunt admittance of the element i.e.,
dI=Currentthroughshuntadmittanceofelement=Vydx

or $$\frac{dI}{dx} = V y \qquad \text{...}(ii)$$

Differentiating eq. (*i*) w.r.t. *x*, we get,

$$\frac{d^2V}{dx^2} = z\frac{dI}{dx} = z(Vy) \qquad \left[\because \frac{dI}{dx} = V\,y \text{ from exp.}(ii)\right]$$

or $$\frac{d^2V}{dx^2} = yzV \qquad \text{...}(iii)$$

The solution of this differential equation is

$$V = k_1\cosh\left(x\sqrt{yz}\right) + k_2\sinh\left(x\sqrt{yz}\right) \qquad \text{...}(iv)$$

or $$\frac{dI}{dx} = V y \qquad \text{...}(ii)$$

Differentiating eq. (*i*) w.r.t. *x*, we get,

$$\frac{d^2V}{dx^2} = z\frac{dI}{dx} = z(Vy) \qquad \left[\because \frac{dI}{dx} = V\,y \text{ from exp.}(ii)\right]$$

or $$\frac{d^2V}{dx^2} = yzV \qquad \text{...}(iii)$$

The solution of this differential equation is

$$V = k_1\cosh\left(x\sqrt{yz}\right) + k_2\sinh\left(x\sqrt{yz}\right) \qquad \text{...}(iv)$$

Equations(iv)and(v)givetheexpressionsforVandIintheformofunknownconstants$k_1$andK_2 .Thevaluesof$k_1$and$k_2$canbefoundbyapplyingendconditionsasunder

$$\text{At } x = 0, \quad V = V_R \text{ and } I = I_R$$

Putting these values in eq. (*iv*), we have,

$$V_R = k_1 \cosh 0 + k_2 \sinh 0 = k_1 + 0$$

$$\therefore \quad V_R = k_1$$

Similarly, putting $x = 0$, $V = V_R$ and $I = I_R$ in eq. (*v*), we have,

$$I_R = \sqrt{\frac{y}{z}}\left[k_1 \sinh 0 + k_2 \cosh 0\right] = \sqrt{\frac{y}{z}}\left[0 + k_2\right]$$

$$\therefore \quad k_2 = \sqrt{\frac{z}{y}}\, I_R$$

Substituting the values of k_1 and k_2 in eqs. (*iv*) and (*v*), we get,

$$V = V_R \cosh(x\sqrt{y\,z}) + \sqrt{\frac{z}{y}}\, I_R \sinh(x\sqrt{y\,z})$$

and

$$I = \sqrt{\frac{y}{z}} V_R \sinh(x\sqrt{y\,z}) + I_R \cosh(x\sqrt{y\,z})$$

The sending end voltage (V_S) and sending end current (I_S) are obtained by putting $x = l$ in the above equations *i.e.*,

$$V_S = V_R \cosh(l\sqrt{yz}) + \sqrt{\frac{z}{y}} I_R \sinh(l\sqrt{yz})$$

$$I_S = \sqrt{\frac{y}{z}} V_R \sinh(l\sqrt{yz}) + I_R \cosh(l\sqrt{yz})$$

Now, $l\sqrt{yz} = \sqrt{ly \cdot lz} = \sqrt{YZ}$

and $\sqrt{\frac{y}{z}} = \sqrt{\frac{yl}{zl}} = \sqrt{\frac{Y}{Z}}$

where Y = total shunt admittance of the line

Z = total series impedance of the line

Therefore, expressions for V_S and I_S become :

$$\mathbf{V}_S = \mathbf{V}_R \cosh\sqrt{\mathbf{YZ}} + \mathbf{I}_R \sqrt{\frac{\mathbf{Z}}{\mathbf{Y}}} \sinh\sqrt{\mathbf{YZ}}$$

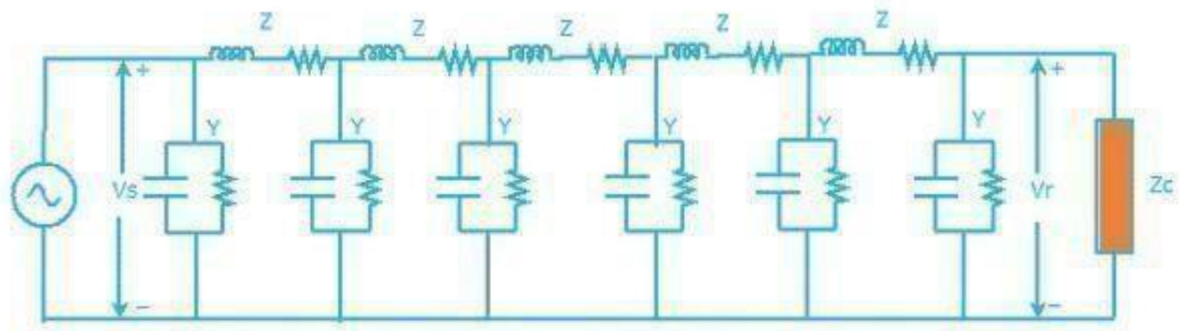
$$\mathbf{I}_S = \mathbf{V}_R \sqrt{\frac{\mathbf{Y}}{\mathbf{Z}}} \sinh\sqrt{\mathbf{YZ}} + \mathbf{I}_R \cosh\sqrt{\mathbf{YZ}}$$

It is helpful to expand hyperbolic sine and cosine in terms of their power series.

$$\cosh\sqrt{YZ} = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \ldots\ldots\right)$$

$$\sinh\sqrt{YZ} = \left(\sqrt{YZ} + \frac{(YZ)^{3/2}}{6} + \ldots\ldots\right)$$

LONGTRANSMISSIONLINE(ABCDPARAMETERS)



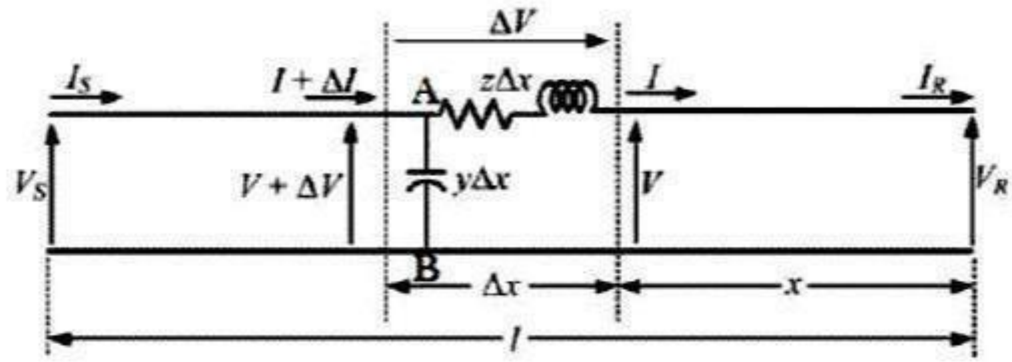
Long Transmission Line model

Apowertransmissionlinewithitseffectivelengthofaround250Kmsorabove is referred to as a **long transmission line**. Calculations related to circuitparameters (ABCD parameters) of such a power transmission is not that simple, as was the case for a short or medium transmission line. The reason being that, the effective circuit length in this case is much higher than what it was for the former models(long and medium line) and, thus ruling out the approximations considered there like.

a) Ignoringtheshuntadmittanceofthenetwork,likeinasmalltransmissionlinemodel.
b) Consideringthecircuitimpedanceandadmittancetobelumpedandconcentratedata point as was the case for the medium linemodel.

Rather, for all practical reasons we should consider the circuit impedance and admittancetobedistributedovertheentirecircuitlengthasshowninthefigurebelow.

The calculations of circuit parameters for this reason is going to be slightly more rigorous as we will see here. For accurate modeling to determine circuitparameters letusconsiderthecircuit ofthe**longtransmission line**asshowninthediagrambelow.



Long Transmission Line.

Here a line of length l> 250km is supplied witha sending end voltage and current ofVS andISrespectively,whereastheVRandIRarethevaluesofvoltageandcurrent obtained fromthereceivingend. LetsusnowconsideranelementofinfinitelysmalllengthΔxata distance x from the receiving end as shown in the figure where.

V = value of voltage just before entering the

element Δx. I = value of current just before

enteringtheelementΔx.V+ΔV=voltageleaving the

element Δx.

I+ΔI= current leaving the

element Δx. ΔV = voltage drop

across element Δx. zΔx = series

impedenceofelementΔxyΔx=

shunt admittance ofelement Δx

WhereZ=zlandY=ylarethevaluesoftotalimpedanceandadmittanceofthelong

transmission line.

∴ThevoltagedropacrosstheinfinitelysmallelementΔxisgivenby ΔV

= I z Δx

OrIz=ΔV/Δx

OrIz=dV/dx————————————(1)

NowtodeterminethecurrentΔI,weapplyKCLtonode

A.ΔI=(V+ΔV)yΔx=VyΔx+ΔVyΔx

SincethetermΔVyΔxistheproductof2infinitelysmallvalues,wecanignoreitforthesake of easier calculation.

∴WecanwritedI⁄dx=Vy———————(2)Nowderevatingbothsidesofeq (1)w.r.tx,d^2V/dx^2=z dI⁄dxNow substituting dI⁄ dx = V yfrom equation (2) $d^2 V / d x^2 = zyV$

or$d^2V/dx^2-zyV=0$————(3)

Thesolutionoftheabovesecondordersdifferentialequationis givenby.$V=A1e^{x\sqrt{yz}}+A2e^{-x\sqrt{yz}}$—————(4)

Derivatingequation(4)w.r.tox.

$dV/dx=\sqrt{(yz)}A1e^{x\sqrt{yz}}-\sqrt{(yz)}A2e^{-x\sqrt{yz}}$—————(5)Nowcomparingequation(1)withequation(5)

$$I=\frac{dV}{dx}=\frac{zA_1e^{x\sqrt{(yz)}}}{\sqrt{(z/y)}}-\frac{zA_1e^{-x\sqrt{(yz)}}}{\sqrt{(z/y)}}\text{-----------------}(6)$$

NowtogofurtherletusdefinethecharacteristicimpedanceZcandpropagationconstantδof a long transmission line as

$Zc=\sqrt{(z/y)}$ Ω$\delta=\sqrt{(yz)}$

Thenthevoltageandcurrentequationcanbeexpressedintermsofcharacteristicimpedance and propagation constant as

$V=A1e^{\delta x}+A2e^{-\delta x}$————(7)

$I=A1/Zce^{\delta x}+A2/Zce^{-\delta x}$—————(8)

Nowatx=0,V=VRandI=Ir.Substitutingtheseconditionstoequation(7)and(8) respectively. VR = A1 + A2 —————(9) IR=A1/Zc+A2/Zc—————(10)

Solving equation (9) and(10),Wegetvalues of A1andA2 as,

$A1=(VR+ZCIR)$

$/2$ And $A1=(VR$

$-ZCIR)$

Nowapplyinganotherextremeconditionatx=l,wehaveV=VSandI=IS.

NowtodetermineVSandISwesubstitutexbylandputthevaluesofA1andA2inequation(7) and (8) we get

$$VS=(VR+ZCIR)e^{\delta l}/2+(VR-ZCIR)e^{-\delta l}/2 \text{———————}(11)$$

$$IS=(VR/ZC+IR)e^{\delta l}/2-(VR/ZC-IR)e^{-\delta l}/2 \text{————————}(12)$$

Bytrigonometricandexponentialoperatorswe know

$\sinh \delta l = (e^{\delta l} - e^{-\delta l})/2$

And $\cosh\delta l=(e^{\delta l}+e^{-\delta l})/2$

∴equation(11)and(12)canbere-

written as

$VS=VR\cosh\delta l+ZCIR \sinh$

$\delta l IS=(VR\sinh\delta l)/ZC+$

$IR\cosh\delta l$

ThuscomparingwiththegeneralcircuitparametersequationwegettheABCD parameters of a long transmission line as,

$C=\sinh\delta l/ZC$ $A=\cosh\delta l$ $D=\cosh\delta l$ $B=ZC\sinh\delta l$

CIRCLE DIAGRAMS

Transmission line problems often involve manipulations with complex numbers, making the time and effort required for a solutionseveral times greater than that needed for a similar sequence of operations on real numbers. One means of reducing the labor without seriouslyaffectingtheaccuracyisbyusingtransmission-linecharts.Probablythemostwidely used one is the Smith chart. Basically, this diagram shows curves of constant resistance and constant reactance; thesemayrepresent either input impedance or load impedance. The latter, ofcourse,istheinputimpedanceofazero-lengthline.Anindicationoflocationalongtheline is also provided, usually in terms of the fraction of a wavelength from a voltage maximum or minimum. Although they are not specifically shown on the chart,the standing-wave ratio and themagnitude and angleofthe reflectioncoefficientareveryquicklydetermined. As amatter of fact, the diagram isconstructed within acircle ofunit radius,usingpolarco-ordinates,thebasicrelationshipuponwhichthechartisconstructedis

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

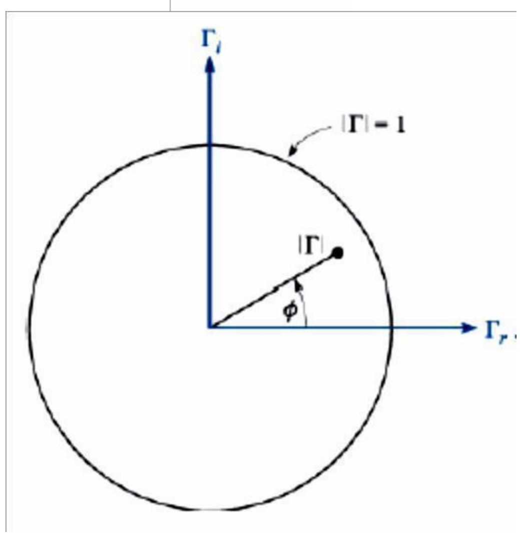
Theimpedanceswhichweplotonthechartwillbenormalizedwithrespecttothecharacteristicimpedance.

Let us identify the normalized load impedance as z_L

$$z_L = r + jx = \frac{Z_L}{Z_0} = \frac{R_L + jX_L}{Z_0}$$

$$\Gamma = \frac{z_L - 1}{z_L + 1}$$

$$z_L = \frac{1 + \Gamma}{1 - \Gamma}$$



FACTORSGOVERNINGTHEPERFORMANCEOFTRANSMISSIONLINES

SURGE IMPEDANCE:

The characteristic impedance or surge impedance (usually written Z_0) of a uniform transmission line is the ratio of the amplitudes of voltage and current of a single wave propagating along the line; that is, a wave travelling in one direction in the absence of reflections in the other direction. Characteristic impedance is determined by the geometryandmaterialsofthetransmissionlineand,foruniformline,isnotdependent on its length. The SI unit of characteristic impedance is the ohm.

Thecharacteristicimpedanceofalosslesstransmissionlineispurelyreal,withno reactivecomponent.Energysuppliedbyasourceatoneendofsuchalineistransmittedthrought he line without being dissipated inthe line itself. Atransmission line offinite length (lossless or lossy) that is terminated at one end with an impedance equal to the characteristic impedance appears to the source like an infinitely long transmission line and produces no reflections.

THESURGEIMPEDANCELOADING:

The surge impedance loading (SIL) ofa line is the power load at whichthe net reactive power is zero. So, if your transmission line wants to "absorb" reactive power, the SILis the amount of reactive power you would haveto produceto balanceit out to zero.Youcancalculateit bydividingthesquareoftheline-to-linevoltagebythe line's characteristic impedance. Transmission lines can be considered as, a smallinductance inseriesandasmallcapacitancetoearth, -averylargenumberofthiscombinations, in series. Whatever voltage drop occurs due to inductance gets compensated by capacitance. If this compensation is exact, you have surge impedance loading and no voltagedropoccursforaninfinitelengthor,afinite lengthterminated byimpedanceof this value (SIL load). (Loss-less line assumed!). Impedance ofthis line (Zs) can be proved to be sq. root (L/C). If capacitive compensation is more than required, which mayhappen on an unloaded EHVline, and then you havevoltage riseat theotherend, theFerrantieffect. Althoughgiveninmanybooks,it continuesto remainaninteresting discussion always.

Thecapacitivereactivepowerassociatedwithatransmissionlineincreasesdirectlyasthesquareof the voltage and is proportional to line capacitance and length.

Capacitancehastwoeffects:

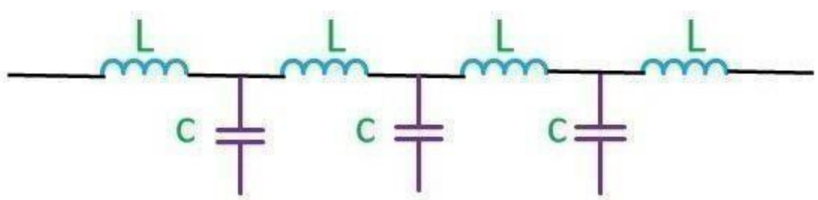
1 Ferrantieffect

2 Riseinthevoltageresultingfromcapacitivecurrentofthelineflowingthroughthe source impedances at the terminations of the line.

SILisSurgeImpedanceLoadingandiscalculatedas(KVxKV)/Zstheirunitsare megawatts. WhereZsisthesurgeimpedance....beaware...onethingisthesurgeimpedanceand other very different is the surge impedance loading.

SURGEIMPEDANCELOADING

Capacitance and reactance are the main parameters of the transmission line. It is distributed uniformly along the line. These parameters are also called distributed parameters. When the voltage drops occur in transmission line due to inductance, it is compensated by the capacitance of the transmission line.

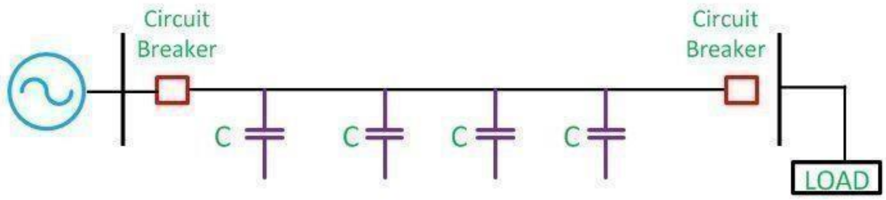


Distributed Parameters of transmission line Circuit Globe

Thetransmissionlinegeneratescapacitivereactivevolt-amperesinitsshunt capacitanceand absorbingreactivevolt-amperesinitsseriesinductance.The loadat whichthe inductiveand capacitivereactivevolt-amperesareequalandopposite,suchloadiscalledsurgeimpedanceload.

Itisalso called naturalloadofthetransmissionlinebecausepowerisnotdissipatedintransmission. Insurgeimpedance loading, thevoltageandcurrentareinthesamephaseat allthepointoftheline. When thesurgeimpedanceofthe line hasterminatedthepowerdeliveredbyit iscalledsurge impedance loading.

Shuntcapacitancechargesthetransmissionlinewhenthecircuitbreakeratthesendingendofthelineis close. As shown below

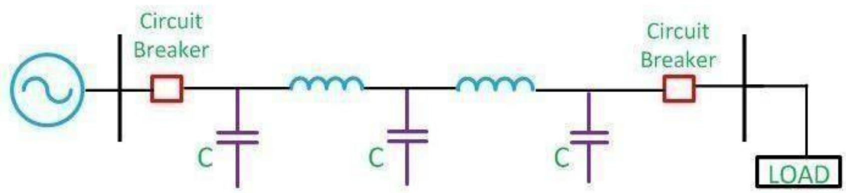


Shunt Capacitance Charges

LetV=phasevoltageatthereceivingendL=
series inductance per phase
X_L = series inductance reactance per phase
X_C=shuntcapacitancereactanceperphaseZ_o
= surge impedance loading per phase
Capacitivevolt-amperes(VAr)generatedintheline

$$= \frac{V^2}{X_C} = V^2 wc \; per\; phase$$

Theseries inductanceofthe lineconsumestheelectricalenergywhenthesending and receivingend terminals are closed.

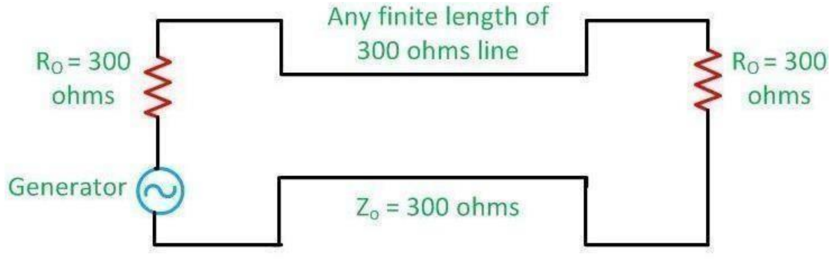


Series Inductance consume energy

Inductivereactivevolt-amperes(VAr)absorbedbytheline

$$= I^2 X_L = I^2 wL$$

Undernaturalload,thereactivepowerbecomesterminated,andtheloadbecomespurelyresistive.



Surge Impedance Loading

Anditiscalculatedbytheformulagivenbelow

$$V^2wC = I^2wL$$

$$\frac{V}{I} = \frac{\sqrt{L}}{\sqrt{C}} = Z_0$$

Surgeimpedance loadingisalso definedasthepowerload inwhichthetotalreactivepowerofthe lines becomeszero.Thereactivepowergeneratedbytheshunt capacitance isconsumedbytheseries inductance of the line.

IfPoisitsnaturalloadofthelines,$(SIL)_{1\emptyset}$ofthelineperphase

$$(SIL)_{1\emptyset} = P_O = V_p I_p cos\emptyset$$

Sincetheloadispurelyresistive,

$$cos\emptyset = 1$$

$$P_O = V_P I_P = V_P \frac{V_P}{Z_O}$$

$$P_O = \frac{V_P^2}{Z_O} W/phase$$

Thus,perphasepowertransmittedundersurgeimpedanceloadingis$(V_P{}^2)/Z_O$watts,Where$V_p$isthe phase voltage.

$$Line\ voltage\ V_L = \sqrt{3}V_P$$

$$(SIL)_{3\emptyset} = 3P_O = \frac{3V_P^2}{Z_O} = \frac{V_L^2}{Z_O}\ W$$

IfkVListhereceivingendvoltageinkV,then

$$(SIL)_{3\emptyset} = \frac{(kV_L)^2}{Z_O}\ \mathrm{MW}$$

Surgeimpedanceloadingdependsonthevoltageofthetransmissionline.Practicallysurge impedance loading always less than the maximum loading capacityof the line.

Ifthe load islessthantheSIL,reactivevolt-amperesaregenerated,andthevoltageatthereceiving endisgreaterthanthesendingendvoltage.Ontheotherhand,iftheSILisgreaterthantheload,thevoltage at receiving end is smaller because the line absorbs reactive power.

IftheshuntconductanceandresistanceareneglectedandSILisequaltotheloadthanthevoltageatboththe ends will be equal.

Surgeimpedanceload is theideal loadbecausethecurrent and voltage are uniform alongtheline. Thewaveofcurrentandvoltageisalsoinphasebecausethereactivepowerconsumedareequalto the reactive power generated by the transmission line.

CORONA

Electric-power transmission practically deals in the bulk transfer of electrical energy, from generating stations situated many kilometers away from the main consumption centers or the cities.Forthisreasonthelongdistancetransmissioncablesareofutmostnecessityforeffective power transfer, which in-evidently results in huge losses across the system. Minimizing those has been a major challenge for power engineers of late and to do that one should have a clear understandingofthe type and nature oflosses. One ofthem beingthe **corona effect inpower system**, which has a predominant role in reducing the efficiency of EHV(extra high voltage lines) which we are going to concentrate on, in this article.

Whatiscoronaeffectinpowersystemandwhyitoccurs?

Forcoronaeffecttooccureffectively, twofactorshereareofprimeimportanceasmentioned below:-

1) Alternatingpotentialdifferencemustbesuppliedacrosstheline.
2) Thespacingoftheconductors,mustbelargeenoughcomparedtothelinediameter.

CoronaEffectinTransmissionLine

Whenanalternatingcurrentismadetoflowacrosstwoconductorsofthetransmissionlinewhose spacingis large comparedto their diameters, then air surroundingthe conductors (composed of ions)issubjectedtodi-electricstress.Atlowvaluesofsupplyendvoltage,nothingreallyoccursasthe stress is too less to ionize the air outside. But when the potential difference is made to increasebeyondsomethresholdvalueofaround30kVknownasthecriticaldisruptivevoltage,thenthe field strength increases and then the air surrounding it experiences stress high enough to be dissociated into ionsmakingthe atmosphere conducting. This results in electric discharge aroundtheconductorsduetotheflowoftheseions,givingrisetoafaintluminescentglow,alongwiththe hissing sound accompanied by the liberation of ozone, which is readily identified due to its characteristic odor. This phenomena of electrical discharge occurring in transmission line for high values of voltage is known as the corona effect in power system. If the voltage across the lines is still increased the glow becomes more and more intense along with hissing noise, inducing very high power loss into the system which must be accounted for.

FactorsAffectingCorona

Thephenomenon ofcorona isaffectedbythe physicalstate oftheatmosphereaswellasbythe conditions ofthe line. The following are the factors upon which corona depends:

(i) *Atmosphere.* As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather,thenumberofionsismorethannormalandassuchcoronaoccursatmuchless voltage as compared with fair weather.

(ii) *Conductor size.* The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

(iii) *Spacingbetweenconductors.*Ifthespacingbetweentheconductorsismadevery largeascomparedtotheirdiameters,theremaynotbeanycoronaeffect.Itisbecause larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.

(iv) *Linevoltage.*Thelinevoltagegreatlyaffectscorona.Ifitislow,thereisnochange in the condition of air surrounding the conductors and hence no corona is formed. However,ifthe linevoltagehassuchavaluethat electrostaticstressesdevelopedatthe conductorsurfacemaketheairaroundtheconductorconducting,thencoronaisformed.

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it is profitable to consider the following terms much used in the analysis of corona effects:

*(i) Criticaldisruptivevoltage***.**Itistheminimumphase-neutralvoltageatwhichcorona *occurs.*Considertwoconductorsofradii*r*cmandspaced*d*cmapart.If*V*isthephase-

$$g = \frac{V}{r \log_e \frac{d}{r}} \text{ volts / cm}$$

neutralpotential,thenpotentialgradientattheconductorsurfaceisgivenby:

Inorderthatcoronaisformed,thevalueof*g*mustbemadeequaltothebreakdownstrength of air. Thebreakdownstrengthofairat76cmpressureandtemperatureof25ºCis30 kV/cm(*max*)or21·2kV/cm(*r.m.s.*)andisdenotedby*go*.If*Vc*isthephase-neutralpotentialrequired under these conditions, then,

$$g_o = \frac{V_c}{r \log_e \frac{d}{r}}$$

where g_o = breakdown strength of air at 76 cm of mercury and 25°C = 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*)

$$\therefore \text{ Critical disruptive voltage, } V_c = g_o\, r \log_e \frac{d}{r}$$

The above expression for disruptive voltage is under standard conditions *i.e.*, at 76 cm of Hg and 25ºC. However, if these conditions vary, the air density alsochanges, thus altering the value of*go*. The valueof *go* isdirectlyproportionalto air density. Thusthe breakdown strength of air at a barometric pressure of *b* cm of mercuryand temperatureof *t*ºCbecomes

™*go*where

$$\delta = \text{air density factor} = \frac{3 \cdot 92b}{273 + t}$$

Under standard conditions, the value of $\delta = 1$.

$$\therefore \quad \text{Critical disruptive voltage}, \quad V_c = g_o \, \delta \, r \log_e \frac{d}{r}$$

Correction must also be made for the surface condition of the conductor. This is accounted for by multiplying the above expression by irregularity factor m_o.

$$\therefore \text{Critical disruptive voltage}, \quad V_c = m_o g_o \, \delta \, r \log_e \frac{d}{r} \text{ kV/phase}$$

where m_o = 1 for polished conductors
= 0·98 to 0·92 for dirty conductors
= 0·87 to 0·8 for stranded conductors

(ii) Visual critical voltage. *It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors.*

It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage V_c but at a higher voltage V_v, called *visual critical voltage.* The phase-neutral effective value of visual critical voltage is given by the following empirical formula :

$$V_v = m_v g_o \, \delta \, r \left(1 + \frac{0 \cdot 3}{\sqrt{\delta \, r}}\right) \log_e \frac{d}{r} \text{ kV/phase}$$

where m_v is another irregularity factor having a value of 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

(iii) Power loss due to corona. Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is exceeded, the power loss due to corona is given by :

$$P = 242 \cdot 2 \left(\frac{f + 25}{\delta}\right) \sqrt{\frac{r}{d}} \, (V - V_c)^2 \times 10^{-5} \text{ kW / km / phase}$$

where f = supply frequency in Hz
V = phase-neutral voltage (*r.m.s.*)
V_c = disruptive voltage (*r.m.s.*) per phase

AdvantagesandDisadvantagesofCorona

Corona hasmanyadvantagesanddisadvantages. Inthecorrectdesignofa highvoltage overhead line,a balance should be struck between the advantages and disadvantages.

Advantages

(i) Due to corona formation, the air surrounding the conductor becomes conducting andhencevirtualdiameteroftheconductorisincreased.Theincreaseddiameterreduces the electrostatic stresses between the conductors.

(ii) Coronareducestheeffectsoftransientsproducedbysurges.

Disadvantages

(i) Coronaisaccompaniedbyalossofenergy.Thisaffectsthetransmissionefficiencyofthe line.

(ii) Ozoneisproducedbycoronaandmaycausecorrosionoftheconductordueto chemicalaction.

(iii) Thecurrentdrawnbythelineduetocoronaisnon-sinusoidalandhencenon-sinusoidal voltagedropoccursintheline.Thismaycauseinductiveinterferencewithneighboring communication lines.

MethodsofReducingCoronaEffect

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, carefuldesignshould be made to avoid corona onthe sub-stationsor bus- bars rated for 33 kV and higher voltages otherwise highly ionized air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment. The corona effects can be reduced by the following methods:

(i) *Byincreasingconductorsize.* Byincreasingconductorsize,thevoltageat which coronaoccursisraisedandhencecoronaeffectsareconsiderablyreduced. This isone ofthereasonsthat*ACSR* conductorswhichhavealargercross-sectionalareaareused in transmission lines.

(ii) *By increasing conductor spacing.* By increasing the spacing between conductors, thevoltageatwhichcoronaoccursisraisedandhencecoronaeffectscanbeeliminated. However,spacingcannotbeincreasedtoomuchotherwisethecostofsupporting structure (*e.g.,* bigger cross arms and supports) may increase to a considerable extent.

DISRUPTIVECRITICALVOLTAGE:

- Thecriticaldisruptivevoltageisdefinedastheminimumphasetoneutralvoltageatwhich Corona occurs. It is denoted as Vd.

VISUALCRITICALVOLTAGE:

- Thecriticalvisualdisruptivevoltageistheminimumphaseto neutralvoltageatwhich corona glow appears and visible along the conductors.
- Inparallelconductors,thecoronaglowdoesnotbeginatthedisruptivevoltageVcbutahigher voltage Vv called visual critical voltage.

CORONAPOWERLOSS:

The corona effect due to which several losses occur in transmission lines. These losses decreasetheefficiencyoftransmissionlines.Outofallthelossesthecoronapowerlossistheonewhich affects most, the proficiency of lines.

The power dissipated in the systemdue to corona discharges is called corona loss. Accurate estimationofcoronalossisdifficultbecauseofitsvariablenature.Ithasbeenfoundthatthecoronaloss under fair weather conditionis lessthanunder foulweather conditions. Thecoronalossunder appropriate weather conditions is given below by the Peek’s formula;

$$P_C = \frac{244}{\delta}(f+25)(E_n - E_O)^2 \frac{\sqrt{r}}{\sqrt{D}} 10^{-5}\, kW/km/phase$$

WhereP_c–coronapowerlossf
– frequencyof supplyinHzδ
– airdensityfactor
E_n–r.m.sphasevoltageinkV
E_o–disruptivecriticalvoltageperphaseinkVr–
radius of the conductor in meters
D–spacingbetweenconductorsin meters

Itisalsotobenoticedthatforasingle–phaseline,

E_n=1/2×linevoltage

andforathreephaseline,E_n

=1/(√3)×line voltage

Peek'sformulaisapplicablefordecidedvisualcorona.Thisformulathegivestheinaccurateresultwhenthe losses are low, and En/Eo is less than 1.8. It is superseded by Peterson's formula given below;

$$P_C = 2.1fF\frac{E_n^2}{(log_{10}\frac{D}{r})^2} \times 10^{-5}$$

Where,
P_c–coronapowerloss
f–frequencyofsupplyinHzE_n– voltage
per phase
r–radiusoftheconductor
D–spacingbetweenconductorsin meters
FactorFiscalledthecoronalossfunction.Itvarieswiththeratio(En/Eo).Eoiscalculatedbythe formula given below,

$$E_o = G_o m_o r \delta^{\frac{2}{3}} In\frac{Deq}{r} V/phase$$

Where,
G_o–maximumvalueofdisruptivecriticalvoltagegradientinV/m.m_o=
irregularity factor

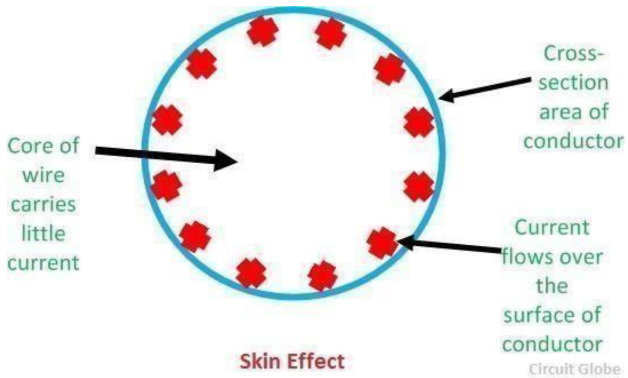
FactorsAffectingCoronaLoss
Thefollowingarethefactorswhichaffectthecoronaloss:

- **Effectofsystemvoltage**–Theelectricfieldintensityaroundtheconductordependson the potentialdifference betweentheconductors.Ifthepotentialdifference ishigh, electric field intensity is also high, and hence corona loss isalsohigh.
- **EffectofFrequency**–Thecoronalossisdirectlyproportionaltosystemfrequency.
- **EffectofDensityofAir**–Thecoronalossisinverselyproportionalto airdensityfactor.The coronaloss increases with the decreases in densityof air. The coronaloss of thehillyareais more than that of the plains because plain have low density of air.
- **EffectofConductorRadius**–Ifthewireareahashighsurfacearea,thentheirsurface field intensityislow,andhencecoronalossisless.

SKINEFFECT

Thenon-uniformdistributionofelectriccurrentoverthesurfaceorskinoftheconductorcarrying is called the skin effect. In other words, the concentration of charge is more near the surface as compared to the core of the conductor. The ohmic resistance of the conductor is increased due to the concentration of current on the surface of the conductor.

Skineffect increaseswiththe increaseinfrequency. Atlowfrequency,suchas50Hz,thereisa small increaseinthecurrentdensitynearthesurfaceoftheconductor;but,athighfrequencies,suchasradiofrequency, practically the whole of the currents flows on the surface of the conductor. If d.c current (frequency=0) is passed in a conductor, the current is uniformlydistributed over the cross-section of the conductors



WHYSKINEFFECTOCCURS?

Let usconsider the conductoris made upofa number ofconcentric cylinders. WhenA.Cispassed in a conductor,the magnetic flux induces in it.Themagnetic flux linking a cylindricalelement nearthe center is greaterthan that linking another cylindricalelement near the surface ofthe conductor. This is duetothefact that thecentercylindrical element is surrounded byboth theinternal as well as the external flux, while the externalcylindricalelement is surrounded bythe external fluxonly.

Theself-inductanceintheinnercylindricalelementismoreand,therefore,willofferagreater inductivereactancethantheoutercylindricalelement.Thisdifferenceintheinductivereactancegives a tendencyto the current to concentrate towards the surface or skin of theconductor.

- AconductorcarriesasteadyD.Ccurrent.Thiscurrentisuniformlydistributedoverthewhole cross- section of the conductor.
- Thecurrentdistributionisnon–uniformifconductorcarriesalternatingcurrent.
- Thecurrentdensityishigheratthesurfacethanatthesurfacethanatitscentre
- Thisbehaviorofalternatingcurrentto concentratenearthesurfaceoftheconductoris known as skin effect.

Factorsaffectingskineffect

1. **Frequency**–Skineffectincreaseswiththeincreaseinfrequency.
2. **Diameter**–Itincreaseswiththeincreaseindiameteroftheconductor.
3. **Theshapeoftheconductor**–Skineffectismoreinthesolidconductorandlessinthestranded conductor because the surface area of the solid conductor is more.
4. **Typeofmaterial**–Skineffectincreasewiththeincreaseinthepermeabilityofthematerial (Permeabilityistheabilityofmaterialtosupporttheformationofthemagneticfield).

Points-to-remember

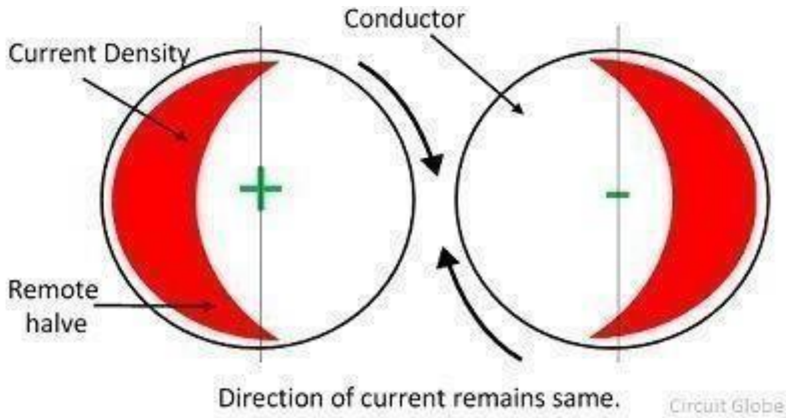
1. TheSkineffectisnegligibleifthefrequencyislessthanthe50Hzandthediameterofthe conductor is less than the 1cm.
2. Inthestrandedconductorslike ACSR(AluminiumConductorSteelReinforced)thecurrent flows mostlyinthe outer layer made ofaluminum, while the steelnear the center carries no currentandgiveshightensilestrengthtotheconductor.Theconcentrationofcurrent nearthe surface enabled the use of ACSR conductor.

PROXIMITYEFFECT

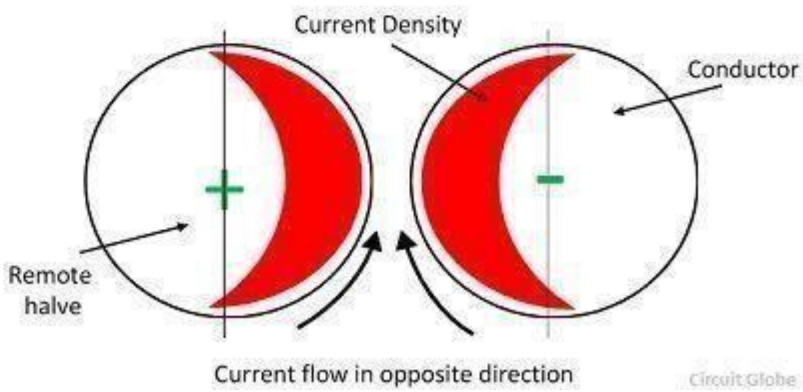
Definition: When the conductors carry the high alternating voltage then the currents are non-uniformlydistributedonthecross-sectionareaoftheconductor.Thiseffect iscalledproximityeffect. The proximity effect results in the increment of the apparent resistance of the conductor dueto the presence of the other conductors carrying current in its vicinity.

Whentwoormoreconductorsareplacedneartoeachother,thentheirelectromagneticfieldsinteract witheachother.Duetothisinteraction,thecurrentineachofthemisredistributedsuchthatthegreatercurrent densityis concentrated in that part ofthe strand most remotefromthe interfering conductor.

If the conductors carrythe current in the same direction, then the magnetic field of the halves of the conductors whichare close to eachother is cancelling eachother and hence no current flow through that halves portion of the conductor. The current is crowded in the remote half portion of the conductor.



Whentheconductorscarrythecurrentintheoppositedirection,thenthe closepartoftheconductor carries,themorecurrentandthemagneticfieldofthefaroffhalfoftheconductorcanceleachother.Thus,the current is zero in the remote halfofthe conductor and crowded at the nearer part ofthe conductor.



IfDCflowsonthesurfaceoftheconductor,thenthecurrentareuniformlydistributedaroundthe cross sectionareaoftheconductor.Hence, no proximityeffect occursonthesurfaceofthe conductor.

Theproximityeffectisimportantonlyforconductorsizesgreaterthan125mm^2.Correctionfactorsareto be applied to take this fact into account.

IfR_{dc}–uncorrectedDClevelofthecore
Y_s–skineffectfactor,i.e.,thefractionalincrementinresistancetoallowingforskineffect.
y_p–proximityeffectfactor,i.e.,thefractionalincrementinresistancetoallowingforskineffect.R_e–effective or corrected ohmic resistance of the core.
Theallowanceforproximityeffectismade,theACresistanceoftheconductorbecomes

$$R_e = R_{dc}(1 + y_{dc} + y_p)$$

TheresistanceR$_{dc}$isknownfromstrandedtables.

FactorsAffectingtheProximityEffect

Theproximityeffectmainlydependsonthefactorslikeconductor'smaterial,conductordiameter, frequency and conductor structure. The factors are explained below in details

1. **Frequency**–Theproximityincreaseswiththeincreasesinthefrequency.
2. **Diameter**–Theproximityeffectincreaseswiththeincreaseintheconductor.
3. **Structure –** This effect is more on the solid conductor as compared to the stranded conductor(i.e.,ASCR)becausethesurfaceareaofthestrandedconductorissmallerthan the solid conductor.
4. **Material**–Ifthematerialismadeupofhighferromagneticmaterialthentheproximity effect is more on their surface.

HowtoreduceProximityEffect?

The proximity effect can be reduced by using the ACSR (Aluminum Core Steel Reinforced) conductor. In ACSR conductor the steel is placed at the centre of the conductor and the aluminium conductor is positioned around steel wire.

Thesteelincreasedthestrengthoftheconductorbutreducedthesurfaceareaoftheconductor.Thus, thecurrentflowmostlyintheouterlayeroftheconductorandnocurrentiscarriedinthe centreofthe conductor. Thus, reduced the proximityeffect on the conductor.

- Thecurrentdistributionmaybenon-uniformbecauseofanothereffectknownas proximity effect. Consider a two wire line as shown in fig. below

- Leteachofthelineconductorisassumedtobedividedinto3sectionshaving equal Cross-sectional area. These parallel loops are formed bythe pairs xx', yy' and zz'.
- Theinductanceofinterloopisless.Thus,thecurrentdensityishighestatinner edges of the conductor.
- Duetothisnonuniformdistributionofcurrent,theeffectiveconductor resistance increases.
- Theproximityeffectalsodependsonthesamefactorsasthatofskineffect.

FERRANTIEFFECT

FerrantiEffectinTransmissionLinesandItsCalculation

Generally, we know that the flow of current in every electrical system will be from the higherpotential areato lowerpotential area, to reimburseforthedifferencethat lives in thesystem. In practical, the voltage at the transmitting end is superior to the voltage at the receiving end due to line losses, so the flow of current will be from the supply to the load. In the year 1989, Sir S.Z. Ferranti came up with a theory, namely astonishing theory. The main concept of this theory is all about “Medium Distance Transmission Line” or Long Distance Transmission Lines proposing that in case ofno-loadoperation ofthe transmission system. Thevoltageat the receiving end frequently enhances beyond the transmitting end. This is the Ferranti Effect in power system

WhatisaFerrantiEffect?

TheFerrantieffect definitionis,thevoltageeffectonthecollectingendofthetransmission line ishigherthanthetransmittingendiscalledas“FerrantiEffect”.Generally,thissortofeffect happens due to an open circuit, light load at the collecting end or charging-current of the transmission line. Here, chargingcurrent canbedefinedas, wheneveran exchangingvoltageis connected,the current willflowsthroughthecapacitor,anditisalsocalledas“capacitivecurrent”. Whenthevoltageatthe collecting end of the line is superior to the transmitting end, then the charging current rises in the line.

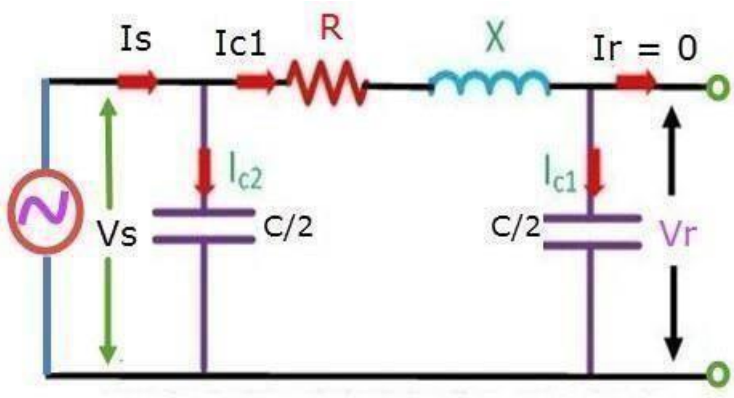
ParametersofFerrantiEffect

Ferranti effect mainlyoccurs due to the charging current, and couples with the line capacitance. In addition, the following parameters must be noticed.
Capacitance depends on composition and length of a line. In capacitance, cables have more capacitance than bare conductor per length. Whereas in line length, long lines have higher capacitance than short lines.

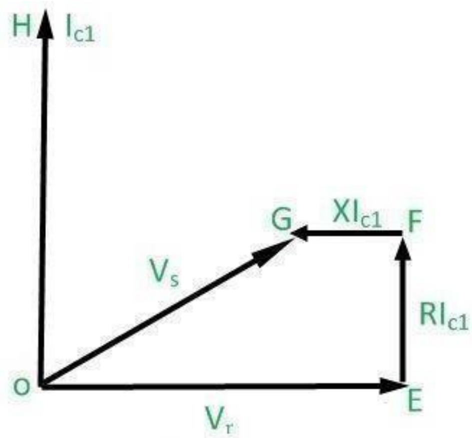
Charging current turns into more important as load current decreases, and it Increases with the voltage of the system given the similar capacitive charge. As a result, the Ferranti effect happens only for long lightly loaded or open-circuited energized lines. In addition, the fact becomes clearer with higher applied voltage and underground cables.

FerrantiEffectInTransmissionLine,Calculation

Let us think the Ferrenki Effect in extensive transmission line where OE-signifies the collecting end voltage, OH-signifies the flow of current in the capacitorat the collecting end. The FE-phasor signifies a decrease in a voltage across the resistance R. FG-signifies a decrease in a voltageacrossthe(X)inductance.TheOG-phasorsignifiesthetransmittingendvoltageinano-load state. The nominalPi model of the transmission line at no load condition circuit is shown below.



Inthefollowingphasor graphicalrepresentationthatOE isgreaterthanOG(OE>OG).Inother terms,thevoltageatthereceivingend issuperiortothevoltageatthetransmittingendwhenthe transmission line is at no load condition. Here the **Ferranti effect phasor diagram** is shown below.



Phasor Diagram

Foranominalpi(п)model

$$V_s = \left(1 + \frac{ZY}{2}\right)V_r + ZI_r$$

Atnoload,Ir=0

$$V_s = \left(1 + \frac{ZY}{2}\right)V_r$$

$$V_s - V_r = \left(1 + \frac{ZY}{2}\right)V_r - V_r$$

$$V_s - V_r = V_r\left[1 + \frac{YZ}{2} - 1\right]$$

$$V_S - V_r = \frac{YZ}{2}V_r$$

$$Z = (r + jwl)S, Y = (jwc)S$$

Iftheresistanceofthelineisneglected,

$$Z = jwlS$$

$$V_S - V_r = \frac{1}{2}(jwlS)(jwcS)V_r$$

$$V_S - V_r = -\frac{1}{2}(w^2S^2)lcV_r$$

Foroverheadlines,1/√lc=velocityofpropagationofelectromagneticwavesonthetransmissionlines= 3×10^8m/s.

$$\sqrt{lc} = \frac{1}{3 \times 10^8}$$

$$lc = \frac{1}{(3 \times 10^8)^2}$$

$$V_S - V_R = -\frac{1}{2} w^2 S^2 . \frac{1}{(3 \times 10^8)^2} V_r$$

$$w = 2\pi f$$

$$V_S - V_R = -\left(\frac{4\pi^2}{18} \times 10^{-16}\right) f^2 S^2 V_r$$

Aboveequationshowsthat(VS-Vr)isnegative.ThatisVr>VS.ThisequationalsoshowsthatFerranti effect also depends on frequency and the electrical length of the lines.

Ingeneral,foranyline

$$V_S = AV_r + BI_r$$

Atnoload

$$I_r = 0, V_r = V_{rnl}$$

$$V_S = AV_{rnl}$$

$$|V_{rnl}| = \frac{|V_s|}{|A|}$$

Foralongline,Aislessthanunity,andit decreasewiththeincreaseinthelengthoftheline. Hence, the voltageatno loadisgreaterthanthe voltageat noload(Vrnl>Vs).Asthe line lengthincreasesthe rise in the voltage at the receiving end at no load becomes more predominant.

HowtoreduceFerrantieffect:

Electricaldevicesaredesignedtoworkatsomeparticularvoltage.Ifthevoltagesarehighattheuserendstheir equipment get damaged, and their windings burn because ofhigh voltage. Ferrantieffect onlongtransmissionlinesatlowloadornoloadincreasesthereceivingendvoltage.Thisvoltagecanbe controlled byplacing the shunt reactors at the receiving end of the lines.

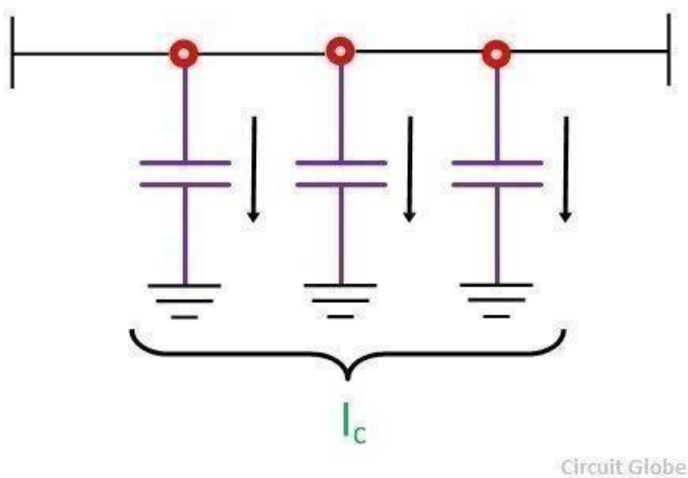
Shunt reactorisan inductive current element connected between line and neutralto compensatethe capacitivecurrentfromtransmissionlines.Whenthiseffectoccursinlongtransmissionlines,shunt reactorscompensatethecapacitive VArofthelinesandthereforethevoltage isregulated withinthe prescribed limits.

Note:

- Voltageriseisdirectlyproportionaltothesquareofthelengthofaline.
- Ferrantieffectismoreoccursinshorttransmissioncablesbecausetheircapacitanceishigh.

CHARGINGCURRENTINTRANSMISSIONLINE

Inatransmissionline, airactsasadielectric mediumbetweentheconductors.Whenthe voltageisappliedacrossthesendingendofthetransmissionline,currentstartsflowingbetweenthe conductors(dueto imperfections ofthe dielectric medium). This current is called the **charging current in the transmission line**.



Inotherwords,wecansay,thecurrentassociatedwiththecapacitanceofalineisknownasthe charging current.Thestrengthofthecharging current dependsonthevoltage, frequency, and capacitance of the line. It is given by the equations shown below.

Forasingle-phaseline,thechargingcurrent

$$I_c = \frac{V_n}{-jX_c} = \frac{V}{-j/wC} = j2\pi fCVA$$

Where,

C=line-to-lineinfarads
X_c=capacitivereactanceinohmsV=
line voltage in volts

$$Charging\ voltamperes = VI_c = \frac{V.V}{X_C} = \frac{V^2}{X_c}\ VAr$$

Also,reactivevolt-amperegeneratedbytheline=chargingvolt-amperesofthe lines

$$Q = VI_c = \frac{V^2}{X_c} VAr$$

Forathreephaseline,thechargingcurrentphase

$$I = \frac{V_n}{-jX_c} = \frac{V_n}{-j/wC} = jwC_nV_n\ A$$

whereV$_n$=voltagetoneutralinvolts=phasevoltagesinvoltsC$_n$=
capacitance to neutral in farads

C_n=capacitancetoneutralinfarads

$$Charging\ voltamperes\ per\ phase = V_nI_c = V_n \times \frac{V_n}{X_c} = \frac{V_n^2}{X_c} VAr$$

$$Total\ three\ phase\ charging\ voltamperes = 3V_nI_c = \frac{V_n^2}{X_C} \text{VAr}$$

Reactivevolt-amperegeneratedbytheline=chargingvolt-amperesofthelines

$$Q_c = \frac{3V_nI_n}{X_c} = \frac{3}{X_c}\left(\frac{V_t}{\sqrt{3}}\right)^2 = \frac{V_t^2}{X_c} VAr$$

whereV$_t$=line-to-linevoltageinvolts.

Significanceofchargingcurrent

1. Itreducestheloadcurrent,duetowhichlinelossesdecreases,andhencetheefficiencyofthelineis increased.
2. Itimprovesthepowerfactorofthetransmissionline.
3. Chargingcurrentimprovestheloadcapacityoftheline.
4. Itimprovesthevoltageregulationofthelinebecausethevoltagedropisquitesmall.

INDUCTIVEINTERFERENCEWITHNEIGHBOURINGCOMMUNICATIONCIRCUITS

It is usual practice to run telephonelines along the same route as the powerlines. The transmission lines transmit bulk power at relatively high voltages and, therefore, these lines give rise to electro-magneticandelectrostaticfieldsofsufficientmagnitudewhichinducearesuperposed onthetruespeech currents in the neighboring telephone wires and set up distortion while the voltage so induced raise the potential of the communication circuit as a whole. In extreme cases the effect of these may make it impossibletotransmitanymessage faithfullyandmayraisethepotentialofthetelephonereceiverabove thegroundtosuchanextenttorenderthehandling ofthetelephonereceiverextremelydangerousand in such cases elaborate precautions are required tobe observed to avoid thisdanger.

In practice it is observed that the power lines and the communication lines run along the same path. Sometimes it can also be seen that both these lines run on same supports along the same route. The transmission lines transmit bulk power with relatively high voltage. Electromagnetic and electrostatic fields are produced by these lines having sufficient magnitude. Because of these fields, voltages and currentsareinducedintheneighboringcommunicationlines.Thusit givesrisetointerferenceofpower linewith communication circuit.

Duetoelectromagneticeffect,currentsareinducedwhichissuperimposedonspeechcurrentofthe neighboringcommunicationlinewhichresultsintodistortion.Thepotentialofthecommunicationcircuit asawholeisraisedbecauseofelectrostaticeffectandthecommunicationapparatusandtheequipments maygetdamagedduetoextraneousvoltages. Intheworstsituation,thefaithfultransmissionofmessage becomes impossible due to effect of these fields. Also the potential of the apparatus is raised above the ground to such an extent that the handling of telephone receiver becomes extremely dangerous.

The electromagnetic and the electrostatic effects mainly depend on what is the distance between power andcommunicationcircuitsandthelengthoftherouteoverwhichtheyareparallel.Thusitcanbenoted thatifthe distortioneffect and potential rise effect are within permissiblelimits then thecommunication willbeproper.Theunacceptabledisturbancewhichisproducedinthetelephonecommunicationbecause of power lines is called Telephone Interference.

Therearevariousfactorsinfluencingthetelephoneinterference.Thesefactorsareasfollows

1) Becauseofharmonicsinpowercircuit,theirfrequencyrangeandmagnitudes.
2) Electromagneticcouplingbetweenpowerandtelephoneconductor.

The electric coupling is in the form of capacitive coupling between power and telephone conductorwhereas themagneticcouplingisthroughspaceandisgenerallyexpressedinterms of mutual inductance at harmonic frequencies.

3) Duetounbalanceinpowercircuitsandintelephonecircuits.
4) Typeofreturntelephonecircuiti.e.eithermetallicorgroundreturn.
5) Screeningeffects.

StepsforReducingTelephoneInterference

Therearevariouswaysthatcanreducethetelephoneinterference.Someofthemareaslistedbelow

i) Theharmonicsatthesourcecanbereducedwiththeuseof A.C.harmonic filters,D.C. harmonic filters and smoothing rectors.
ii) Usegreaterspacingbetweenpowerandtelephonelines.
iii) Theparallelrunbetweentelephonelineandpowerlineisavoided.
iv) Insteadofusingoverheadtelephonewires,undergroundtelephonecablesmaybeused.
v) Ifthetelephonecircuitisgroundreturnthenreplaceitwithmetallicreturn.
vi) Usemicrowaveorcarriercommunicationinsteadoftelephonecommunication.

ThebalanceofACpowerlineisimprovedbyusingtransposition.Transpositionoflines reduces the induced voltages to a considerable extent. The capacitance of the lines is balancedbytranspositionleadingtobalanceinelectrostaticallyinducedvoltages.Using transpositionthe fluxes due to positive and negative phase sequence currents cancelout sotheelectromagneticallyinducede.m.f'sisdiminished.Forzerosequencecurrentsthe telephone lines are also transposed

UNIT-

IVDC DISRIBUTION

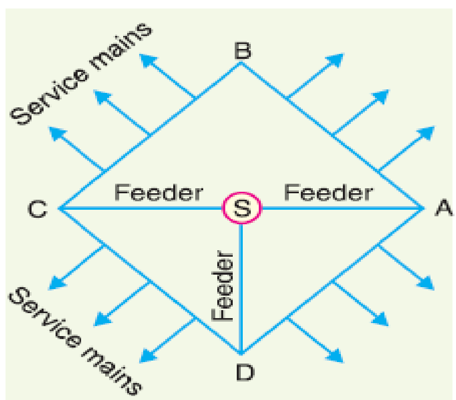
Syllabus:

Classification of distribution systems. Comparison of DC vs. AC and underground vs. over- Head distribution systems. - Requirements and Design features of Distribution Systems. - Voltage Drop Calculations (NumericalProblems)inD.CDistributorsforthefollowingcases:RadialD.CDistributorfedoneendandatboththeends (equal/unequalVoltages)andRingMainDistributor.

DISTRIBUTIONSYSTEM:

The electricalenergyproduced atthe generating station is conveyed tothe consumers througha network of transmissionanddistributionsystems. Ingeneral, distributionsystemisthat partofpowersystemwhichdistributes powerto theconsumersforutilisation.

Thepartofpower systemwhichdistributeselectricpowerforlocaluseisknownasdistributionsystem. Ingeneral,thedistributionsystemistheelectricalsystembetweenthesub-stationfedbythetransmissionsystem andtheconsumersmeters.Itgenerallyconsistsoffeeders,distributorsandtheservicemains.Thebelowfig.showsthesingle line diagram of a typical low tension distribution system.



(i) ***Feeders:***

Afeederisaconductorwhichconnectsthesub-station(orlocalisedgeneratingstation)totheareawherepoweris tobedistributed. Generally, notapingsaretakenfromthe feederso thatcurrentinit remainsthesamethroughout. Themainconsiderationinthedesignofafeederisthecurrentcarrying capacity.

(ii) ***Distributor:***

Adistributorisaconductorfromwhichtapingsaretakenforsupplytotheconsumers.Inabovefig.AB,BC, CD and DA are the distributors. The current through a distributor is not constant because tapings are taken at variousplacesalong itslength.Whiledesigninga distributor,voltagedropalongitslengthisthemain considerationsuch-estatutorylimitofvoltagevariationsis±6%ofratedvalueattheconsumers'terminals.

(iii) ***Servicemains:***

Aservicemainisgenerallyasmallcablewhichconnectsthedistributortotheconsumers'terminals.

CLASSIFICATIONOFDISTRIBUTIONSYSTEMS:

Adistributionsystemmaybeclassifiedaccordingto,

(i) Natureofcurrent. Accordingtonatureofcurrent,distributionsystemmaybeclassifiedas

(a) D.C.distributionsystem

(b) A.C.distributionsystem.

Now-a-days,A.C.systemisuniversallyadoptedfordistributionofelectricpoweras itissimplerand more economical than D.C. distribution system

(ii) Typeofconstruction. Accordingtotypeofconstruction,distributionsystemmaybeclassifiedas

(a) Overheadsystem

(b) Undergroundsystem.

The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalentundergroundsystem.Ingeneral,theundergroundsystemisusedatplaceswhereoverheadconstruction is impracticableorprohibitedbythelocallaws.

(iii) Schemeofconnection. Accordingtoschemeofconnection,thedistributionsystemmaybeclassifiedas

(a) Radialsystem

(b) Ringmainsystem

(c) Inter-connectedsystem.

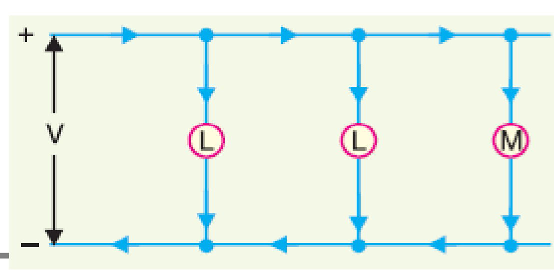
D.C.Distribution

Itisacommonknowledgethatelectricpowerisalmostexclusivelygenerated,transmittedanddistributed as A.C. However,forcertainapplications,D.C.supplyisabsolutelynecessary.Forinstance,d.c.supplyisrequired forthe operationofvariablespeedmachinery(*i.e*.,D.C.motors),forelectrochemicalwork andfor congested areas where storagebatteryreservesare necessary.

Forthispurpose,A.C.powerisconvertedintoD.C.poweratthesubstationbyusingconvertingmachinery *e.g.*,mercuryarcrectifiers,rotaryconvertersandmotor-generatorsets.TheD.C.supplyfromthesubstationmaybe obtained in the formof(*i*) 2-wire (*ii*) 3-wire for distribution.

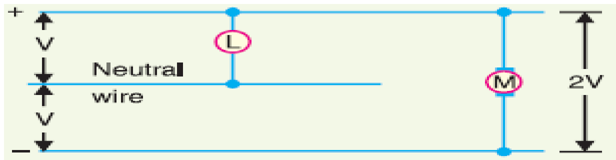
(i) ***2-wireD.C.system:***

Asthenameimplies,thissystemofdistributionconsistsoftwowires.Oneistheoutgoingorpositive wire andtheotheristhereturnornegativewire.Theloadssuchaslamps,motorsetc.areconnectedinparallelbetweenthetwowires asshowninbelow fig.Thissystemisneverused fortransmissionpurposesdueto lowefficiencybut maybe employed for distribution of D.C. power.



(ii) ***3-wireD.C.system:***

It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer and neutral wire as shown in below fig. The principal advantage of this system is that it makes available two voltages at the consumer terminals *viz*., *V* between any outer and the neutral and 2V between the outers. Loads requiring high voltage (*e.g*., motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral.

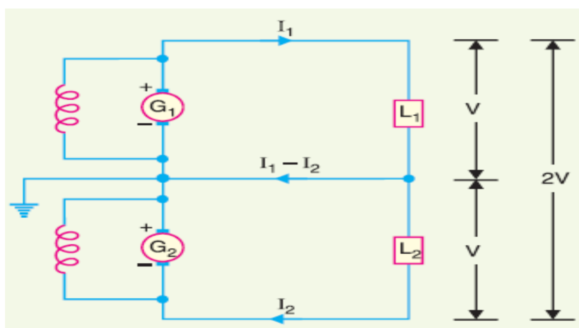


Methods of obtaining 3-wire D.C. System:

There are several methods of obtaining 3-wire D.C. system. However, the most important ones are:

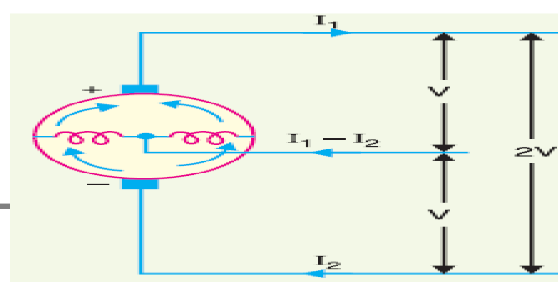
(i) ***Two generator method:***

In this method, two shunt wound D.C. generators G_1 and G_2 are connected in series and the neutral is obtained from the common point between generators as shown in below fig. Each generator supplies the load on its own side. Thus generator G_1 supplies a load current of I_1, whereas generator G_2 supplies a load current of I_2. The difference of load currents on the two sides, known as out of balance current ($I_1 - I_2$) flows through the neutral wire. The principal disadvantage of this method is that two separate generators are required



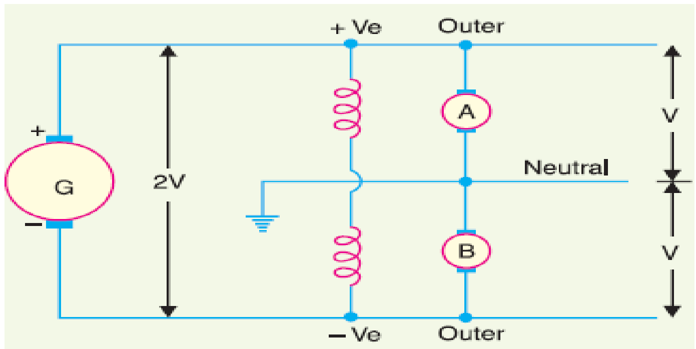
(ii) ***3-wire D.C. generator:***

The above method is costly on account of the necessity of two generators. For this reason, 3-wire d.c. generator was developed as shown in below fig. It consists of a standard 2-wire machine with one or two coils of high reactance and low resistance, connected permanently to diametrically opposite points of the armature winding. The neutral wire is obtained from the common point as shown.



(iii) Balancerset:

The 3-wire system can be obtained from 2-wire D.C. system by the use of balancer set as shown in below fig.Gisthemain2-wireD.C.generatorandsuppliespowertothewholesystem.ThebalancersetconsistsoftwoidenticalD.C shunt machines A and B coupled mechanically with their armatures and field windings joined in series acrossthe outers. The junction of their armatures is earthed and neutralwire is taken out from here. The balancersethastheadditionaladvantagethatitmaintainsthepotentialdifferenceontwo sidesofneutralequalto each other.



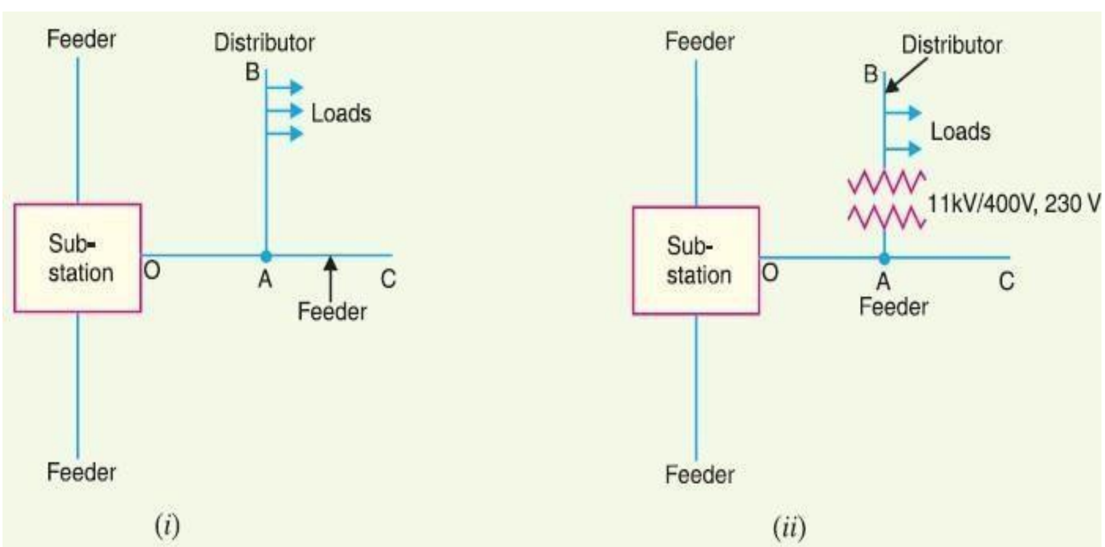
CONNECTIONSCHEMESOFDISTRIBUTIONSYSTEM:

Alldistributionofelectricalenergyisdonebyconstant voltagesystem. Inpractice, thefollowing distribution circuits are generally used

(i) ***RadialSystem:***

Inthissystem, separate feedersradiate fromasingle substationand feed thedistributorsat oneend only. The belowfig(i)showsasinglelinediagramofaradialsystemford.c.distributionwhereafeederOCsuppliesadistributor ABatpointA.Obviously,thedistributorisfedatoneendonlyi.e., pointA.

Thebelow fig(ii)showsasingle linediagramofradialsystemfora.c.distribution.Theradialsystemis employed onlywhenpower is generated at low voltage andthe substation is located at the centreofthe load.



Thisisthesimplestdistributioncircuitand hasthelowestinitialcost.However,itsuffersfromthe following drawbacks:

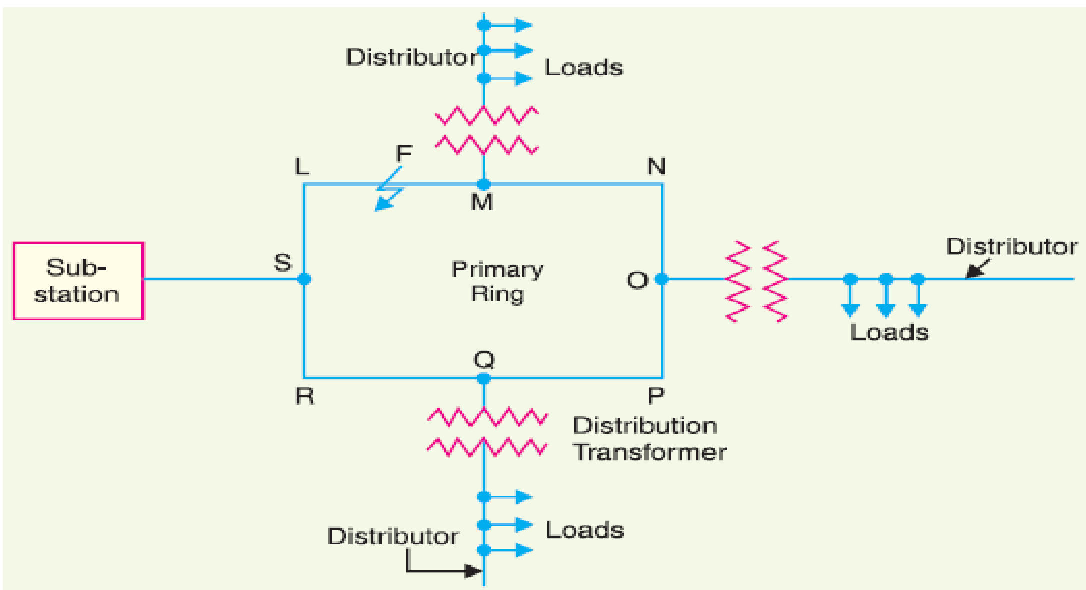
The end of the distributor nearest to the feeding point will be heavily loaded.

(b) Theconsumersaredependentonasingle feederand singledistributor.Therefore,anyfault onthefeederor distributor cutsoffsupplyto the consumers who are onthe side ofthe fault away fromthe substation.

(c) Theconsumersatthedistant endofthedistributorwouldbesubjected to seriousvoltagefluctuationswhen the load onthe distributor changes. Due tothese limitations, thissystemis used for short distances only.

(ii) Ringmainsystem:

In this system, the primaries of distribution transformers forma loop. The loop circuit starts fromthe substationbus-bars, makesa loopthroughtheareatobeserved, andreturnstothesubstation. Thebelowfig. shows thesingle linediagramofring mainsystemfor a.c.distributionwheresubstationsuppliestotheclosedfeeder LMNOPQRS. Thedistributorsaretappedfromdifferent pointsM, OandQofthefeeder throughdistribution transformers.



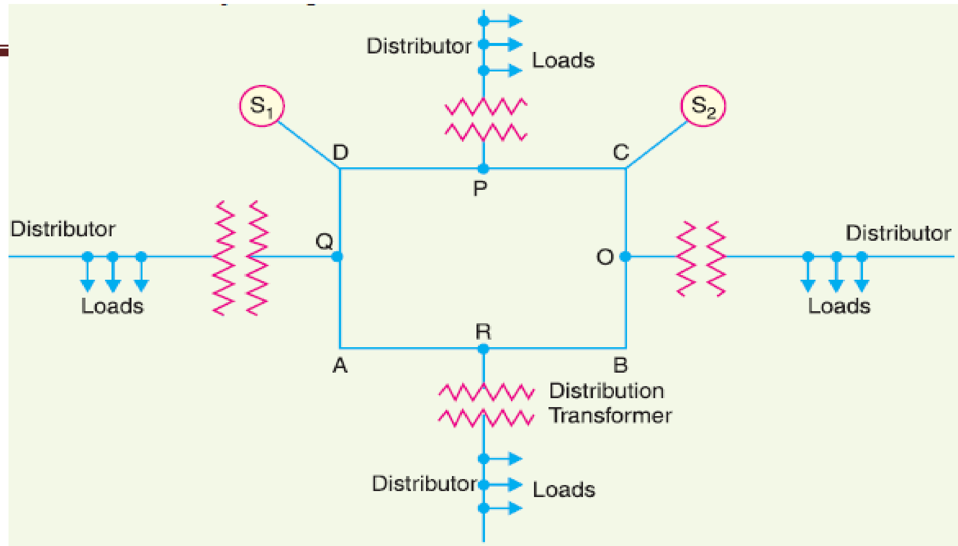
Theringmainsystemhasthefollowingadvantages:

(a) Therearelessvoltagefluctuationsatconsumer'sterminals.

(b) The systemis veryreliable as eachdistributor is fed via two feeders. Inthe event of fault onanysectionof thefeeder,thecontinuityofsupplyismaintained.Forexample,supposethatfaultoccursatanypointFofsection SLMofthe feeder.ThensectionSLMofthefeedercanbeisolatedforrepairsandatthesametimecontinuityofsupplyis maintained to allthe consumers via the feeder SRQPONM.

(iii) Interconnectedsystem:

Whenthefeederringisenergisedbytwoormorethantwogeneratingstationsorsubstations, it iscalledinter-connectedsystem. Thebelow fig. showsthesingle linediagramofinterconnectedsystemwheretheclosed feeder ring ABCD issuppliedbytwosubstationsS_1andS_2atpointsDandCrespectively. Distributorsareconnectedtopoints O, P, Q and R ofthe feeder ring through distribution transformers.



Theinterconnectedsystemhasthefollowingadvantages:

(a) Itincreasestheservicereliability.

(b) Anyareafedfromonegeneratingstationduringpeakloadhourscanbefedfromtheothergeneratingstation.This reduces reserve power capacityand increases efficiencyofthe system.

COMPARISONOFD.C.ANDA.C.DISTRIBUTION:

TheelectricpowercanbedistributedeitherbymeansofD.C.orA.C.Eachsystemhasitsownmeritsanddemerits

D.C DISTRIBUTION:

Advantages:

- ItrequiresonlytwoconductorsascomparedtothreeforA.C.distribution.
- Thereisnoinductance,capacitance,phasedisplacementandsurgeproblemsinD.C.distribution.
- Duetotheabsenceofinductance,thevoltagedropinaD.C.distributionlineislessthantheA.C.lineforthesame load and sending end voltage. Forthis reason, a D.C. distribution line has better voltage regulation.
- ThereisnoskineffectinaD.C.system.Therefore,entirecross-sectionofthelineconductorisutilized.
- Forthesameworking voltage,thepotentialstress ontheinsulationislessincaseofD.C.systemthanthat in A.C. system. Therefore, a D.C. line requires less insulation.
- AD.C.linehaslesscoronalossandreducedinterferencewithcommunicationcircuits.
- ThehighvoltageD.C.distributionisfreefromthedielectriclosses.
- InD.Cdistribution,therearenostabilityproblemsandsynchronizingdifficulties.

Disadvantages

- ElectricpowercannotbegeneratedathighD.C.voltageduetocommutationproblems.
- TheD.C.voltagecannotbesteppedupfordistributionofpowerathighvoltages.
- TheD.C.switchesandcircuitbreakershavetheirownlimitations.

A.C DISTRIBUTION:

Advantages:

- Thepowercanbegenerated athighvoltages.
- ThemaintenanceofA.C.sub-stationsiseasyandcheaper.
- TheA.C.voltagecanbesteppeduporsteppeddownbytransformerswitheaseandefficiency.This permits to transmit power at high voltages and distribute it at safe potentials.

Disadvantages:

- TheconstructionofA.CdistributionlineismorecomplicatedthanaD.Cdistributionline.
- DuetoskineffectintheA.C.system,theeffectiveresistanceofthelineisincreased.
- AnA.C.linehascapacitance.Therefore,thereisacontinuouslossofpowerduetochargingcurrentevenwhen theline isopen.
- AnA.C.linerequiresmorecopperthanaD.C.line

COMPARISONOFOVERHEADVERSUSUNDERGROUNDDISTRIBUTIONSYSTEM:

Thedistributionsystemcanbeoverheadorunderground.

- Overhead linesaregenerally mountedonwooden,concreteor steelpoleswhicharearranged to carry distribution transformers in addition to the conductors.
- Theundergroundsystemusesconduits,cablesandmanholesunderthesurfaceofstreetsandsidewalks.

Thechoicebetweenoverheadandundergroundsystemdependsuponanumberofwidelydifferingfactors. Therefore,itisdesirabletomakeacomparisonbetweenthetwo.

(i) Publicsafety: Theundergroundsystemissaferthanoverheadsystembecausealldistributionwiringisplaced underground and there are little chances of any hazard.

(ii) Initialcost: Theundergroundsystemis moreexpensiveduetothehighcostoftrenching, conduits, cables, manholesandother specialequipment. Theinitialcostofanundergroundsystemmaybe fivetotentimesthan thatofanoverheadsystem.

(iii) Flexibility: Theoverheadsystemismuchmoreflexiblethantheundergroundsystem.Inthe lattercase, manholes,ductlinesetc.,arepermanentlyplacedonceinstalledandtheloadexpansioncanonlybemetbylaying new lines.However,onanoverheadsystem,poles,wires,transformersetc.,canbeeasilyshiftedtomeet thechanges in load conditions.

(iv) Faults: Thechancesoffaultsinundergroundsystemareveryrareasthecablesarelaidundergroundandare generally provided with better insulation.

(v) Appearance: Thegeneralappearance ofanundergroundsystemisbetterasallthe distribution linesare invisible. This factorisexertingconsiderablepublicpressureonelectricsupplycompaniestoswitchoverto undergroundsystem.

(vi) **Fault location and repairs**:Ingeneral,therearelittlechancesoffaultsinanundergroundsystem.However,ifa faultdoesoccur,itisdifficulttolocateandrepaironthissystem.
Onanoverheadsystem,theconductorsarevisibleandeasilyaccessiblesothatfaultlocationsandrepairscanbe easilymade.

(vii) **Currentcarryingcapacityandvoltagedrop:** Anoverheaddistributionconductorhasaconsiderably highercurrentcarryingcapacitythananundergroundcableconductorofthesamematerialandcross-section.On the otherhand,undergroundcableconductorhasmuchlower inductivereactancethanthatofanoverhead conductor because of closer spacing of conductors.

(viii) **Usefullife:** The usefullife ofunderground systemis much longer thanthat ofanoverhead system. An overheadsystemmayhaveausefullifeof25 years, whereasanundergroundsystemmayhaveausefullifeof morethan50years.

(ix) **Maintenance cost:** The maintenance cost ofunderground system is very low as compared with that of overheadsystembecauseoffewerchancesoffaultsandservice interruptionsfromwind, ice,and lightningas wellasfromtraffichazards.

(x) **Interferencewithcommunicationcircuits:** Anoverheadsystemcauseselectromagnetic interferencewith thetelephonelines.Thepowerlinecurrentsaresuperimposedonspeechcurrents,resultinginthepotentialofthe communicationchannelbeingraisedtoanundesirable level.However,thereisno suchinterferencewiththe underground system.

Itisclear fromtheabovecomparisonthat eachsystemhas itsownadvantagesanddisadvantages. However, comparative economics (i.e., annualcost ofoperation) is the most powerfulfactor influencing the choice between undergroundandoverhead system.

Thegreatercapitalcostofundergroundsystemprohibits itsuse fordistribution. But sometimes non- economic factors (e.g., general appearance, public safetyetc.) exert considerable influence on choosing undergroundsystem.Ingeneral,overheadsystemisadoptedfordistributionandtheuseofundergroundsystemis made only where overhead construction is impracticable or prohibited by local laws.

REQUIREMENTSOFADISTRIBUTIONSYSTEM:

Aconsiderableamountofeffortisnecessarytomaintainanelectricpowersupplywithintherequirementsofvarious types of consumers. Some of the requirements of a good distribution system are proper voltage, availability of powerondemandandreliability.

(i) *Propervoltage:*

One importantrequirement ofadistributionsystemisthat voltagevariationsat consumer'sterminalsshould be as low as possible. The changes in voltage are generally caused due to the variation of load on the system.Lowvoltagecauseslossofrevenue,inefficientlightingandpossibleburningoutofmotors.Highvoltagecauses lampstoburnoutpermanentlyandmaycausefailureofotherappliances.

Therefore, a good distribution system should ensure that the voltage variations at consumer's terminals are within permissible limits. The statutory limit of voltage variations is ±6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230V, then the highest voltage of the consumer should not exceed 244V while the lowest voltage of the consumer should not be less than 216 V.

(ii) Availability of power on demand:

Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers.

This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(iii) Reliability:

Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (a) interconnected system (b) reliable automatic control system (c) providing additional reserve facilities.

DESIGN CONSIDERATIONS IN DISTRIBUTION SYSTEM:

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

(i) Feeders:

A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

(ii) Distributors:

A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (±6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

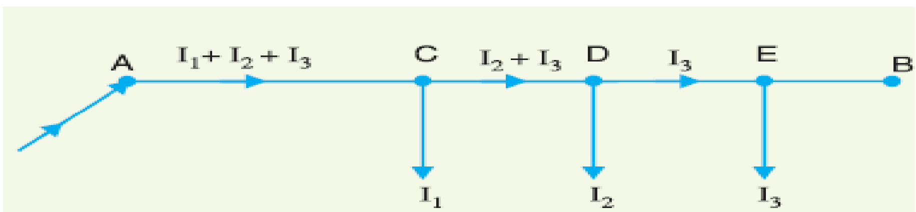
TYPESOFD.C.DISTRIBUTORS:

Themost generalmethodofclassifyingd.c. distributorsisthewaytheyarefedbythefeeders. Onthisbasis, d.c.distributorsareclassifiedas:

1. Distributorfedatoneend
2. Distributorfedatbothends
3. Distributorfedatthecentre
4. Ringdistributor.

1. ***Distributorfedatoneend:***

Inthistypeoffeeding,thedistributorisconnectedtothesupplyatoneendandloadsaretakenatdifferentpointsalong the lengthofthe distributor. The below fig. shows the single line diagramofa D.C. distributor AB fed at the end AandloadsI$_1$, I$_2$andI$_3$tappedoffatpointsC,DandE respectively.



Thefollowingpointsareworthnotinginasinglyfeddistributor:

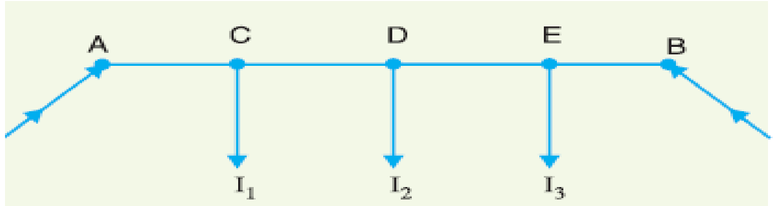
(a) Thecurrentinthevarioussectionsofthedistributorawayfromfeedingpointgoesondecreasing.Thuscurrent insectionACismorethanthecurrentinsectionCDandcurrentinsectionCDismorethanthecurrentinsectionDE.

(b) Thevoltageacrosstheloadsawayfromthefeedingpointgoesondecreasing.ThusintheaboveFig.theminimum voltage occurs at the load point E.

(c) Incaseafaultoccursonanysectionofthedistributor,thewholedistributorwillhavetobedisconnectedfromthe supply mains. Therefore, continuity of supply is interrupted.

2. ***Distributorfedatbothends:***

Inthistypeoffeeding, thedistributorisconnectedtothesupplymainsat bothendsand loadsaretappedoffat differentpointsalongthelengthofthedistributor.Thevoltageatthefeedingpointsmayor maynotbeequal. The below fig. showsa distributor AB fed at theends Aand B and loads ofI$_1$, I$_2$and I$_3$tapped offat pointsC, D and E respectively. Here, the load voltage goes on decreasing as we move away fromone feeding point sayA, reachesminimumvalueandthenagainstartsrisingandreachesmaximumvaluewhenwereachtheother feeding pointB.Theminimumvoltageoccursatsomeloadpointandisneverfixed.Itisshiftedwiththevariationofloadondifferent sections of the distributor.



Advantages:

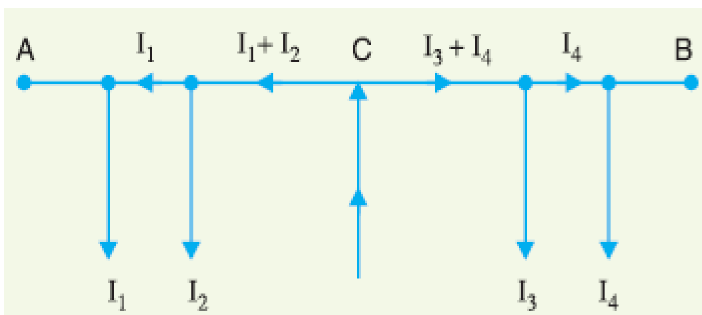
(a) Ifafaultoccursonanyfeedingpointofthedistributor,thecontinuityofsupplyis maintainedfromtheother feeding point.

(b) Incaseoffaultonanysectionofthedistributor,thecontinuityofsupplyismaintainedfromtheotherfeedingpoint.

(c) TheareaofX-sectionrequiredforadoublyfeddistributorismuchlessthanthatofasinglyfeddistributor.

3. Distributorfedatthecentre:

Inthistypeoffeeding,thecentreofthedistributorisconnectedtothesupplymainsasshowninbelowfig. Itisequivalenttotwosinglyfeddistributors,eachdistributorhavingacommonfeedingpointandlengthequaltohalfofthe total length.

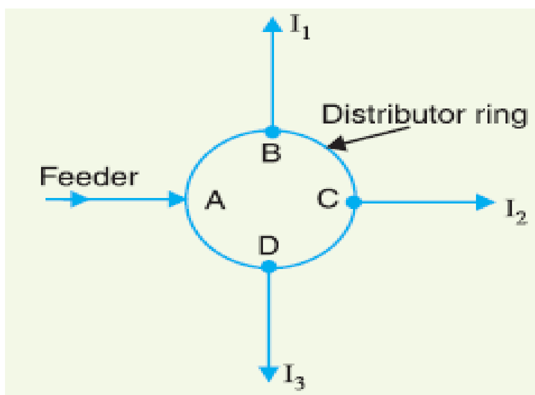


4. Ringmaindistributor:

Inthistype,thedistributorisintheformofaclosedringasshowninbelowFig.Itisequivalenttoastraightdistributor fedatbothendswithequalvoltages,thetwoendsbeingbroughttogethertoformaclosedring. Thedistributor ring maybefedatoneor morethanonepoint.

VOLTAGEDROPCALCULATIONSD.C.DISTRIBUTION:

Inadditiontothemethodsoffeedingdiscussedabove,adistributormayhave(i)concentratedloading (ii) uniform loading (iii) both concentrated and uniform loading. The concentrated loads are those which act on particular points ofthe distributor. Acommon example ofsuch loads is that tappedoff for domestic use. Onthe other hand, distributedloadsarethosewhichact uniformlyonallpointsofthedistributor. Ideally, thereareno distributed loads. However, a nearest example ofdistributed load is a large number of loads ofsame wattage connected to the distributor at equaldistances.

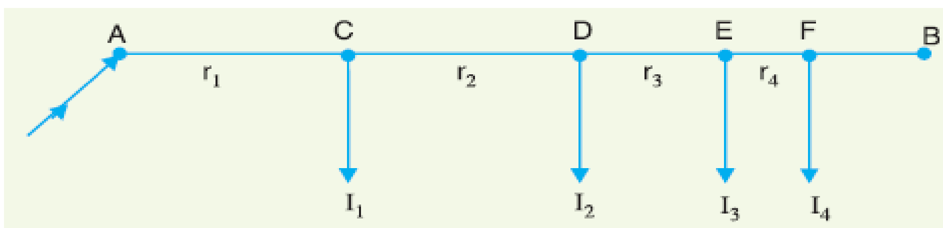


Ind.c.distributioncalculations, one important point ofinterest isthe det erminationofpointofminimumpotentialonthedistributor.Thepoint where itoccursdependsuponthe loadingconditionsandthemethodof feedingthedistributor.Thedistributorissodesignedthattheminimumpotentialonitisnotlessthan6%ofrated voltageattheconsumer'sterminals.Inthenextsections,weshalldiscusssomeimportantcasesofd.c.distributors separately.

D.C.DISTRIBUTORFEDATONEEND:

CONCENTRATEDLOADING:

Thebelowfig.showsthesinglelinediagramofa2-wired.c.distributorABfedatoneendAandhaving concentrated loads I_1, I_2, $I_3$and I_4tappedoffat points C, D, E and Frespectively.



Letr_1,r_2,$r_3$and$r_4$betheresistancesofbothwires(goandreturn)ofthesectionsAC,CD,DEandEFofthedistributor respectively.

Current fed frompoint A=$I_1+I_2+I_3+I_4$Current in section AC = $I_1 + I_2 + I_3 + I_4$Current in sectionCD=$I_2+I_3+I_4$Current insectionDE =I_3+I_4

CurrentinsectionEF=I_4

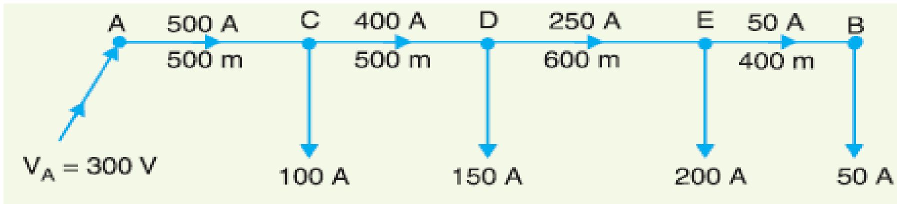
VoltagedropinsectionAC=$r_1(I_1+I_2+I_3+I_4)$Voltagedrop in sectionCD = $r_2 (I_2 +I_3 + I_4)$ Voltage dropinsection DE = $r_3(I_3+ I_4)$

VoltagedropinsectionEF=r_4I_4

∴Totalvoltage dropinthedistributor=$r_1(I_1+I_2+I_3+I_4)+r_2(I_2+I_3+I_4)+r_3(I_3+I_4)+r_4I_4$Itiseasytoseethattheminimumpotentialwilloccuratpoint Fwhichisfarthestfromthefeedingpoint A.

PROBLEMS:

1. 2-wired.c.distributorcableABis2kmlong andsuppliesloadsof100A,150A,200Aand50Asituated 500m,1000m, 1600mand2000mfromthefeedingpointA.Eachconductorhasaresistanceof0·01Ωper 1000m.Calculatethep.d.ateachloadpointifap.d.of300V ismaintainedatpointA.



Theabovefig.showsthesinglelinediagramofthedistributorwithitstappedcurrents.

Resistance per 1000 mofdistributor = 2 × 0·01 = 0·02 Ω Resistance ofsectionAC, R_{AC} =0·02×500/1000=0·01ΩResistanceofsection CD, R_{CD} = 0·02 × 500/1000 = 0·01 Ω ResistanceofsectionDE, R_{DE}=0·02×600/1000=0·012 Ω Resistance ofsectionEB,R_{EB}= 0·02×400/1000= 0·008Ω

Referringtotheabovefig.thecurrentsinthevarioussectionsofthedistributorare:I_{EB}=50A, I_{DE}= 50 + 200 = 250 A, I_{CD}= 250 + 150 = 400 A, I_{AC}= 400 + 100 = 500 A

P.D.atloadpointC,V_C=Voltageat A−VoltagedropinAC

$=V_A-I_{AC}R_{AC}$

=300−500×0·01=295V

P.D.atloadpointD,$V_D=V_C-I_{CD}R_{CD}$

=295−400×0·01=291V

P.D.atloadpointE,$V_E=V_D-I_{DE}R_{DE}$

=291−250×0·012=288V

P.D.atloadpointB,$V_B=V_E-I_{EB}R_{EB}$

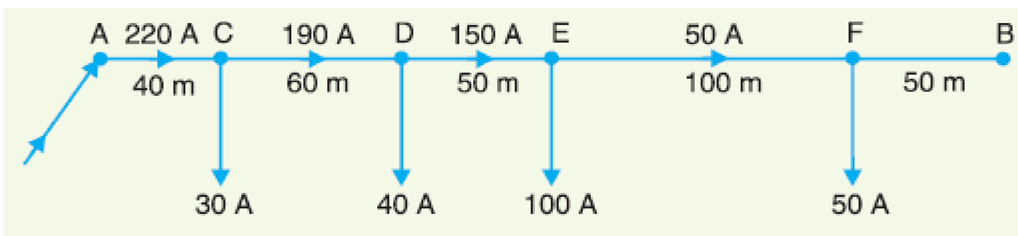
=288−50×0·008=287·6V

2. 2-wired.c.distributorAB is300metreslong.ItisfedatpointA.Thevariousloadsandtheir positions aregivenbelow:

Atpoint	distancefromAinmetres	concentratedloadinamperes
C	40	30
D	100	40
E	150	100
F	250	50

Ifthemaximumpermissiblevoltagedropisnottoexceed10V,findthecross-sectionalareaofthedistributor.Takeρ= $1{\cdot}78 \times 10^{-8}\Omega$m.

Thesinglelinediagramofthedistributoralongwithitstappedcurrentsisshowninbelowfig.



Supposethatresistanceof100mlengthofthedistributoris*r*ohms.Thenresistanceofvarioussectionsofthe distributoris

R_{AC}=0·4rΩ,R_{CD}=0·6rΩ,R_{DE}=0·5rΩ,R_{EF}=rΩ

Thecurrentsinthevarioussectionsofthedistributorare:

I_{AC}=220A,I_{CD}=190A,I_{DE}=150A,I_{EF}=50A

Totalvoltagedropoverthedistributor

$=I_{AC}R_{AC}+I_{CD}R_{CD}+I_{DE}R_{DE}+I_{EF}R_{EF}$

$=220\times0\cdot4r+190\times0\cdot6r+150\times0\cdot5r+50\times r$

$=327r$

Asthemaximumpermissibledropinthedistributoris10V,

$\therefore 10=327r$ r

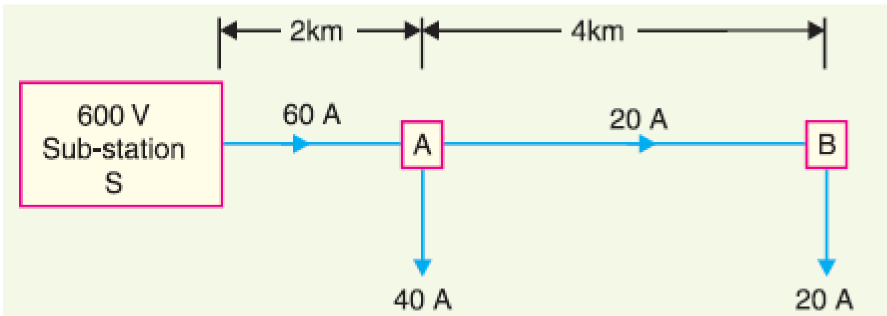
$=10/327$

$=0\cdot03058\Omega$

X-sectionalareaofconductor$=\frac{\rho l}{r/2}=\frac{1.78\times10^{-8}\times100}{0.03058/2}=116.4\times10^{-6}m^2=1.164cm^2$

3. Twotramcars(A&B)2kmand6kmawayfromasub-stationreturn40Aand20Arespectivelytotherails. The sub-station voltageis 600 V d.c. The resistance oftrolleywireis 0·25 Ω/kmand thatoftrack is 0·03 Ω/km.Calculatethevoltageacrosseachtramcar.

Thetramcaroperatesond.c.supply.Thepositivewireisplacedoverheadwhiletherailtrackactsasthenegativewire.Fig. 13.8showsthesinglelinediagramofthearrangement.



Resistanceoftrolleywireandtrack/km=0·25+0·03=0·28Ω

Current in section *SA* = 40 + 20 = 60 A

Currentinsection*AB*=20A

Voltagedropinsection*SA*=60×0·28×2=33·6V

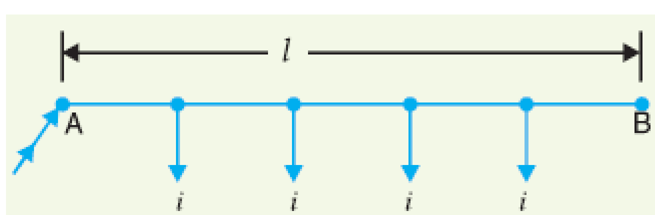
Voltagedropinsection*AB*=20×0·28×4= 22·4V

∴ Voltageacrosstram*A* =600−33·6 =566·4V

Voltageacrosstram*B* =566·4−22·4=544V

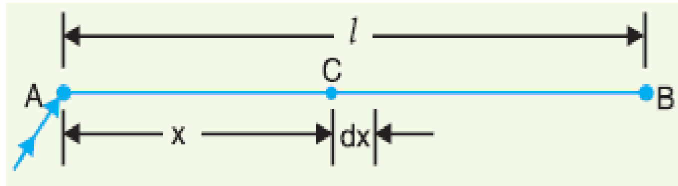
UNIFORMLYLOADEDDISTRIBUTOR:

The below fig shows the single line diagramofa 2-wire d.c. distributor *AB* fed at one end *A* and loaded uniformlywith*i*amperespermetrelength.Itmeansthatatevery1mlengthofthedistributor,theloadtappedis*i*amperes.Let *l*metresbethelengthofthedistributorand*r*ohmbetheresistancepermetrerun.



Considerapoint*C*onthedistributoratadistance*x*metresfromthefeedingpoint*A*asshowninbelowfig.

Thencurrentat point*C*is=*i l*−*ix*amperes= *i*(*l*−*x*)amperes



Now,considerasmalllengthdxnearpoint$C$.Itsresistanceisrdxandthevoltagedropoverlength$dx$is

$$dv = i(l-x)r\,dx = ir\,(l-x)dx$$

Totalvoltagedropinthe distributoruptopoint$C$is

$$V = \int_0^x ir(l-x)\,dx$$

$$= ir\left(lx - \frac{x^2}{2}\right)$$

Thevoltagedropuptopoint$B$($i.e.$overthewholedistributor)canbeobtainedbyputting$x=l$intheabove expression.

$$\therefore \text{Voltagedropoverthedistributor}AB = ir\left(l \times l - \frac{l^2}{2}\right)$$

$$= \frac{1}{2} i\,r l^2$$

$$= \frac{1}{2}(il)(rl)$$

$$= \frac{1}{2} IR$$

Where, $il = I$,thetotalcurrententeringatpointA

$r\,l = R$,thetotalresistanceofthedistributor

Thus, inauniformlyloadeddistributorfedatoneend,thetotalvoltagedropisequaltothatproducedbythewhole ofthe load assumed to be concentrated at the middle point.

PROBLEMS:

1. A2-wired.c.distributor200metreslongisuniformlyloadedwith2A/metre.Resistanceofsinglewireis 0·3Ω/km.Ifthedistributorisfedat oneend,calculate(i)thevoltagedropuptoadistanceof150 m fromthe feedingpoint(ii)the maximumvoltage drop.

Current loading, i = 2 A/m

Resistanceofdistributorpermetrerun,

r= 2× 0·3/1000=0·0006Ω

Lengthofdistributor,l=200m

(i) Voltagedropuptoadistancexmetresfromfeedingpoint $= ir(lx - \frac{x^2}{2})$

Here,x=150m

$\therefore$Desiredvoltagedrop $= 2\times 0\cdot 0006(200\times 150 - \frac{150^2}{2}) = 22.5$V

(ii) Totalcurrententeringthedistributor,

$I = i\times l = 2\times 200 = 400$A

Totalresistanceofthedistributor,

$R = r\times l = 0\cdot 0006\times 200 = 0\cdot 12\Omega$

Totaldropoverthedistributor $= \frac{1}{2}$IR

$= \frac{1}{2}\times 400\times 0.12 = 24$V

2. Auniform2-wired.c. distributor500metreslong is loadedwith0.4ampere/ metreand is fedatoneend. Ifthe maximumpermissiblevoltagedropis notto exceed10V,findthecross-sectionalareaofthedistributor conductor.Take $\rho = 1\cdot 7\times 10^{-6}$ Ωcm.

Current enteringthedistributor, $I = i\times l = 0\cdot 4\times 500 = 200$AMax.

permissiblevoltagedrop =10 V

Let$r$ohmbetheresistancepermetre lengthofthedistributor(bothwires).

Max.voltagedrop $= \frac{1}{2}IR$

$10 = \frac{1}{2}Irl$

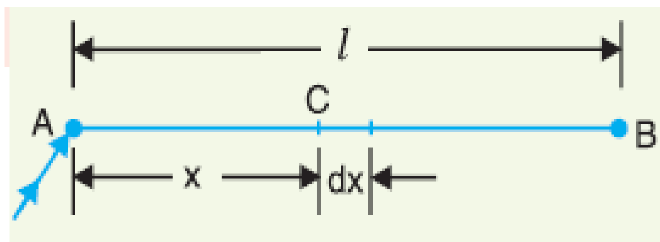
$r = \frac{20}{Il} = \frac{20}{200\times 500} = 0.2\times 10^{-3}\Omega$

∴Areaofcross-sectionofthedistributorconductorisa=ρl
$r/2$

$= \frac{1.7\times10^{-6}\times500}{0.2\times10^{-3}/2}$ =8.5cm ^{2}

Powerlossinauniformlyloadeddistributorfedatoneend:

Thebelowfig.showsthesinglelinediagramofa2-wired.c.distributor*AB*fedatend*A*andloadeduniformlywith*i* amperesper metrelength.



Let,

l=lengthofthedistributorinmetresand

r=resistanceofdistributor(bothconductors)permetrerun.

Considerasmalllength*dx*ofthedistributoratpoint*C*atadistance*x*fromthefeedingend*A*.Thesmalllength*dx* willcarrycurrentwhichistappedinthelength*CB*.

∴Currentindx= $il-ix$ =$i(l-x)$

Powerlossinlengthdx=(currentinlengthdx)^2×Resistanceoflengthdx=$[i(l-x)]^2\times rdx$

Totalpowerloss*P*inthewholedistributoris

$$P=\int_0^l [i(l-x)]^2 rdx = \int_0^l i^2(l^2+x^2-2lx)rdx$$

$$=i^2r\int_0^l (l^2+x^2-2lx)dx$$

$$=i^2r\left[l^2x+\frac{x^3}{3}-\frac{2lx^2}{2}\right]_0^l$$

$$=i^2r\left[l^3+\frac{l^3}{3}-l^3\right]$$

$$P=\frac{i^2rl^3}{3}$$

PROBLEMS.

1. Calculate the voltage at a distance of 200 m of a 300 m long distributor uniformly loaded at the rate of 0.75 A per metre. The distributor is fed at one end at 250 V. The resistance of the distributor (go and return) per metre is 0·00018 Ω. Also find the power loss in the distributor.

Voltage drop at a distance x from supply end $= ir\left(lx - \frac{x^2}{2}\right)$

Here $i = 0·75$ A/m, $l = 300$ m, $x = 200$ m, $r = 0·00018$ Ω/m

Voltage drop $= 0.75 \times 0.00018\left(300 \times 200 - \frac{200^2}{2}\right)$

$= 5.4$ V

Voltage at a distance of 200 m from supply end

$= 250 - 5·4 = 244·6$ V

Total power loss P in the whole distributor is

$$P = \frac{i^2 r l^3}{3}$$

$$= \frac{0.75^2 \times 0.00018 \times 300^3}{3} = 911.25 \text{ W}$$

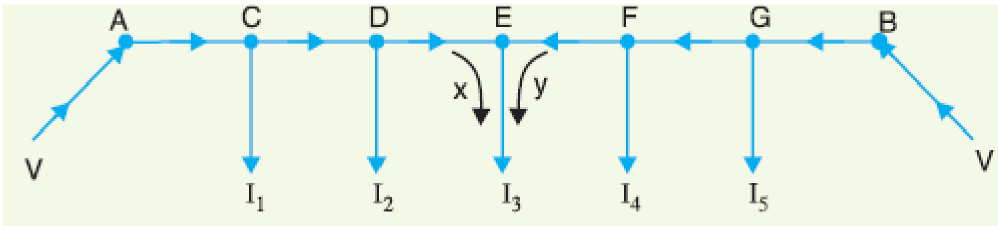
DISTRIBUTOR FED AT BOTH ENDS:

CONCENTRATED LOADING:

Whenever possible, it is desirable that a long distributor should be fed at both ends instead of at one end since total voltage drop can be considerably reduced without increasing the cross-section of the conductor. The two ends of the distributor may be supplied with (*i*) equal voltages (*ii*) unequal voltages.

(ii)***Twoendsfedwithequalvoltages:***

ConsideradistributorABfedat bothendswithequalvoltages Vvoltsand havingconcentratedloads I_1,I_2, I_3,I_4andI_5at points*C*,*D*,*E*,*F*and*G*respectivelyasshowninbelow fig.Aswe moveawayfromoneofthe feeding points, sayA, p.d. goesondecreasing till it reachesthe minimumvalue at some load point, sayE, andthenagain



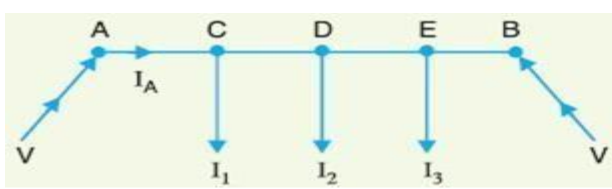
startsrisingandbecomes *V*voltsaswereachtheotherfeedingpoint*B*.

Allthecurrentstappedoffbetweenpoints*A*and*E*willbesupplied fromthe feedingpoint *A*whilethose tappedoffbetween*B*and*E*willbesupplied fromthefeedingpoint *B*.Thecurrenttappedoffat point*E*itselfwill be partlysupplied from*A* and partly from*B*. Ifthese currentsare *x* and *y* respectively, then, $I_3 = x + y$ Therefore, wearriveat averyimportantconclusionthatatthepointofminimumpotential, current comes from bothendsofthe distributor.

Pointofminimumpotential:

Itisgenerallydesiredto locatethepointofminimumpotential. There isasimple methodfor it. Consider adistributor*AB*havingthreeconcentratedloadsI_1,I_2andI_3atpoints*C*,*D*and*E*respectively.Supposethatcurrentsuppliedby feedingend*A*isI_A.Thencurrent distributioninthevarioussectionsofthedistributorcanbeworkedoutasshownin below fig. Thus

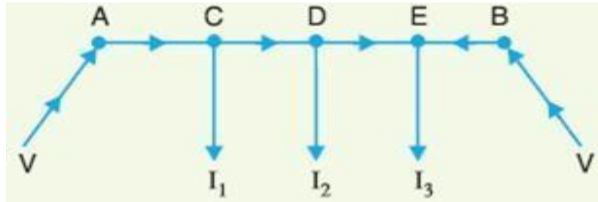
$I_{AC}=I_A$,$I_{CD}=I_A-I_1$ $I_{DE}=I_A-I_1-I_2$;$I_{EB}=I_A-I_1-I_2-$



VoltagedropbetweenAandB=VoltagedropoverAB

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

Fromthisequation,theunknown$I_A$canbecalculatedasthevaluesofotherquantitiesaregenerallygiven. Supposeactualdirectionsofcurrentsinthevarioussectionsofthedistributorareindicatedasshowninbelowfig. Theloadpointwherethecurrentsarecomingfrombothsidesofthedistributoristhepointofminimumpotential *i.e.* point *E* in this case


A
C
D
E
B
V
I_1
I_2
I_3
V

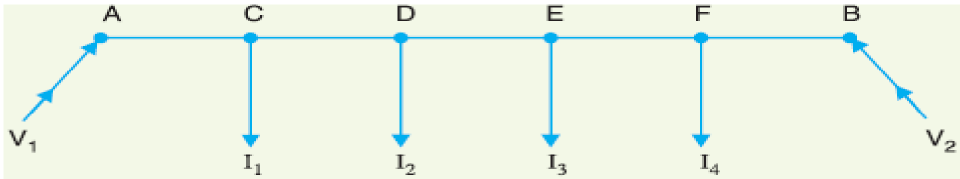
(iii)

(iv) ***Twoendsfedwithunequalvoltages:***

Thebelowfig. showsthedistributor*AB* fedwithunequalvoltages;end*A*beingfedatV_1voltsandend *B*atV_2volts.Thepointofminimumpotentialcanbefoundbyfollowingthesameprocedureasdiscussedabove.Thusinthis case,

Voltagedropbetween*A*and*B*=Voltagedropover*AB*

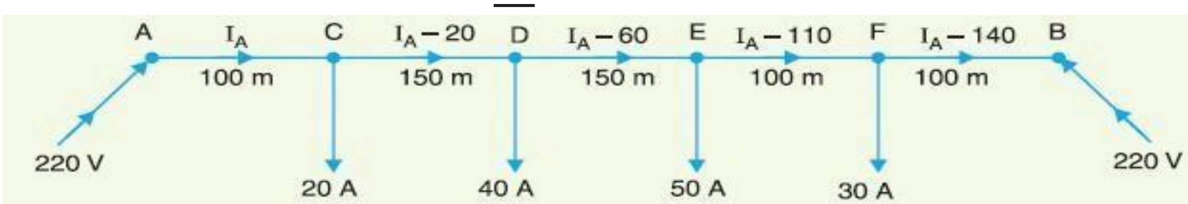
$V_1 - V_2$= Voltage dropover*AB*



PROBLEMS:

1. A2-wired.c.streetmains AB,600mlongisfedfrombothendsat220V.Loadsof20A,40A,50A and 30 Aaretappedatdistancesof100m,250m,400mand500mfromtheendArespectively.Iftheareaof X-sectionofdistributor conductor is 1cm2, find the minimumconsumer voltage. Take ρ =1·7 × 10^{-6} Ω cm. The below fig shows the distributor with its tapped currents. Let $I_A$amperes be the currentsuppliedfromthefeedingend *A*. Thencurrentsinthevarioussectionsofthedistributorareasshowninbelowfig.

ρl



Resistanceof1mlengthofdistributor a= $r/2$

$$r=\frac{2\rho l}{a}=\frac{2\times 1.7\times 10^{-6}\times 100}{1}=3.4\times 10^{-4}$$

Resistanceofsection*AC*,R_{AC}=(3·4×10^{-4})×100=0·034Ω

Resistanceofsection*CD*, R_{CD}=(3·4 ×10^{-4}) ×150 =0·051 Ω

Resistance ofsection *DE*, R_{DE} =(3·4× 10^{-4}) × 150 = 0·051 Ω

Resistance ofsection *EF*, R_{EF}= (3·4 ×10^{-4})×100 = 0·034Ω

Resistance ofsection *FB*, R_{FB}= (3·4 × 10^{-4}) × 100= 0·034 Ω

Voltageat *B*=Voltageat*A*−Dropoverlength*AB*

$$V_B=V_A-[I_AR_{AC}+(I_A-20)R_{CD}+(I_A-60)R_{DE}+(I_A-110)R_{EF}+(I_A-140)R_{FB}]$$

$$220=220-[0\cdot034I_A+0\cdot051(I_A-20)+0\cdot051(I_A-60)+0\cdot034(I_A-110)+0\cdot034(I_A-140)]$$

$$=220-[0\cdot204I_A-12\cdot58]$$

$0\cdot204\, I_A = 12\cdot58$

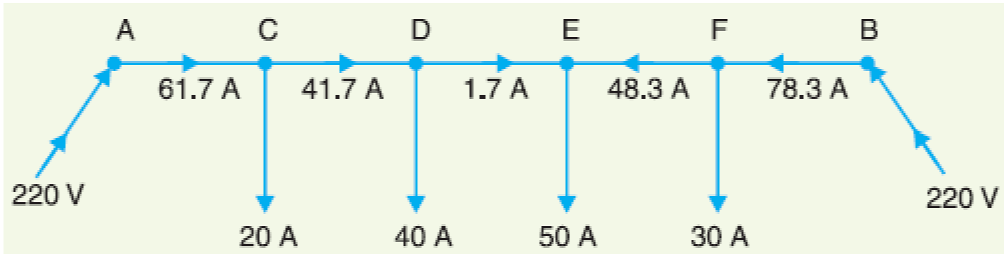
$\therefore I_A = 12\cdot58/0\cdot204 = 61\cdot7\text{A}$

KnowingthevalueofI_A,current inanysectioncanbedetermined.Thus,

CurrentinsectionCD,$I_{CD}=I_A-20=61\cdot7-20=41\cdot7$AfromCtoD

CurrentinsectionEF,$I_{EF}=I_A-110=61\cdot7-110=-48\cdot3$AfromEtoF

$=48\cdot3$AfromFtoE



Theactualdistributionofcurrentsinthevarioussectionsofthedistributorisshowninabovefig.Itisclearthatcurrents arecomingtoloadpoint*E* frombothsides*i.e*. frompoint*D*andpoint*F*. Hence, *E* isthepointofminimumpotential.

∴Minimumconsumervoltage,

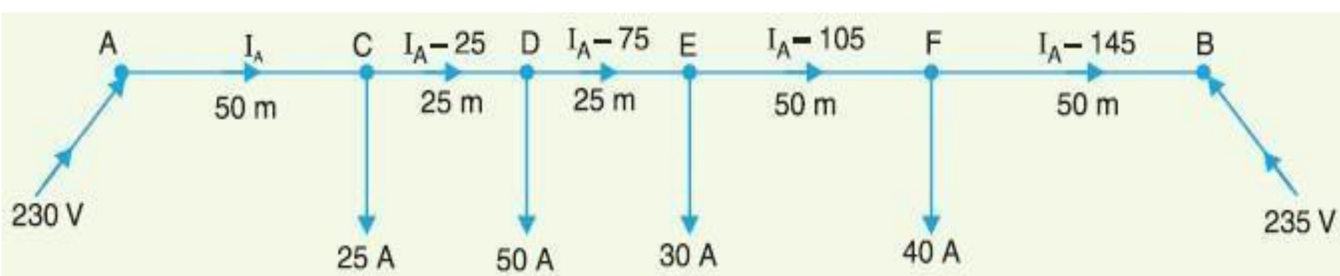
$$V_E=V_A-[I_{AC}R_{AC}+I_{CD}R_{CD}+I_{DE}R_{DE}]$$

$$=220-[61\cdot7\times0\cdot034+41\cdot7\times0\cdot051+1\cdot7\times0\cdot051]$$

$$=220-4\cdot31=215\cdot69\text{V}$$

2. A2-wired.c.distributorABisfedfrombothends.AtfeedingpointA,thevoltageismaintainedasat230 Vandat B235V.Thetotallengthofthedistributoris200 metresand loadsaretapped offas25Aat 50 metres from A ; 50 A at 75 metres from A 30 A at 100 metres from A ; 40 A at 150 metres fromATheresistanceper kilometreofoneconductoris0·3 Ω. Calculate: (i) currents in various sections of the distributor (ii) minimum voltage and the point at which it occurs.

Thebelowfig.showsthedistributorwithitstappedcurrents.Let$I_A$amperesbethecurrentsuppliedfromthefeedingpoint *A*. Thencurrentsinthevarioussectionsofthedistributorareasshowninbelow Fig.



Resistanceof1000mlengthofdistributor(bothwires)$=2\times0\cdot3=0\cdot6\Omega$ Resistance ofsection*AC*, $R_{AC}=0\cdot6\times50/1000=0\cdot03\Omega$ Resistanceofsection*CD*, $R_{CD}=0\cdot6\times25/1000=0\cdot015\Omega$ Resistance ofsection*DE*,$R_{DE}=0\cdot6\times25/1000=0\cdot015\Omega$Resistance ofsection

EF, R_{EF}=0·6×50/1000=0·03Ω Resistance of section FB, R_{FB}=0·6

×50/1000= 0·03Ω

Voltage at B = Voltage at A – Drop over AB

$$V_B=V_A-[I_AR_{AC}+(I_A-25)R_{CD}+(I_A-75)R_{DE}+(I_A-105)R_{EF}+(I_A-145)R_{FB}]$$

$$235=230-[0·03I_A+0·015(I_A-25)+0·015(I_A-75)+0·03(I_A-105)+0·03(I_A-145)]$$

$$235=230-[0·12I_A-9]$$

$$0·12I_A=230+9-235$$

$$I_A=4/0.12=33.34A$$

(i) Current in section AC, $I_{AC}=I_A$=33·34A

Current in section CD, $I_{CD}=I_A-25$= 33·34 −25=8·34A

Current in section DE, $I_{DE}=I_A-75$=33·34−75=−41·66A from D to E

=41·66A from E to D

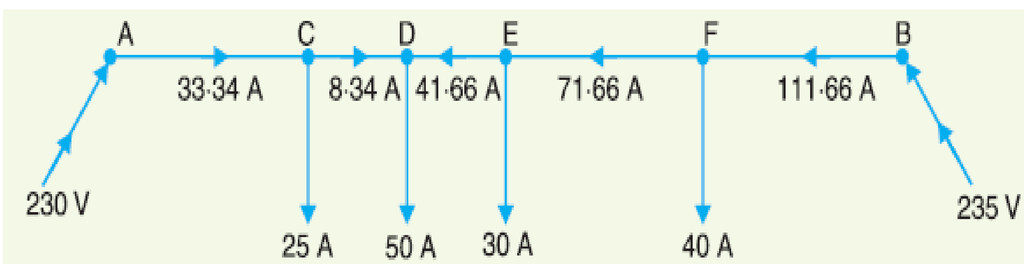
Current in section EF, $I_{EF}=I_A-105$ = 33·34 − 105 = −71·66 A from E to F

=71·66A from F to E

Current in section FB, $I_{FB}=I_A-145$=33·34−145=−111·66A from F to B

=111·66A from B to F

The actual distribution of currents in the various sections of the distributor is shown in below fig. The currents are coming to load point D from both sides of the distributor. Therefore, load point D is the point of minimum potential.



Voltage at D, $V_D=V_A-[I_{AC}R_{AC}+I_{CD}R_{CD}]$

=230−[33·34×0·03+8·34×0·015]

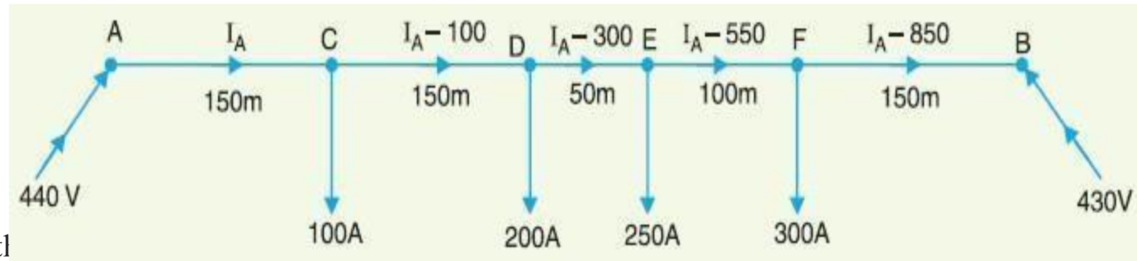
=230−1·125=228·875V

3. A two-wire d.c. distributor AB, 600 metres long is loaded as under,

Distance from A (metres):	150	300	350	450
Loads in Amperes:	100	200	250	300

The feeding point A is maintained at 440V and that of B at 430V. If each conductor has a resistance of 0·01Ω per 100 metres, calculate, (i) the currents supplied from A to B, (ii) the power dissipated in the distributor.

The below fig. shows the distributor with its tapped currents. Let I_A amperes be the current supplied from the feeding point A. Then currents in the various sections of the distributor are as shown in below fig.



Resistanceof100mlengtl

of section AC, R_{AC}=0·02×150/100=0·03Ω Resistance of section CD,

R_{CD}=0·02×150/100=0·03Ω Resistance of section DE, R_{DE}=0·02×50/100=0·01Ω Resistance of section EF,

R_{EF}=0·02×100/100=0·02 Ω Resistance of section FB, R_{FB}=0·02 × 150/100=0·03Ω

Voltage at B = Voltage at A — Drop over AB

$V_B=V_A-[I_AR_{AC}+(I_A-100)R_{CD}+(I_A-300)R_{DE}+(I_A-550)R_{EF}+(I_A-850)R_{FB}]$ 430 = 440−[0·03I_A+0·03(I_A−100)+0·01(I_A−300) +0·02(I_A−550)+0·03(I_A−850)]

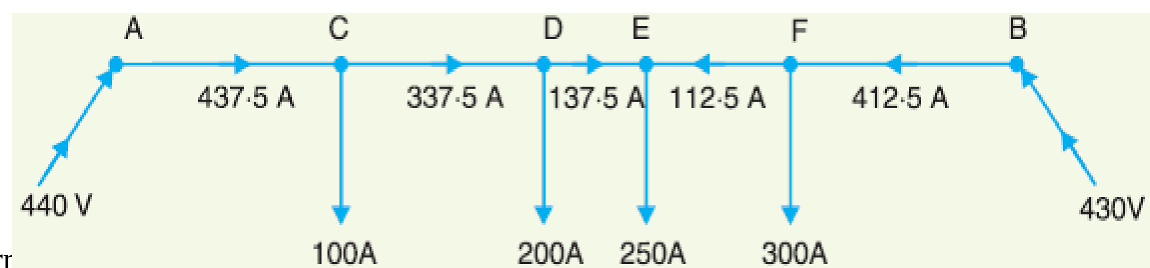
430=440−[0·12I_A−42·5]

0.12I_A=440+42.5–430

=52.5/0.12

I_A=437.5A

The actual distribution of currents in the various sections of the distributor is shown in below fig. Incidentally, E is the point of minimum potential.



i. Curr

Current supplied from end B, I_B=412·5A

ii. Power loss in the distributor=$I^2_{AC}R_{AC}+I^2_{CD}R_{CD}+I^2_{DE}R_{DE}+I^2_{EF}R_{EF}+I^2_{FB}R_{FB}$

=$(437·5)^2×0·03+(337·5)^2×0·03+(137·5)^2×0·01+(112·5)^2×0·02+(412·5)^2×0·03$

=5742+3417+189+253+5104=14,705watts=14·705kW

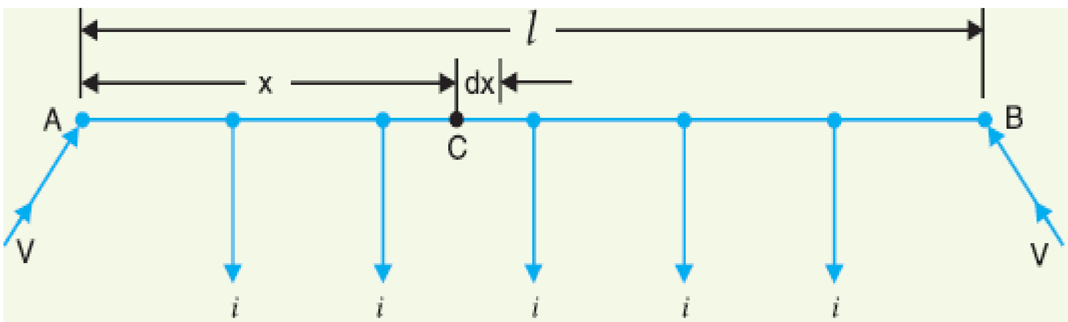
UNIFORMLYLOADEDDISTRIBUTOR:

Weshallnowdeterminethevoltagedropinauniformlyloadeddistributorfedatbothends.Therecanbetwocases viz. thedistributorfedatbothendswith(i) equalvoltages(ii) unequalvoltages. Thetwo casesshall be discussed separately.

Distributorfedatbothendswithequalvoltages:

Consider a distributor AB of length *l* metres, having resistance r ohms per metre runand withuniform loading ofiamperespermetre runasshown inbelowfig.Let the distributor be fed at the feeding points*A* and *B* at equalvoltages,say*V*volts.Thetotalcurrentsuppliedto thedistributoris*il*.Asthetwoendvoltagesareequal, therefore,currentsuppliedfromeachfeedingpointis*il*/2*i.e.*

$$\text{Currentsuppliedfromeachfeedingpoint} = \frac{il}{2}$$



Considerapoint*C*atadistance*x*metresfromthefeedingpoint*A*.Thencurrentatpoint*C*is

$$= \frac{il}{2} - ix = i\left(\frac{l}{2} - x\right)$$

Now,considerasmalllength*dx*nearpoint*C*.Itsresistanceis*rdx*andthevoltagedropoverlength*dx*is

$$dV = i\left(\frac{l}{2} - x\right) r\,dx$$

$$= ir\left(\frac{l}{2} - x\right) dx$$

$$\therefore \text{Voltagedropuptopoint}C = \int dV = \int_0^x ir\left(\frac{l}{2} - x\right) dx$$

$$V = ir\left(\frac{lx}{2} - \frac{x^2}{2}\right)$$

$$V = \frac{ir}{2}(lx - x^2)$$

Obviously,thepointofminimumpotentialwillbethemid-point.Therefore,maximumvoltagedropwilloccurat mid-point*i.e.*where*x*=*l*/2.

$$\text{Max.Voltagedrop} = \frac{ir}{2}(lx - x^2)$$

$$= \frac{ir}{2}\left(l \times \frac{l}{2} - \frac{l^2}{4}\right)$$

$$= \frac{irl^2}{8} = \frac{(il)(rl)}{8} = \frac{IR}{8}$$

Where $il = I$,thetotalcurrentfedtothedistributorfrombothends

$rl = R$,thetotalresistanceofthedistributor

Minimumvoltage $= V - \frac{IR}{8}$ *volts*

Distributor fed at both ends with unequal voltages:

Consider a distributor *AB* of length *l* metres having resistance *r* ohms per metre run and with a uniform loading of *i* amperes per metre run as shown in below fig. Let the distributor be fed from feeding points *A* and *B* at voltages V_A and V_B respectively. Suppose that the point of minimum potential *C* is situated at a distance *x* metres from the feeding point *A*. Then current supplied by the feeding point *A* will be *i x*.

Resistance of section AC is $= rx$

Voltage drop in section $AC = \frac{(ix)(rx)}{2} = \frac{irx^2}{2}$ volts

As the distance of *C* from feeding point *B* is $(l-x)$, therefore, current fed from *B* is $i(l-x)$.

Resistance of section CB is $= r(l-x)$

Voltage drop in section $BC = \frac{[i(l-x)][r(l-x)]}{2} = \frac{ir(l-x)^2}{2}$ volts

Voltage at point C, $V_C = V_A -$ Drop over AC

$$= V_A - \frac{irx^2}{2}$$

Also, voltage at point C, $V_C = V_B -$ Drop over BC

$$= V_B - \frac{ir(l-x)^2}{2}$$

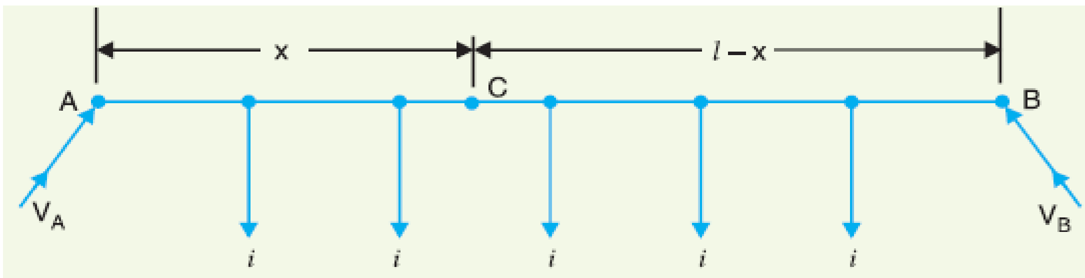
Fromequations(*i*)and(*ii*),weget,

$$V_A - \frac{irx^2}{2} = V_B - \frac{ir(l-x)^2}{2}$$

Solvingtheequationfor*x*,weget,

$$x = \frac{V_A - V_B}{irl} + \frac{l}{2}$$

Asallthequantitiesontherighthandsideoftheequationareknown,therefore,thepointonthedistributorwhere minimum potential occurs can be calculated.



1. A two-wire d.c. distributor cable 1000 metres long is loaded with 0·5 A/metre. Resistance of each conductoris0·05Ω/km.Calculatethemaximumvoltagedropifthedistributorisfedfrombothendswithequal voltages of220 V. What is the minimum voltage and where it occurs?

Currentloading,i=0·5A/m

Resistanceofdistributor/m,r=2×0·05/1000=0·1×10^{-3}Ω

Lengthofdistributor,l=1000m

Totalcurrent supplied bydistributor, $I = il = 0{\cdot}5\times1000 = 500$A

Totalresistanceofthedistributor, $R = rl = 0{\cdot}1\times10^{-3}\times1000 = 0{\cdot}1\ \Omega$

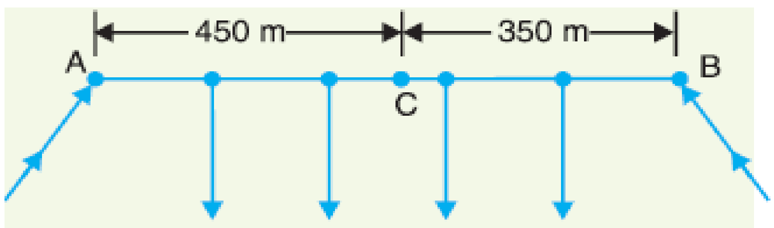
Max.Voltagedrop$=\frac{IR}{8}=\frac{500\times0.1}{8}=6.25$V

Minimumvoltagewilloccuratthemid-pointofthedistributoranditsvalueis

$=220-6{\cdot}25=213{\cdot}75$V

2. A800metres2-wired.c.distributorABfedfrombothendsisuniformlyloadedattherateof1·25A/metre run.CalculatethevoltageatthefeedingpointsAandBiftheminimumpotentialof220VoccursatpointCata distanceof450 metresfromtheend A.Resistanceofeachconductoris0·05 Ω/km.

Thebelowfig.showsthesinglelinediagramofthedistributor.



Currentloading,$i=1{\cdot}25$A/m

Resistanceofdistributor/m,$r=2\times0{\cdot}05/1000=0{\cdot}0001\Omega$

Voltage at C, $V_C = 220$ V

Lengthofdistributor,$l=800$m

DistanceofpointCfromA,$x=450$m

VoltagedropinsectionAC$=\frac{irx^2}{2}=\frac{1.25\times0.0001\times450^2}{2}=12.65$v

∴Voltageatfeedingpoint$A, V_A=220+12{\cdot}65=232{\cdot}65$V

VoltagedropinsectionBC$=\frac{ir(l-x)^2}{2}$

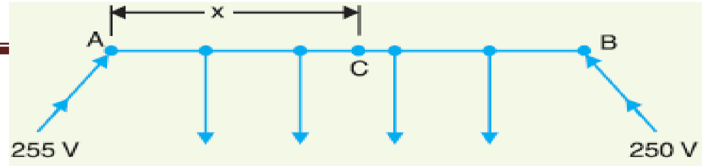
$=\frac{1.25\times0.0001\times(800-450)^2}{2}$

$=7.65$v

∴Voltageatfeedingpoint$B, V_B=220+7{\cdot}65=227{\cdot}65$V

3. A2-wired.c.distributorAB500metreslongisfedfrombothendsandisloadeduniformlyattherateof 1·0A/metre.AtfeedingpointA,thevoltageismaintainedat255VandatBat250V.Iftheresistance of eachconductoris0·1Ωperkilometre,determine:(i)theminimumvoltageandthepointwhereitoccurs (ii)thecurrentssuppliedfromfeeding pointsAand B

Thebelowfig.showsthesinglelinediagramofthedistributor.



Voltageatfeedingpoint$A$, V_A=255V

Voltageatfeedingpoint$B$, V_B=250V

Length of distributor, l = 500 m

Current loading, i = 1 A/m

Resistanceofdistributor/m, r=2×0·1/1000=0·0002Ω

(i) Lettheminimumpotentialoccuratapoint$C$distant$x$metresfromthefeedingpoint$A$.

$$x = \frac{V_A - V_B}{irl} + \frac{l}{2}$$

$$= \frac{255-250}{1\times0.0002\times500} + \frac{500}{2}$$

x=50+250=300m

*i.e.*minimumpotentialoccursat300mfrompoint$A$.

Minimumvoltage, $V_C = V_A - \frac{irx^2}{2}$

$=255-\frac{1\times0.0002\times300^2}{2}$

$=255-9=246V$

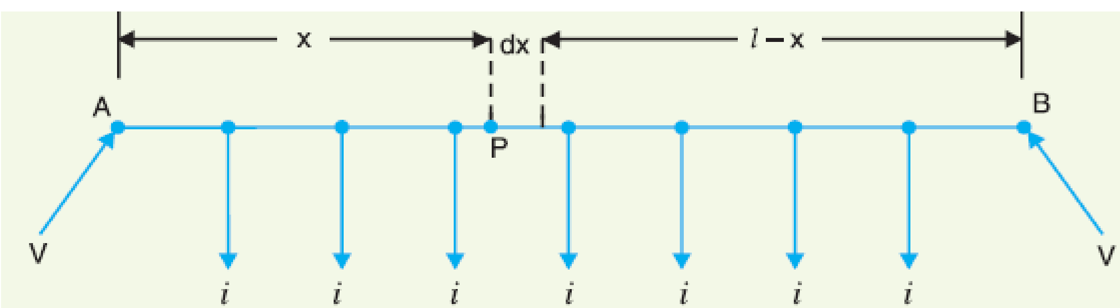
(ii) CurrentsuppliedfromA= ix=1×300 =300A

CurrentsuppliedfromB=$i(l-x)$=1(500−300)=200A

Powerlossinauniformlyloadeddistributorfedatbothendswithequalvoltages:

ConsideradistributorABoflengthlmetres,havingresistancerohmsper metrerunwithuniformloading ofi amperesper metrerunasshowninbelowfig.LetthedistributorbefedatthefeedingpointsAandBatequalvoltages,sayV volts. Thetotalcurrent supplied bythedistributorisil.Asthetwoendvoltagesareequal, therefore,current supplied fromeach feeding point is $i\,l/2$.

Currentsuppliedfromeachfeedingpoint=$\frac{il}{2}$



ConsiderasmalllengthdxofthedistributoratpointPwhichisatadistancexfromthefeedingendA.

Resistance oflengthdx =rdx

Currentinlengthdx=$\frac{il}{2}-ix=i\left(\frac{l}{2}-x\right)$

Powerlossinlengthdx=(currentindx)^2×Resistanceofdx

$=\left[i\left(\frac{l}{2}-x\right)\right]^2\times rdx$

Total power loss in the distributor is $P=\int_0^l \left[i\left(\frac{l}{2}-x\right)\right]^2 \times r\,dx$

$$=i^2 r\int_0^l \left(\frac{l^2}{4}-lx+x^2\right)dx$$

$$=i^2 r\left[\frac{l^2x}{4}-\frac{lx^2}{2}+\frac{x^3}{3}\right]_0^l$$

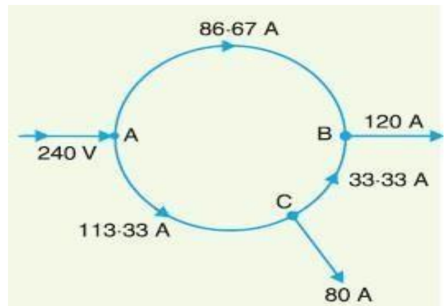
$$=i^2 r\left[\frac{l^3}{4}-\frac{l^3}{2}+\frac{l^3}{3}\right]$$

$$P=\frac{i^2 r l^3}{12}$$

RINGMAINDISTRIBUTOR:

Adistributorarrangedtoformaclosedloopandfedatoneormorepointsiscalledaringdistributor.Such a distributor starts fromone point, makes a loopthroughthe areato be served, and returns to the original point. For the purpose ofcalculatingvoltagedistribution,thedistributorcanbeconsideredasconsisting ofaseriesofopendistributorsfed atbothends.

Theprincipaladvantageofringdistributoristhat byproperchoice inthenumberoffeedingpoints, great economy incoppercanbeaffected. Thesimplest caseofaringdistributoristheonehavingonlyone feedingpoint asshown inbelowfig.HereAisthefeedingpointandtapingsaretaken frompointsBand C.Forthepurposeofcalculations, itisequivalenttoastraightdistributorfedatbothendswithequalvoltages.



PROBLEMS:

1.A2-wired.c. ringdistributoris300 mlongand is fedat240Vat point A. At point B,150mfromA, a load of120 Aistakenand at C, 100 min theoppositedirection, a load of80 Ais taken. Iftheresistance per 100mofsingleconductoris0·03Ω,find:(i) current ineachsectionofdistributor(ii) voltageat points BandC

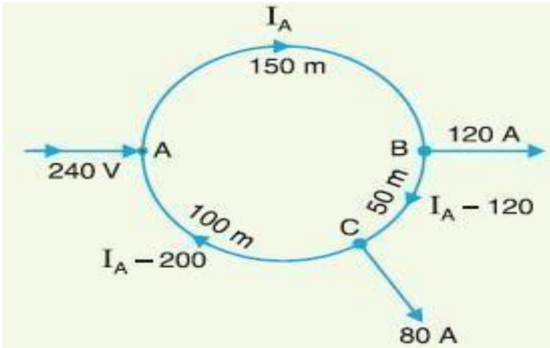
Resistanceper100 mofdistributor=2×0·03=0·06Ω

Resistance ofsection AB, R_{AB}= 0·06× 150/100=0·09 Ω

ResistanceofsectionBC,R_{BC}=0·06×50/100=0·03Ω

ResistanceofsectionCA,R_{CA}=0·06×100/100=0·06Ω

(i) Letussupposethatacurrent$I_A$flowsinsectionABofthedistributor.ThencurrentsinsectionsBC andCAwillbe(I_A−120)and (I_A−200)respectivelyasshown inbelowFig.



AccordingtoKirchhoff'svoltagelaw,thevoltagedropintheclosedloop$ABCA$iszero*i.e.*

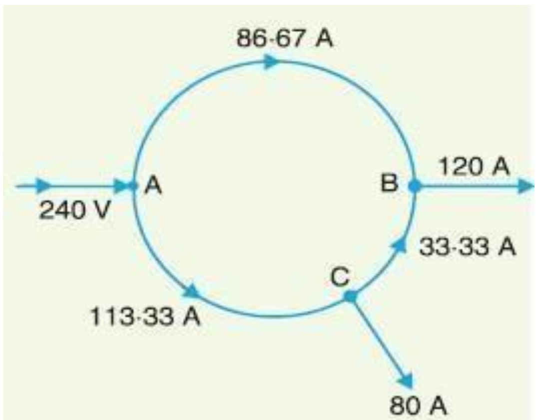
$$I_{AB}R_{AB}+ I_{BC}R_{BC}+I_{CA}R_{CA}=0$$

$$0·09I_A+0·03(I_A-120)+0·06(I_A-200)=0$$

$$0·18I_A=15·6$$

$$\therefore I_A=15·6/0·18=86·67\text{A}$$

TheactualdistributionofcurrentsisasshowninbelowFig.fromwhereitisseenthat$B$isthepointofminimumpotential.



CurrentinsectionAB,I_{AB}= I_A= 86·67A*fromAtoB*

CurrentinsectionBC,I_{BC}=I_A−120=86·67−120=−33·33A

=33.33A*fromCtoB*

CurrentinsectionCA,I_{CA}=I_A−200=86·67−200=−113·33A

=113·33Afrom*AtoC*

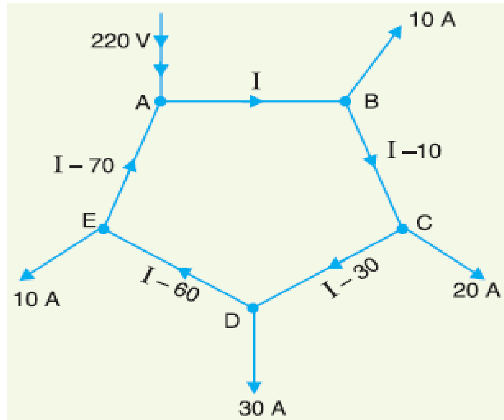
(ii) Voltageatpoint$B$,V_B=V_A−$I_{AB}R_{AB}$=240−86·67×0·09=232·2V

Voltageatpoint$C$,V_C=V_B+$I_{BC}R_{BC}$

=232·2+33·33×0·03=233·2V

2. A 2-wire d.c. distributorABCDEAin the form of a ringmainisfedatpointAat220Vandisloadedas under:10Aat B;20Aat C;30Aat Dand10AatE.Theresistancesofvarioussections(goandreturn)are: AB = 0·1 Ω ; BC = 0·05 Ω ; CD = 0·01 Ω ; DE = 0·025 Ω and EA = 0·075 Ω. Determine, (i) the pointof minimum potential (ii) current in each section of distributor

Thebelow figshowsthering maindistributor. Letussupposethat current *I*flows insection*AB*ofthe distributor. Thencurrents in the various sections ofthe distributor areas shown in below fig.



(i) AccordingtoKirchhoff'svoltagelaw,thevoltagedropintheclosedloop*ABCDEA*iszero*i.e.*

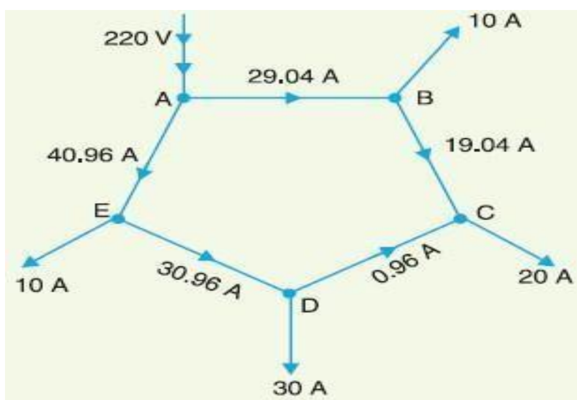
$$I_{AB}R_{AB}+I_{BC}R_{BC}+I_{CD}R_{CD}+I_{DE}R_{DE}+I_{EA}R_{EA}=0$$

$$0{\cdot}1I+0{\cdot}05(I-10)+0{\cdot}01(I-30)+0{\cdot}025(I-60)+0{\cdot}075(I-70)=0$$

$$0{\cdot}26I=7{\cdot}55$$

$$\therefore I=7{\cdot}55/0{\cdot}26=29{\cdot}04\text{A}$$

Theactualdistributionofcurrents isasshowninbelowfig.fromwhereitisclearthat*C*isthepointof minimumpotential.



∴*C*isthepointofminimumpotential.

(ii) CurrentinsectionAB= I= 29·04AfromAtoB

CurrentinsectionBC=I−10=29·04−10=19·04AfromBtoC

CurrentinsectionCD = I− 30=29·04−30=− 0·96A=0·96AfromD toC

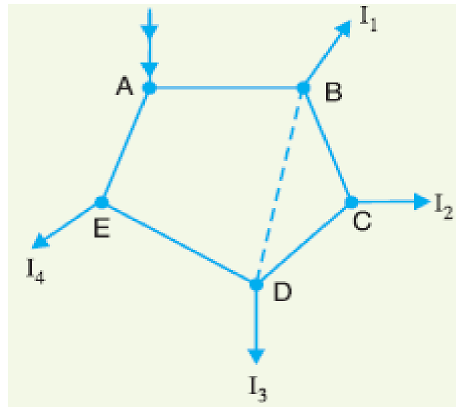
CurrentinsectionDE=I−60=29·04−60=−30·96A=30·96AfromEtoD

CurrentinsectionEA=I−70=29·04−70=−40·96A=40·96AfromAtoE

RingMainDistributorwithInterconnector:

Sometimesaringdistributorhastoservealargearea.Insuchacase,voltagedropsinthevarioussectionsofthe distributor maybecome excessive. Inorderto reduce voltage drops invarious sections, distantpoints ofthe distributorarejoinedthroughaconductor calledinterconnector.

ThebelowfigshowstheringdistributorABCDEA.ThepointsBandDoftheringdistributorarejoinedthroughan interconnector BD. There are several methods for solving such a network.

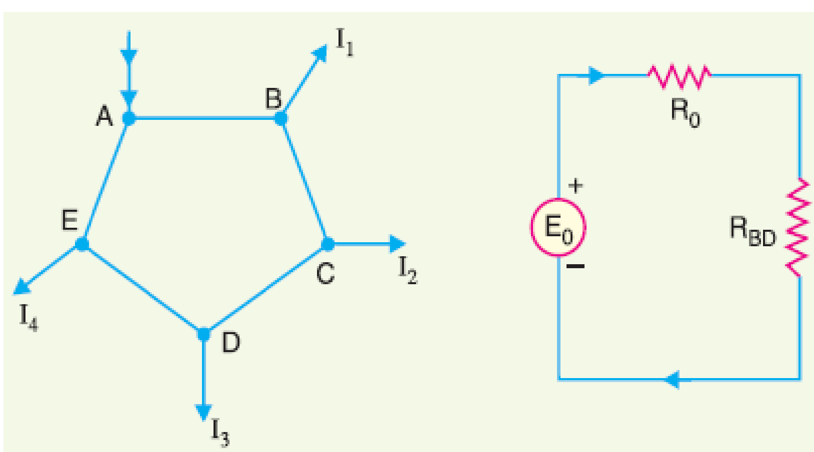


However,thesolutionofsuchanetworkcanbereadilyobtainedbyapplying Thevenin'stheorem.Thestepsof procedure are

(i) Considertheinterconnector*BD*to bedisconnectedand findthepotentialdifference between*B*and*D*.This gives Thevenin's equivalent circuit voltage E_0.

(ii) Next,calculatetheresistanceviewedfrompoints*B*and*D*ofthenetworkcomposedofdistributionlinesonly.This gives Thevenin's equivalent circuit series resistance R_0.

(iii) IfR_{BD}istheresistanceoftheinterconnector*BD*,thenThevenin'sequivalentcircuitwillbeasshowninbelow fig.



$$\therefore \text{Current in interconnector } BD = \frac{E_0}{R_0 + R_{BD}}$$

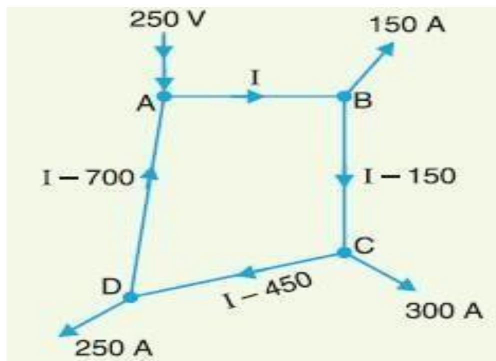
Therefore,currentdistributionineachsectionandthevoltageofloadpointscanbecalculated.

PROBLEMS:

1. Ad.c. ring main ABCDA is fed frompoint A froma 250 V supplyand the resistances (including both lead and return) ofvarious sections are as follows: AB = 0·02 Ω ; BC = 0·018 Ω ; CD = 0·025 Ω and DA=0·02Ω.Themainsuppliesloadsof150AatB;300AatCand250AatD.Determinethevoltageateachload point.IfthepointsAand Carelinked throughan interconnectorofresistance0·02Ω, determinethe new voltage at each load point.

WithoutInterconnector:

Thebelow fig.showstheringdistributorwithoutinterconnector.Letussupposethatacurrent *I*flowsin section*AB*ofthe distributor.Thencurrents invarious sections ofthe distributor will be as shown in below fig.



AccordingtoKirchhoff'svoltagelaw,thevoltagedropintheclosedloop*ABCDA*iszero*i.e.*

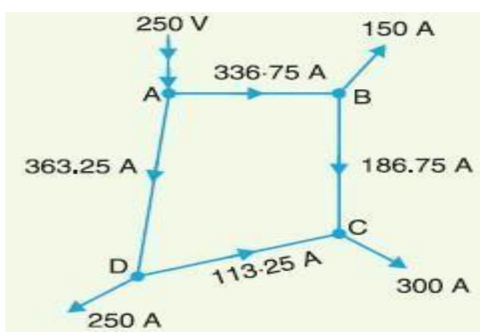
$$I_{AB}R_{AB}+I_{BC}R_{BC}+I_{CD}R_{CD}+I_{DA}R_{DA}=0$$

$$0\cdot02I+0\cdot018(I-150)+0\cdot025(I-450)+0\cdot02(I-700)=0$$

$$0\cdot083I=27\cdot95$$

$$\therefore I=27\cdot95/0\cdot083=336\cdot75\text{A}$$

Theactualdistributionofcurrentsisasshowninbelowfig.



Voltage drop in $AB = I_{AB}R_{AB}$ = 336·75 × 0·02 = 6·735 V

Voltage drop in $BC = I_{BC}R_{BC}$ = 186·75 × 0·018 =3·361 V

Voltagedropin$CD=I_{CD}R_{CD}$=113·25×0·025=2·831VVoltage

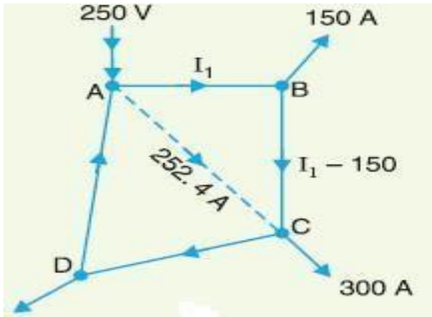
drop in $DA = I_{DA}R_{DA}$ = 363·25 × 0·02= 7·265 V

∴ Voltage at point *B* = Voltage at point A – Voltage drop in AB = 250 − 6·735 = 243·265 V

Voltageatpoint*C*=Voltageatpoint B–VoltagedropinBC=243·265−3·361=239·904VVoltageat point D = Voltage at point C – Voltage drop in CD 239·904 + 2·831 = 242·735 V

WithInterconnector:

Thebelow fig.showstheringdistributorwithinterconnector *AC*.Thecurrent inthe interconnectorcanbe found by applying Thevenin's theorem.



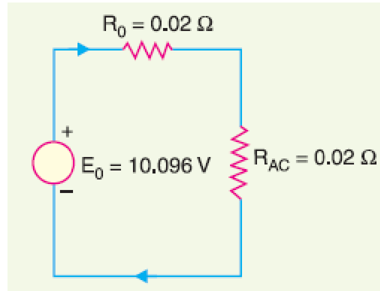
E_0=VoltagebetweenpointsAandC

$=250-239\cdot904=10\cdot096V$

R_0=ResistanceviewedfrompointsAandC

$$=\frac{(0.02+0.018)(0.02+0.025)}{(0.02+0.018)+(0.02+0.025)} \qquad =0.02\Omega$$

R_{AC}=Resistanceofinterconnector=0·02Ω Thevenin's equivalent circuit is shown in below fig.



∴Currentininterconnector$AC = \frac{E_o}{R_o+R_{AC}} = \frac{10.096}{0.02+0.02}$ =252.4AfromAtoC

Letussupposethat current insectionAB isI_1.ThencurrentinsectionBCwillbeI_1-150. Asthevoltagedropproundthe closed mesh $ABCA$ is zero,

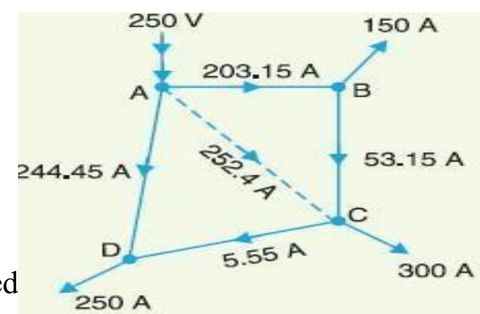
$$\therefore 0{\cdot}02I_1+0{\cdot}018(I_1-150)-0{\cdot}02\times252{\cdot}4=0 \quad 0{\cdot}038I_1= 7{\cdot}748$$

$$\therefore I_1=7{\cdot}748/0{\cdot}038=203{\cdot}15A$$

Theactualdistributionofcurrentsintheringdistributorwithinterconnectorwillbeasshowninbelowfig.

ropinAB =$I_{AB}R_{AB}$= 203·15 ×0·02= 4·063VDropinBC=$I_{BC}R_{BC}$= 53·15 ×0·018=0·960 VDrop inAD= $I_{DA}R_{DA}$= 244·45 × 0·02 = 4·9 V

∴Potentialof$B$ =VoltageatpointA–VoltagedropinAB=250−4·063=245·93V

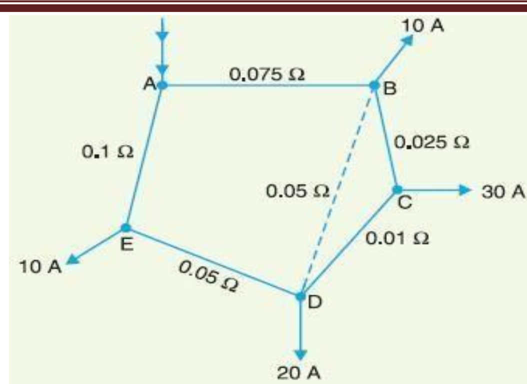


Potentialof$C$=Voltageatpoint B–Voltaged tentialof$D$ = Voltage at point C – Voltage drop inCD 250 − 4·9 = 245·1 V

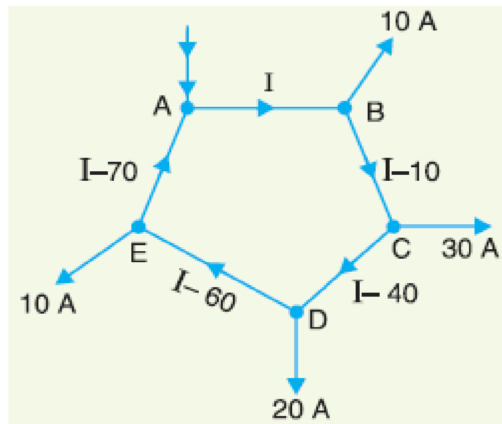
Itmay beseenthatwiththeuse ofinterconnector,thevoltagedropsinthevarioussectionsofthe distributor arereduced.

2. Thebelowfig.showsaringdistributorwithinterconnectorBD.ThesupplyisgivenatpointA.The resistancesofgo andreturnconductorsofvarioussectionsare indicatedinthe figure.Calculate:

(i)currentintheinterconnector(ii)voltagedropintheinterconnector



WheninterconnectorBDisremoved,letthecurrentinbranchABbeI.Thencurrent distributionwillbe as shownninbelowfig

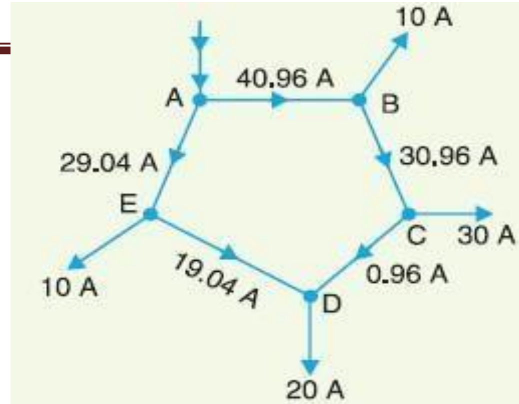


AsthetotaldroproundtheringABCDEAiszero,

$$\therefore 0\cdot075I+0\cdot025(I-10)+0\cdot01(I-40)+0\cdot05(I-60)+0\cdot1(I-70)=0 \quad 0\cdot26I = 10\cdot65$$

$$I=10.65/0.26=40.96A$$

Theactualdistributionofcurrentswillbeasshowninbelowfig.



Voltage drop along $BCD = 30{\cdot}96 \times 0{\cdot}025 + 0{\cdot}96 \times 0{\cdot}01$

$= 0{\cdot}774 + 0{\cdot}0096 = 0{\cdot}7836$ V

This is equal to Thevenin's open circuited voltage E_0 *i.e.*

$$E_0 = 0{\cdot}7836 \text{ V}$$

R_0 = Resistance viewed from B and D

$$= \frac{(0.075+0.1+0.05)(0.025+0.01)}{(0.075+0.1+0.05)+(0.025+0.01)} = \frac{(0.225)(0.035)}{(0.225)+(0.035)} = 0.03\,\Omega$$

(i) Current in interconnector BD is

$$I_{BD} = \frac{E_o}{R_o + R_{BD}}$$

$$= \frac{0.7836}{0.03+0.05} = 9.8 \text{ A}$$

(ii) Voltage drop along interconnector BD