SWITCHGEARAND PROTECTIVEDEVICES (TH- 02)

SixthSemester

ElectricalAndElectronics Engg.

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INTRODUCTIONTOSWITCHGEAR

Switchgear: Theaaparatususedforusedforswitching,controllingandprotectingtheelectrical circuits and equipment is known as switch gear.

Essentialfeaturesofswitchgear: Theessentialfeaturesofswitchgearare:

- Completereliability: Whenfaultoccursonany partof thepowersystem,theswitchgearmust reliable to operate to isolate the fault section from remainder circuit.
- Absolutecertaindiscrimination: Whenfaultoccursonanysectionofthepowersystem,the switch gear must be able to discriminate between the fault section and healthy section.
- Quick operation: When fault occurs on any part of the power system,the switch gear must operatequicklysothatnodamgeisdonetogenerateandotherequipmentsbythe shortcircuit current.
- Provisionformanualcontrol: Itmusthavebeprovisionformanualcontrol.
- Provisionforinstrument: Itisessentialthatfor aswitchgeartomeasure current,power,voltage.So ammeter ,voltmeter,wattmeter etc required.

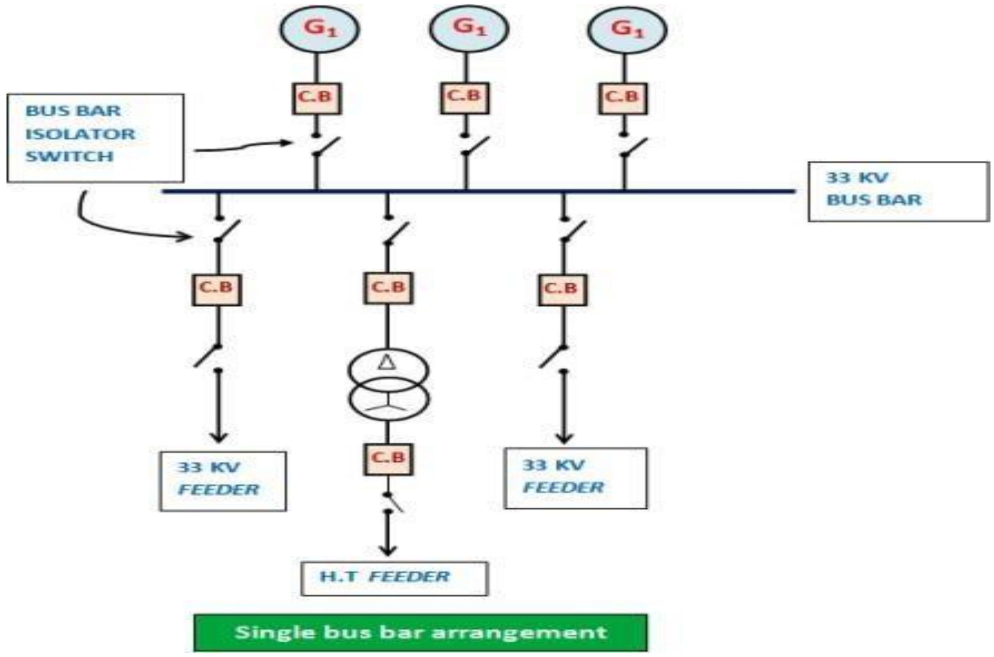
Switchgearequipment:

- Switch: Aswitchisadevicewhichisusedtoopenorclosedanelectricalcircuiteasily.
- Airbreakswitch: Itisanairswitchandisdesignedtoopenacircuitunderload.
- Isolatorordisconnectingswitch: Itisaknifeshapeswitchandisdesignedtoopen underno load.
- Oilswitches: Inoilswitchesthecontactofswitchesareopenunderoil(usuallytransformeroil).
- Fuses: Afuseisashortpieceof wireorthinstripwhich meltswhenexcessivecurrentflows through it for sufficient time.
- Circuitbreaker: Acircuitbreakerisanequipmentwhichcanopen or closeacircuitunder all conditions i.e no load ,full load and fault conditions.
- Realy: Arealyisadevicewhichdetectsthefaultandsuppliesinformationtothe breakerfor circuit interruption.

Busbararrangements: Busbarsarecopperrodsorthinwalledtubesandtubesandoperate at constant voltage.

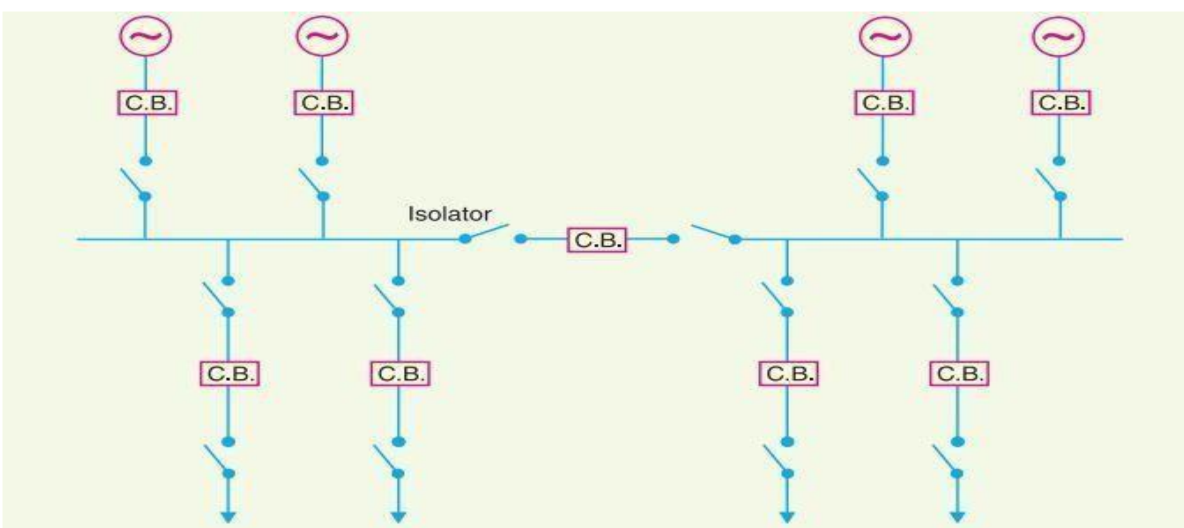
- Singlebusbar system.
- Singlebusbarsystemwithsectionalisation
- Duplicatebus-barsystem

Singlebusbarsystem:



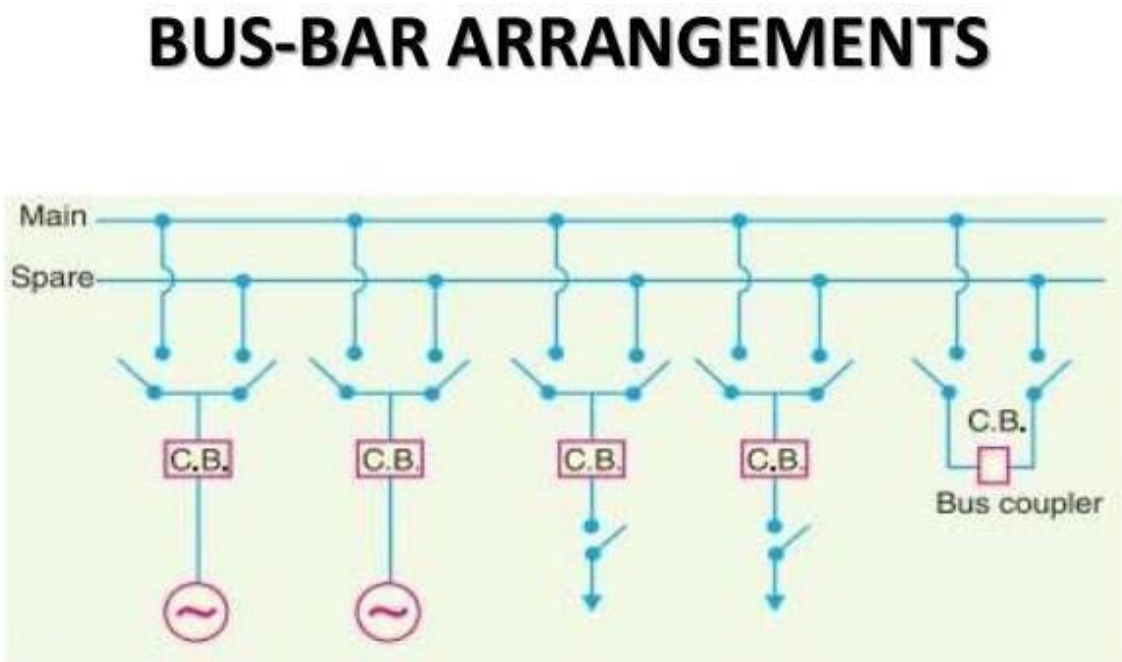
- Hereonlyonebusisused.
- Itissimpleindesign.
- Ithaslowinitialcost,lessmaintenanceandsimpleoperation.
- Iffaultoccursonbusbaritself,thereiscompleteinterruptionofsupply.
- Inthisarrangementthebusbarcannotbecleaned,repairedortested.
- Itisemployedinsmalloutdoorsystem.

Singlebus-barsystemwithsectionalisation:



- Itisemployedinlargegeneratingstation.
- Herethebus-bardividedintotwosectionsconnectedbyacircuitbreakerandisolators.
- Iffaultoccurs onanysectionof thebus-bar ,thatsectioncanbe isolatedwithoutaffectingthe supply to other section.
- Inthissystembus-barmaintenanceandrepairissimple.

Duplicate bus-bar system:



Duplicate bus-bar system

- Heremainbus,sparebusandabus-coupleremployed.
- Thisarrangementisdifficultinnature.
- Eachgenerator ,feedermaybeconnectedto eitherbusbarwiththehelpof buscouplerwhich consists of CB and isolator.
- Itwilltooexpensiveinnature.
- Repairandmaintenanceofmainbus-bareaslywithoutinterruptingthesupply.
- Iffaultoccurs onthe busbar thecontinuityofsupplycanbemaintainedbytransferringittothe other bus bar.

Switchgearaccommodation: Dependinguponthevoltagetobehandledswitchgearmay be broadly classified into:

I. Outdoortype.
II. Indoortype.

Outdoor type:Voltageabove66kv,switchgearequipmentsareinstalledinoutdoor,this typeiscalledas outdoor type accommodation.

Indoortype:For voltagebelow66kv,switchgearequipmentsareinstalledinindoor,thistypeof accommodation is called as indoor type.

Shortcircuit: Wheneverafaultoccursonanetworksuch thatalargecurrent flowsinoneormore phases ,a short circuit is said to have occurred.

Causesofshortcircuit:Causesofshortcircuitistwotypes:

Internal effects: Deterioration of insulation in a generator ,transformer etc.

Externaleffects:Lightningsurges,overloading,mechanicaldamagebypublic. Effects

of short circuit:

- Interruptthepowersupply.
- Heatingthemachines.

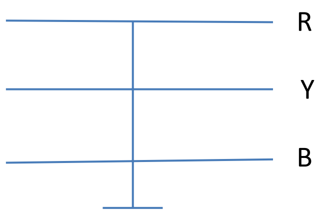
Faultsinpowersystem: Afaultinanelectricalequipmentisdefinedasadefectinthe electrical circuit due to which current is diverted into the intended path.

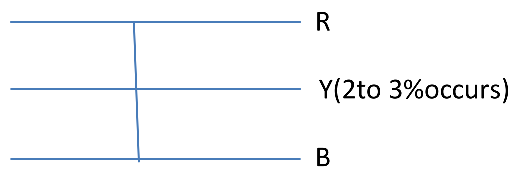
Faultsaretwotypes:

1. Symmetricalfaults.
2. Un-symmetricalfaults.

Symmetricalfaults:Thefaultwhichgivesrisestosymmetricalfaultcurrents(equalfaultcurrentswith 120^0 displacement) is called as symmetrical fault.

Example:Allthreephasestogroundandallthreephasesshortcircuited.

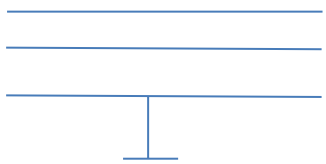




Unsymmetricalfaults:Thefaultwhichgivesrisetounsymmetricalcurrents(i.eequallinecurrentswith unequal displacements) are called unsymmetrical faults.

Againtheunsymmetricalfaultsarefollowingtypes:

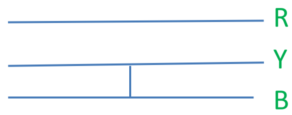
- Singlelinetoground(L-G)



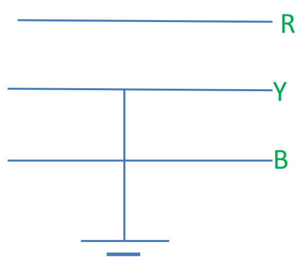
R

Y (70%occurred) B

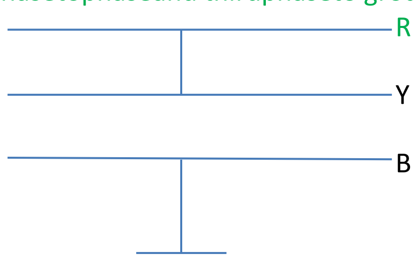
- Phasetophase(L-L):



- Twophasetoground(L-L-G):



- Phasetophaseand thirdphaseto ground:

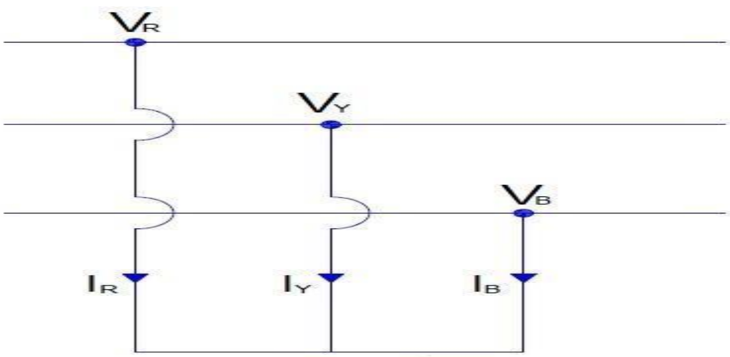


END

FAULTCALCULATION

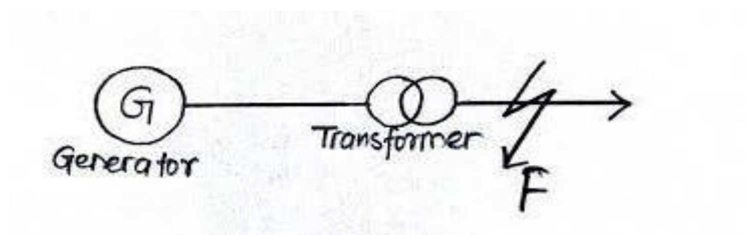
Symmetricalfaultson3-ϕsystem:Thatfaultonthepowersystemwhichgivesriseto symmetrical fault currents (i.e equal fault currents in the lines with 120^0 displacement) is called a symmetrical fault.

Thesymmetricalfaultoccurswhenallthethree conductorsof a3-ϕlinearebroughttogether simultaneously.



Thisfaultismoredangeriousinnature.

Limitationoffaultcurrent:



Asshowninabovefigure,thefaultoccursonthefeederatpointF. After that

the short circuit current flow.

Thatshortcircuitcurrentislimitedbytheimpedanceofthesystemuptothepointoffault.

That´swhy theknowledgeofimpedancesofthevariousequipmentandcircuitsinthe lineofthesystem is very important when calculating the short circuit currents.

Percentagereactance:Itisthepercentageofthetotal phase-voltagedroppedinthecircuit when full load current is flowing.

i.e $\%X = \frac{IX \times 100}{V}$ -------------------(1)

Where,

I=fullloadcurrentin A.

V=phasevoltageinV.

X=reactanceinΩ.

Fromequation(1),

$X = \frac{\% X V}{V}$,Ω

MultiplyinganddividingtherighthandexpressionbyV, $X = (\%X) \times \frac{V \times V}{I \times V \times 100}$

$= \frac{(\% X) \times V^2}{V \times I \times 100}$

WhenthevoltageandtheoutputareexpressedinKVandKVArespectively,then $X = (\% X) \times \frac{(V/1000) \times (V/1000)}{(V/1000) \times (I/1000) \times 100}$

$= \frac{(\% X)\ KV \times KV}{KV \times KA \times 100}$

$= \frac{(\%X)(KV)^2 \times 1000\ KV}{\times A \times 100}$

$X = \frac{(\% X) \times (KV)^2 \times 10}{KVA}$ inΩ.

$\%X = \frac{(X) \times (KVA)}{}$

$10(KV)^2$

IfXistheonlyreactanceelementinthe circuit,thenshortcircuitcurrentisgivenby, $I_{SC}=V/X$

------------------(2)

From equation (1)

V/X=I×(100/%X)

NowthisV/Xputinequation(2)weget $I_{SC}= I$

× (100 / %X)

PercentagereactanceandbaseKVA:Weknowthat,

$$\%X=\frac{(KVA)\times X}{10(KV)^2}$$

Fromaboveweseethat%x dependsupontheKVArating

ThecommonKVAratingamongallequipmentsusedinpowersystemisknownasbasekva.

AbaseKVAmaybechoseninthefollowingmanner,

- Anyarbitraryvalue.
- EqualtotheKVAratingsofthelargestunitconnectedinthenetwork.
- EqualtothesumoftheKVAratingsofalltheunits connectedinthenetwork.
- %agereactanceatbaseKVA=$\frac{\text{BaseKVA}}{\text{RatedKVA}}$×%agereactanceatratedKVA

ShortcircuitKVA:Theproductofnormalsystemvoltageandshortcircuitcurrentatthe pointof fault expressed in KVA is known as short circuit KVA.

SoshortcircuitKVAFOR3-ϕcircuit,

$$=\frac{3VI_{SC}}{1000}$$

$$=\frac{3V\times I}{1000}\times\frac{100}{\%X}$$

=BaseKVA× $\underline{100}$

%X

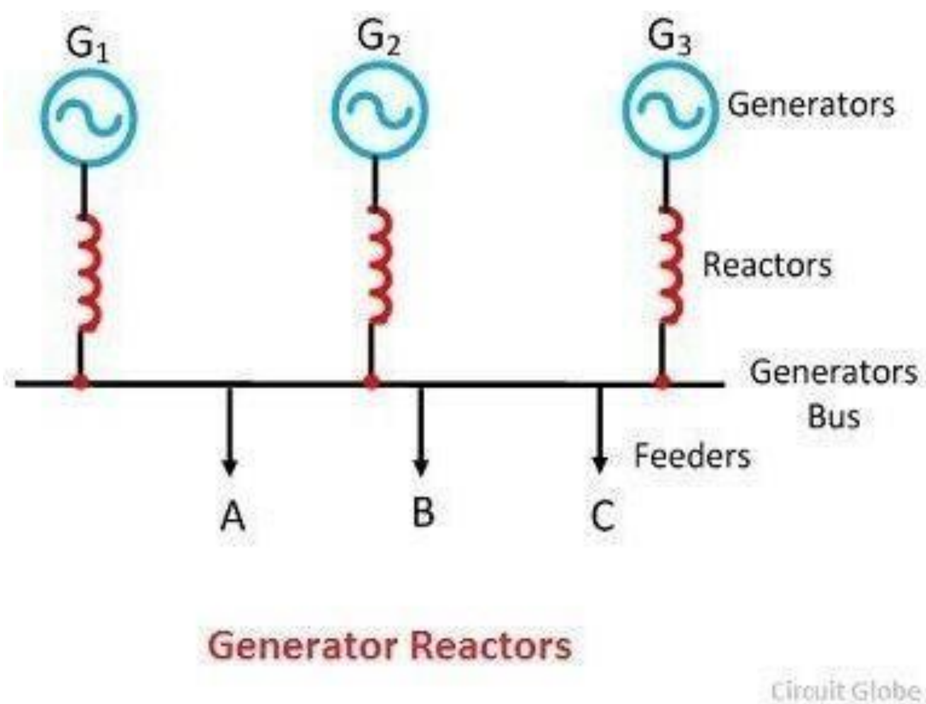
Reactorcontrolofshortcircuitcurrent:

- Reactor:Theadditionalreactance(acoilofnumberofturnsdesignedtohavealargeinductance)ascomparedtoitsohmicresistanceisknownasreactor.
- Reactorslimittheflowofshortcircuitcurrent.
- Reactorspermittheinstallationofcircuitbreakersoflowerrating.
- Reactorsareconnectedinserieswiththesystem.

Locationofreactors:Shortcircuitcurrentlimitingreactorsmaybeconnected

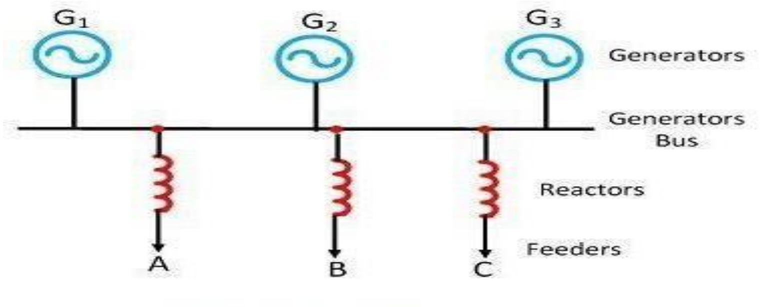
- inserieswith generator.
- inserieswitheachfeeder.
- inbus bars.

Generatorreactors:



- whenthereactors areconnectedinserieswitheachgenerator,theyareknown as generator reactors.
- Inthisarrangementgeneratorsareprotectedinthe caseofanyshortcircuitbeyond the reactors.
- Thereisaconstantvoltagedropandpowerlossinthereactorsevenduringnormaloperation.
- Ifafaultoccursonanyfeeder,thecontinuityofsupplyislikelytobeaffected.
- Ifabusbarorfeederfaultoccursclose tothebus barthevoltageatbusbarreduced.

Feederreactors:



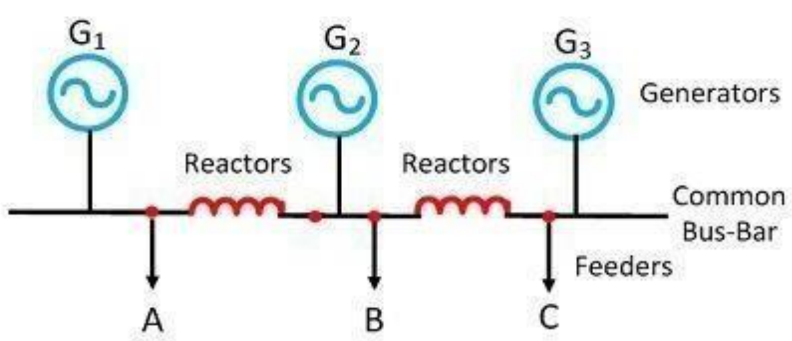
Feeders Reactors

- Whenthereactorsareconnectedinserieswitheachfeeder,theyareknownasfeederreactors.
- Feedersareprotectedverysafely.
- Busbarvoltageshouldbeconstanteveniffaultonanyfeeders.
- Thefaultonafeederwillnotaffectedtheotherfeeder.
- Thereisaconstantvoltagedropand powerlossinthe reactorsevenduringnormaloperation.
- Ifshortcircuitoccurs atthebusbar noprotectionisprovidedtothegenerators. Bus-

bar reactors:Bus-bar reactors are two types:

- Ring system
- Tie-barsystem

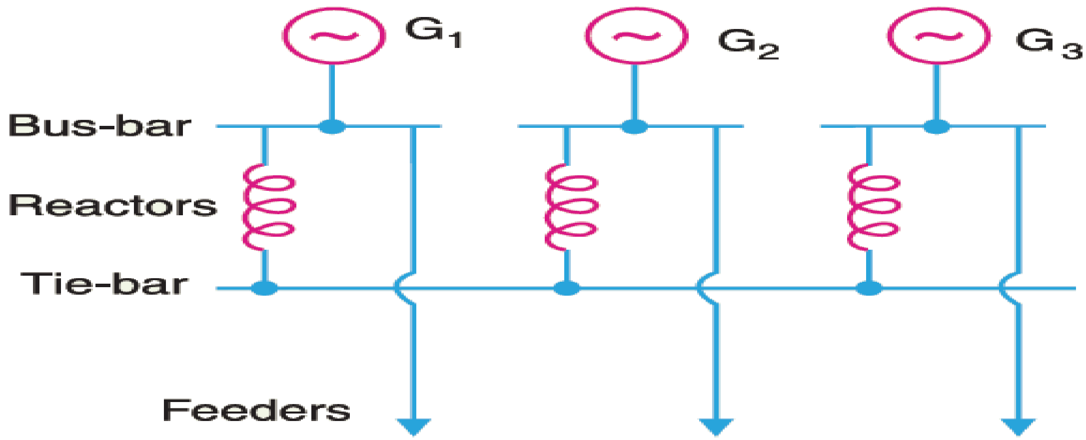
Ring system:



Bus-Bar Reactors (Ring System)

- Inthissystem,bus-barisdividedintosectionsand thesesectionsareconnected through reactors.
- Thereislittlepowerlossandvoltagedropsinthereactors.
- Iffaultoccursinanyfeederthe continuityofsupplytootherfeederdoesnotaffected.

Tie-barsystem:



- Inthissystemtheadditionalbus-bari.etie-barisemployed.
- Thereareeffectivelytworeactorsinseriesbetweenthesections.
- Inthetie-barsystemtheadditionalgeneratorsmay beconnectedtothesystemwithout requiring changes in the existing reactors..

Stepsforsymmetricalfaultcalculation:

- Drawasinglelinediagramofthenetworkindicatingtherating,voltageandpercentage reactance of each element of the network.
- ChoosethevalueofbaseKVAandconvertallpercentagereactancetothisbasevalue.
- Accordingtosinglelinediagram,drawthereactancediagram.
- Findthetotalpercentagereactanceofthe networkuptothepointoffault.Letitbe X%.
- FindfullloadcurrentcorrespondingtotheselectedbaseKVAandthenormalsystemvoltageat the fault point.Let it be I.
- Thenfindoutvariousshortcircuitcalculationsare:

Short circuit current ,

$$I_{SC}=\frac{I\times100}{\%X}$$

ShortcircuitKVA,

$$=\text{BaseKVA}\times\frac{100}{\%X}$$

NUMERICALS:

A 3-Phase,20MVA,10KV alternator has internal reactance of 5% and negligible resistance .Find the external reactance per phase to be connected in series with the alternator so that the steady current onshort-circuit current does not exceed 8 times the full load current .

Solution:

Fullloadcurrent,I= $\frac{20\times10^6}{\sqrt{3}\times10\times10^3}$ =1154.7 A

Voltageperphase,V= $\frac{10\times10^3}{\sqrt{3}}$ = $\frac{10000V}{\sqrt{3}}$

Astheshortcircuitcurrentistobe8timesthefullloadcurrent.

∴Totalpercentagereactancerequired= $\frac{\text{Fullloadcurrent}}{\text{Shortcircuitcurrent}}\times100$

=(1/8)×100=12.5%

∴Externalpercentagereactancerequired=12.5-5=7.5% Let X

Ω be the per phase external reactance required.

Nowpercentagereactance= $\frac{IX}{V}\times100$

$7.5=\frac{1154.7\,X}{(1000/\sqrt{3})}\times100$

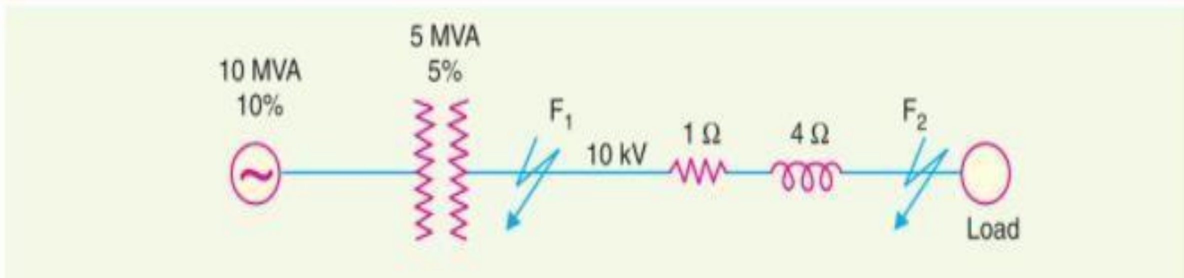
$X=\frac{7.5C\times10000}{\sqrt{3}\times100\times1154.7}=0.375\Omega(\text{Ans})$

A three phase transmission line operating at 10 kv and having a resistance of 1Ω and reactance of4Ω is connected to the generating station bus bar through 5 MVA step-up transformerhavingareactanceof 5%.Thebusbar are suppliedbya10MVAalternator having 10%reactance.calculatetheshortcircuitkvafedtoa symmetrical faultbetween phases if it occurs

(a) attheendofthetransmissionline

(b) atthehighvoltageterminalsofthetransformer

Solution:



' shows the single line diagram of the network. Let 10,000 kVA be the base

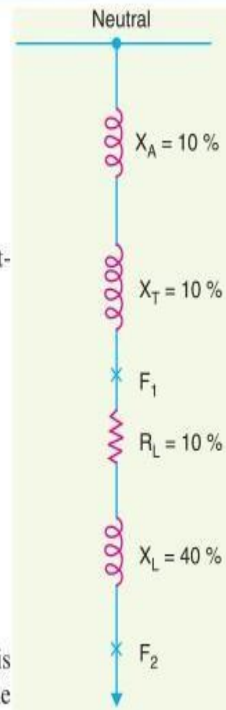


Fig. 17.10

% reactance of alternator on base kVA,

$$\% X_A = \frac{10{,}000}{10 \times 10^3} \times 10 = 10\%$$

% reactance of transformer on base kVA,

$$\% X_T = \frac{10{,}000}{5 \times 10^3} \times 5 = 10\%$$

The line impedance is given in ohms. It can be converted into percentage impedance by using exp. (*ii*) of Art. 17.3.

% reactance of transmission line is

$$\% X_L = \frac{(\text{kVA}) \times \text{reactance in } \Omega}{10\,(\text{kV})^2}$$

$$= \frac{10{,}000 \times 4}{10 \times (10)^2} = 40\%$$

% age resistance of transmission line,

$$\% R_L = \frac{10{,}000 \times 1}{10 \times (10)^2} = 10\%$$

(*i*) The reactance diagram of the network on the selected base kVA is shown in Fig. 17.10. For a fault at the end of a transmission line (point F_2),

$$\text{Total \% reactance} = \%X_A + \%X_T + \%X_L$$

$$= 10 + 10 + 40 = 60\%$$

$$\text{\% resistance} = 10\%$$

∴ % impedance from generator neutral upto fault point F_2

$$= \sqrt{(60)^2 + (10)^2} = 60{\cdot}83\%$$

∴ Short-circuit kVA = 10,000 × 100/60·83 = **16,440 kVA**

(*ii*) For a fault at the high voltage terminals of the transformer (point F_1),

Total % reactance from generator neutral upto fault point F_1

$$= \% X_A + \% X_T = 10 + 10 = 20\%$$

Shortcircuitkva=10000×(100/20)=50,000kva(Ans)

Q-3

Example 17.4. *The plant capacity of a 3-phase generating station consists of two 10,000 kVA generators of reactance 12% each and one 5000 kVA generator of reactance 18%. The generators are connected to the station bus-bars from which load is taken through three 5000 kVA step-up transformers each having a reactance of 5%. Determine the maximum fault MVA which the circuit breakers on (i) low voltage side and (ii) high voltage side may have to deal with.*

Solution. Fig. 17.11 shows the single line diagram of the network. Let 10,000 kVA be the base kVA.

The percentage reactance of generators *A*, *B* and *C* and that of each transformer on the selected base kVA is

$$\% X_A = 12 \times 10{,}000/10{,}000 = 12\%$$
$$\% X_B = 12 \times 10{,}000/10{,}000 = 12\%$$
$$\% X_C = 18 \times 10{,}000/5{,}000 = 36\%$$
$$\% X_T = 5 \times 10{,}000/5{,}000 = 10\%$$

(*i*) When the fault occurs on the low voltage side of the transformer (point F_1 in Fig. 17.11), the reactance diagram at the selected base kVA will be as shown in Fig. 17.12. Obviously, the

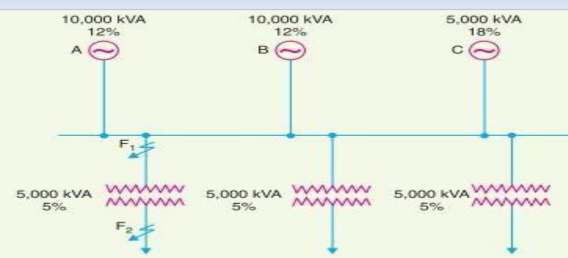


Fig. 17.11

total reactance upto the point of fault F_1 is the parallel combination of the reactances of the three alternators *i.e.*

Total % reactance form generator neutral upto fault point F_1

$$= \% X_A \parallel \% X_B \parallel \% X_C$$

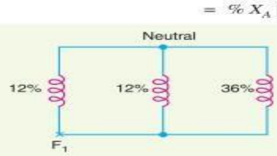


Fig. 17.12

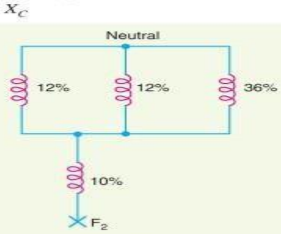


Fig. 17.13

$$= 12\% \parallel 12\% \parallel 36\% = \frac{6 \times 36}{6 + 36} = 5 \cdot 14\%$$

$$\therefore \quad \text{Fault MVA} = 10{,}000 \times \frac{100}{5 \cdot 14} \times \frac{1}{1000} = \mathbf{194 \cdot 5}$$

(*ii*) When the fault occurs on the high voltage side of the transformer (point F_2 in Fig. 17.11), the reactance diagram will be as shown in Fig. 17.13.

Total % reactance from generator neutral upto fault point F_2

$$= 5 \cdot 14 + 10 = 15 \cdot 14\%$$

$$\therefore \quad \text{Fault MVA} = 10{,}000 \times \frac{100}{15 \cdot 14} \times \frac{1}{1000} = \mathbf{66}$$

It may be noted that circuit breakers of lower ratings will be required on the high voltage side of the transformers.

FUSES

Fuses: Afuseisashortpieceofmetal,insertedinthecircuitwhichmeltswhenexcessivecurrent flows through it and thus breaks the circuit.

Desirablecharacteristicsoffuseelement: Thefuseelementshouldhavethe following characteristics:

- Lowmeltingpointe.gtin,lead.
- Highconductivitye.gsilver,copper.
- Freefromdeteriorationduetooxidatione.gsilver.
- Lowcoste.g lead,tin,copper.

Fuseelementmaterials:

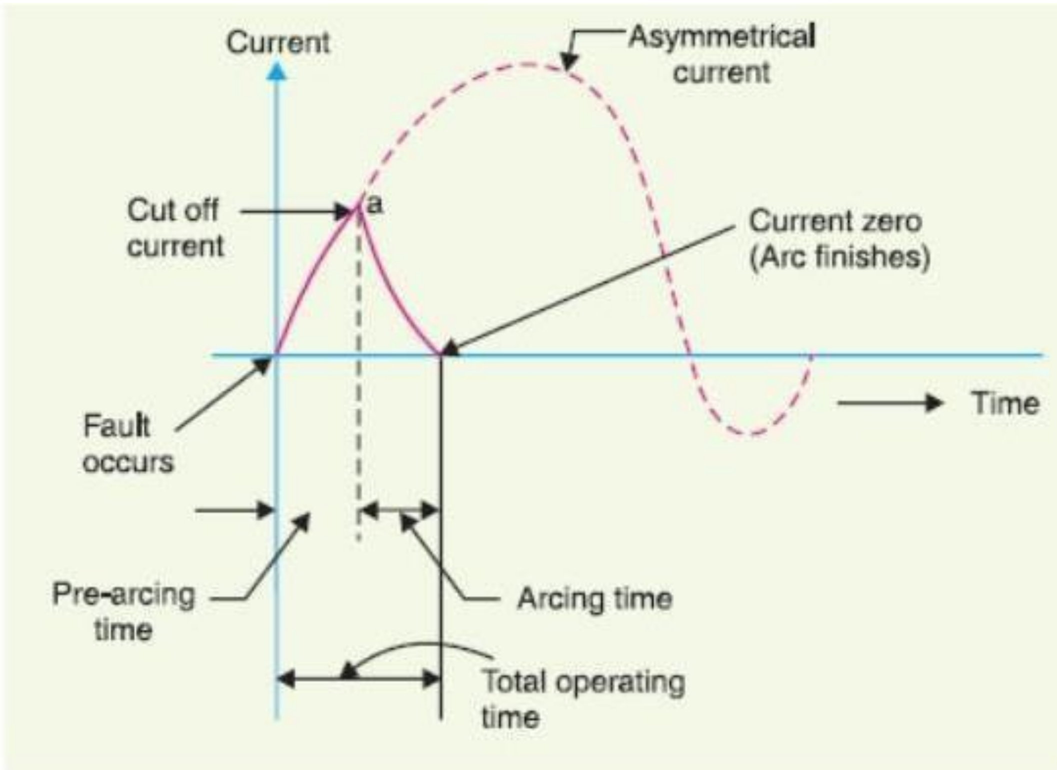
- Themostcommonlyusedmaterialsforfuseelementarelead,tin,copper,zincandsilver.
- Forsmallcurrentsupto 10A,tin oranalloyofleadand tin(lead37%,tin63%) isusedformaking the fuse element .
- Forlargercurrentscopperorsilverisemployed.

Importanttermsusedforfuses: Thefollowingtermsaremuchusedintheanalysisof fuses:

- Currentratingoffuseelement: Itisthecurrentwhich thefuseelementcannormallycarry without overheating or melting.
- Fusingcurrent: Itistheminimumcurrentatwhichthe fuseelementmeltsandthusdisconnect the circuit protected by it.
- Fusingfactor: Itistheratioofminimumfusingcurrenttothecurrentratingofthefuseelement.

$$\text{Fusingfactor} = \frac{\text{minimumfusingcurrent}}{\text{currentratingoffuse}}$$

- Prospectivecurrent: ItistheRMS valueofthefirstlooppfthefaultcurrentobtainedifthefuse is replaced by an ordinary conductor of negligible resistance.



- Cut-offcurrent:Itisthemaximumvalueofcurrentactuallyreachedbeforethefusemelts.
- Pre-arcingtime:Itisthetimebetweenthecommencementoffaultattheinstantwhencut-off occurs.
- Arcingtime:Thisisthetimebetweentheendofpre-arcingtimeandtheinstantwhenthe arc is extinguished (finished).
- Totaloperatingtime:Itisthesumofpre-arcingandarcing times.
- Breakingcapacity:ItistheRMSvalueofaccomponentofmaximumprospectivecurrentthata fuse can deal with at rated service voltage.

Typesoffuses: Therearetwo typesoffuses:

- Lowvoltage fuse
- Highvoltagefuse

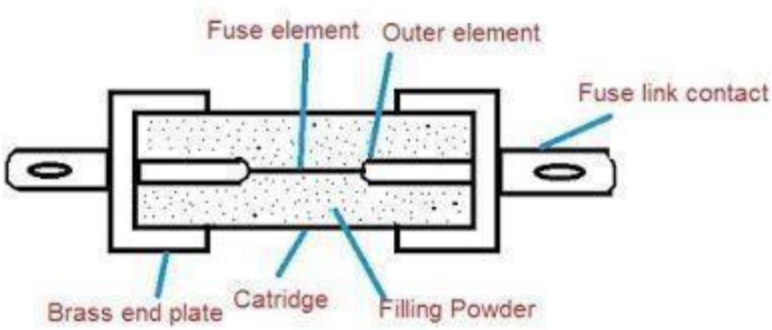
Lowvoltagesfuses: Lowvoltagesfusesaretwotypes:

- Semi-enclosedrewireablefuse(kit-kattype)
- Highrupturingcapacity(HRC)cartridgefuse
- HRCfusewithtripping device.

Semi-enclosedrewireablefuse:

- Semi-enclosedrewireablefusealsoknownaskit-kattypefuse.
- Itconsistsofabaseandafusecarrier.
- Thebaseisofporcelainandcarriesthefixedcontacts towhichtheincomingandoutgoingphase wires are connected.
- Thefusecarriersisalsoofporcelainandholds thefuse element(tinnedcopperwire)between its terminals.
- Whenfaultoccursthefuseelementisblownoutandthecircuitisinterrupted.
- Thenthefusecarrieristakenoutand blownoutfuseelementisreplacedbythenewone.
- Thefusecarrieristhenreinsertedinthebasetorestorethesupply.
- Standardratingoffusesare6,16,32,63and100A.

High rupturing capacity (HRC) cartridge fuse:



High Rupturing Capacity Catridge Fuse

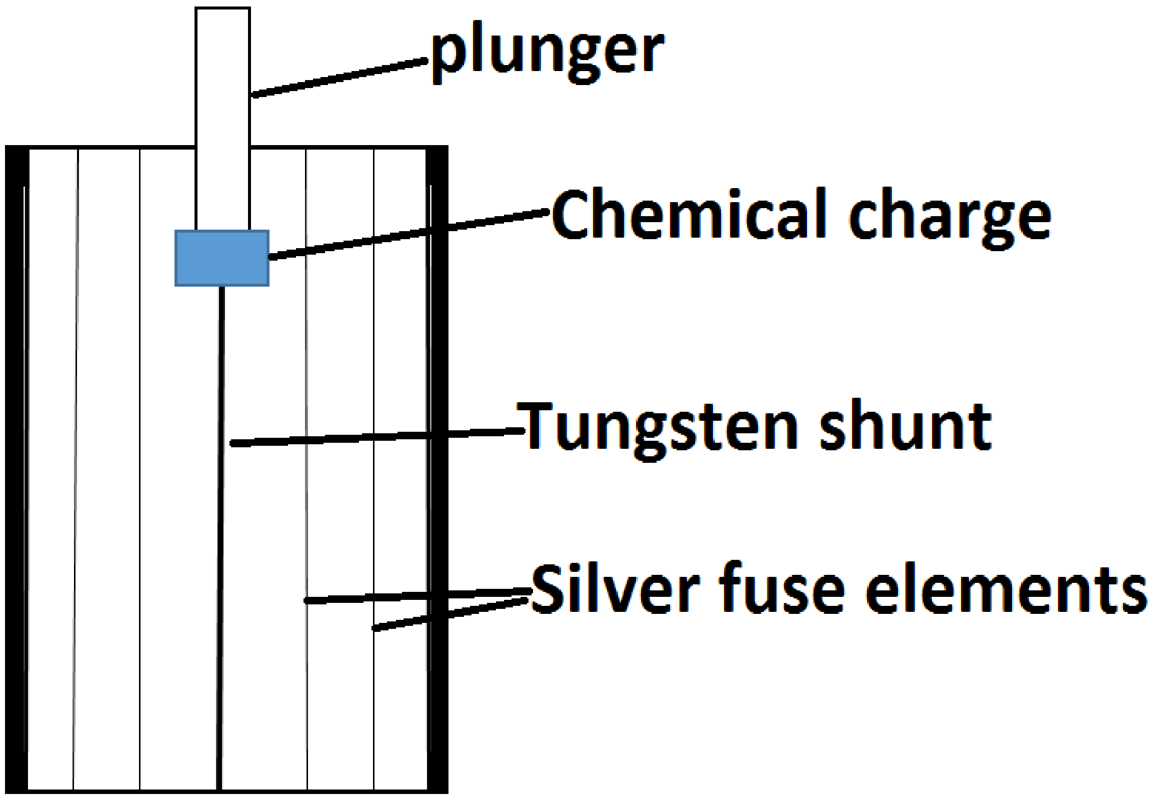
- Itconsistsofheatresistingceramicbodyhavingmetalendcaps.
- Thefillingpowder(chalk,plasterofparis,quartz,marbledust)packedonthecartridge.
- Fuseelementplacedonthecartridgebetweenouterelement.
- Undernormalloadcondition,thefuseelementcarriesthenormalcurrentwithoutoverheating.
- Whenafaultoccurs,thefuseelementmeltsduetoincreaseincurrentinthe circuitand then the circuit is interrupted.

Advantages:

- Theyarecapableofclearinghighaswellaslowfaultcurrents.
- Theydonotdeterioratewithage.
- Theyhavehighspeedofoperation.
- Theyprovidereliablediscrimination.
- Theyrequirenomaintenance.
- Theypermitconsistentperformance.
- Disadvantages:

- Theyhavetoreplaceaftereach operation.
- Heatproducedby thearcmayaffecttheassociatedswitches.

HRC fuse with tripping device:



- Thebodyofthefuseisofceramicmaterialwithametalliccaprigidly fixedateach end.
- Thebodycontainsnumberofsilverfuseelements.
- Theplungerisconnectedtotheoneendof the bodytotrippingmechanisimofcircuitbreaker.
- Theplungeriselectricallyconnectedthroughafuselink,chemicalchargeandatungstenwireto the other end of the cap.
- Whenafaultoccurs,thesilverfuseelementsarethefirstto beblownoutandthencurrentis transferred to the tungsten wire.
- Aftersometimetungstenwiregetsfusedandcausesthechemicalchargesflowsout.
- Whenchargeflowsoutplungershouldimbalancetooperatethecircuitbreaker.
- Thusthecircuitopenedandinterruptedthefaultcurrent.

High voltage fuse:

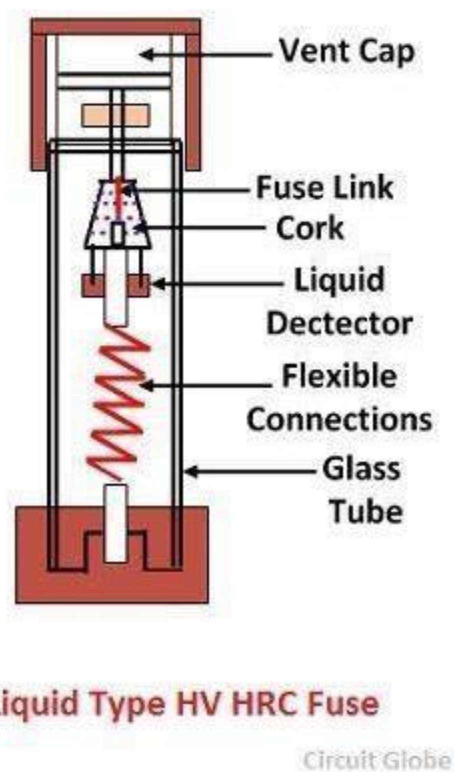
Highvoltagefusesaretwotypes:

- Cartridgetype
- Liquidtype

Cartridgetype:

- Thisisthesimilarconstructionasthelowvoltagecartridgetype.
- Hereonlysomespecialdesignarrangedthattherearetwofuseelementinparallel.
- Oneoflowresistance(silverwire)andotherhighresistance(tungstenwire).
- Undernormalconditionthelowresistanceelementcarriesthenormalcurrent.
- Whenafaultoccursthelowresistanceelementisblownoutand thehighresistanceelement reduces the short circuit current and finally breaks the circuit.
- Thisfuseisusedupto33KVbreakingcapacity8700A.

Liquid type:



- Itconsistsofaglasstubefilledwithcarbontetrachloridesolutionandsealedwithbrasscaps.
- Thefusewireissealedatoneendof thetube andthe otherendof thewireisheldbyastrong phosphor bronze spiral spring fixed at the other end of the glass tube.
- Whenthecurrentexceedstheprescribedlimitthefusewireisblownout.
- Afterthatwiththehelpofspringforce ,liquid(carbon tetrachloridesolution)flowstothefuse link and extinguishes the arc completely.
- Andthusthecircuitshouldinterrupted.

Currentcarryingcapacityoffuseelement: Thecurrentcarryingcapacityofafuse element depends upon the following factors:

- materialoffuse element.
- length.
- diameter.
- sizeandlocationofterminals.

Whenthefuseelementcontainssteadytemperature,

Heatproduced=Heatlostpersecondbyconvection,radiationandconduction. I^2R =

constant × effective surface area.

$=> I^2\rho(l/a)$=constant×d×l

Where ,

d=diameteroffuseelement

l=length of fuse element

$I^2(\rho l \,/\, (\Pi/4)d^2)$=constant×d×l

I^2=constant×d^3

$I^2 \propto d^3$

$=> I \propto d^{3/2}$

$=> I=Kd^{3/2}$

WhereKisaconstant,calledthefuseconstant.It´svaluedependsupon themetalofwhichthe fuse element is made.

Differencebetweenafuseandcircuitbreakers:

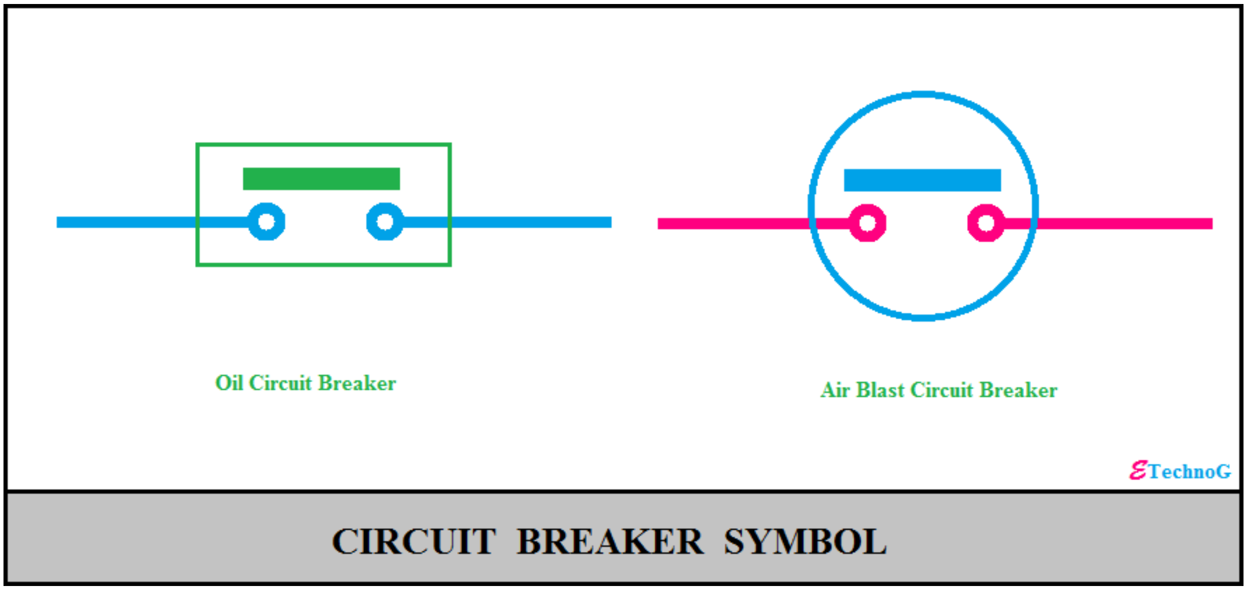
SL NO	PARTICULARS	FUSE	CIRCUITBREAKER
01	Function	Itperformsbothdetectionandinterruptionfunction.	Itperformsinterruption function.The detection offaultismadebyrelay system.
02	Operation	Completelyautomatic	Forcompleteautomatic ,relay´sare used
03	Breaking capacity	Small	Verylarge

04	Operating time	Verysmall(0.002secorso)	Comparativelylarge(0.1 to 0.2 sec)
05	Replacement	Requiresreplacementaftereveryoperation	Noreplacementafter operation.

CIRCUITBREAKERS

Circuitbreaker: Acircuitbreakerisapieceofequipmentwhichcanmakeorbreaka circuiteither manually or by remote control under normal condition ,break a circuit automatically under fault conditions ,make a circuit either manually or by remote control under fault condition.

Symbolofcircuitbreaker



Operating principle: A circuit breaker consists of fixed and moving contacts.Under normal operating condition,thesecontactremainclosedposition.Thesecontactscan beopenedmanuallyorby remote control whenever desired.When a fault occurs on any part of the system ,the trip coil of circuit breakergetenergisedandthemovingcontacts arepulledapartbysomemechanisim,thusopeningthe circuit .

Arcphenomenon:

- Whenshortcircuitoccurs,aheavycurrentwillflowsthroughthecontactsofthecircuitbreaker before open.
- Afterthecontactsopen,theheatwillproducedinthemedium(oilorair)betweencontacts.
- Theheatissufficienttoionizetheairorvapouriseandionizetheoil.
- Theionizedairorvapouractsasconductorandanarcisfoundbetweenthecontacts.

Principleofarcextinction: Thesearetwofactorswhicharresponsibleformaintainthearc between the contacts as follows below:

- p.dbetweenthecontacts.
- ionizedparticlebetweenthecontacts.

Methodsofarcextinction:Therearetwomethodsofextinguishingthearcinthecircuit breakers,

- Highresistancemethods.
- Lowresistancemethodsorcurrentzeromethod.

High resistance method:

- Inthismethodthearcresistanceismadetoincrease withtimesoasthecurrentisreduced toa value insufficient to maintain the arc.
- Consequently,thecurrentisinterruptedorthearcisextinguished.

Theresistanceofthearcmaybeincreasedby,

- Lengtheningthearc.
- Collingthe arc.
- ReducingX-sectionofthearc.
- Splittingthe arc.

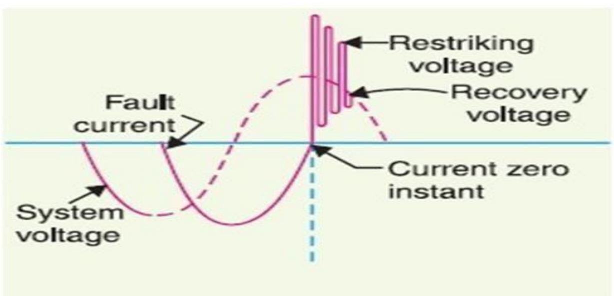
Lowresistanceorcurrentzeromethod:

- Inthismethodthearcresistanceiskeptlowuntilcurrentiszerowherethearcextinguishes naturally and is prevented from restrickinginspite ofthe rising voltageacross the contacts.
- Inthismethodthedielectricstrength ofthemediumbetweencontactsincreasedimmediately after current zero.

Therapidincreasedofdielectricstrength(insulatingproperties)ofthemediumnearzerocanbedone by or this can be achieved by ,

- lengtheningofthegap.
- highpressure.
- colling
- blasteffect.

Importantterms:



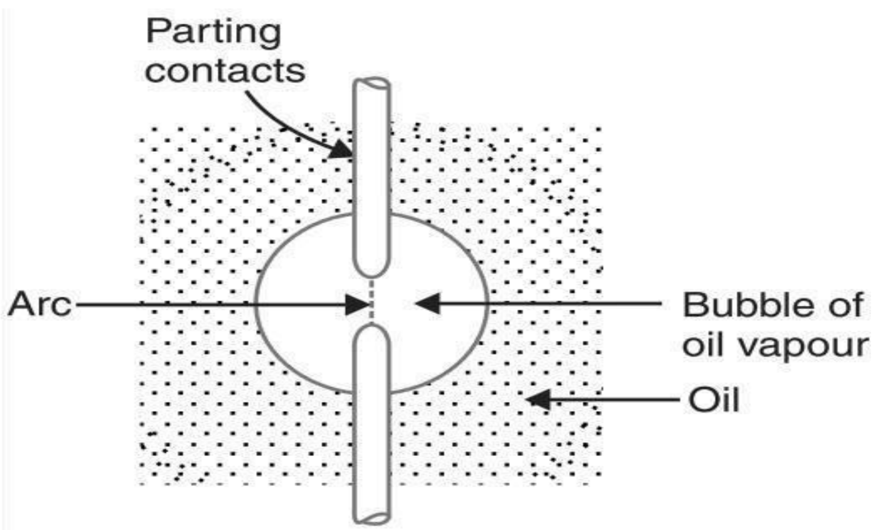
- Arcvoltage:Itisthevoltagethatappearsacrossthe cotactsof the circuitbreaker duringthe arcing period.
- Restrickingvoltage:Itisthetransientvoltagethatappearsacrossthe cotactsatornear current zero during arcing period.
- Recovery voltage: It is the normal frequency (50 Hz) rms voltage that appears across the contactsofthecircuitbreakerafterfinalarcextinction,Itisapproximatelyequaltothesystem voltage.

Classificationofcircuitbreakers:

Accordinglyonthebasisofmediumusedforarc extinction ,circuit breaker may be classified into ,

- Oilcircuitbreakers
- Airblastcircuitbreakers
- Sulphurhexafluoridecircuitbreakers(SF_6)
- Vaccumcircuitbreakers

Oilcircuitbreakers:



- InOCBtherearetwocontacts,oneismovingcontactanotherisfixedcontact.
- Thetransformeroilisusedforarcquenchingmedium.
- Thecontactsareopenunderoilandanarcisstruckbetweenthem.
- Theheatofthearcevaporates thesurroundingoil.
- Thentheoildissociatesintoasubstantialvolumeofgaseousvolume(onethousandtimes).
- Thereforetheoilispushedawayfromthearc,thusthearcextinction takesplaceandcircuitis interrupted .

Advantages:Theadvantagesofoilasarcquenchingmediumare:

- Ithasexcellentcoolingproperties.

- Itactsasgoodinsulator.

Disadvantages:Thedisadvantagesofoilasarcquenchingmediumare:

- Itisinflammableandthereisariskoffire.
- Itmayformexplosivemixtureofair.

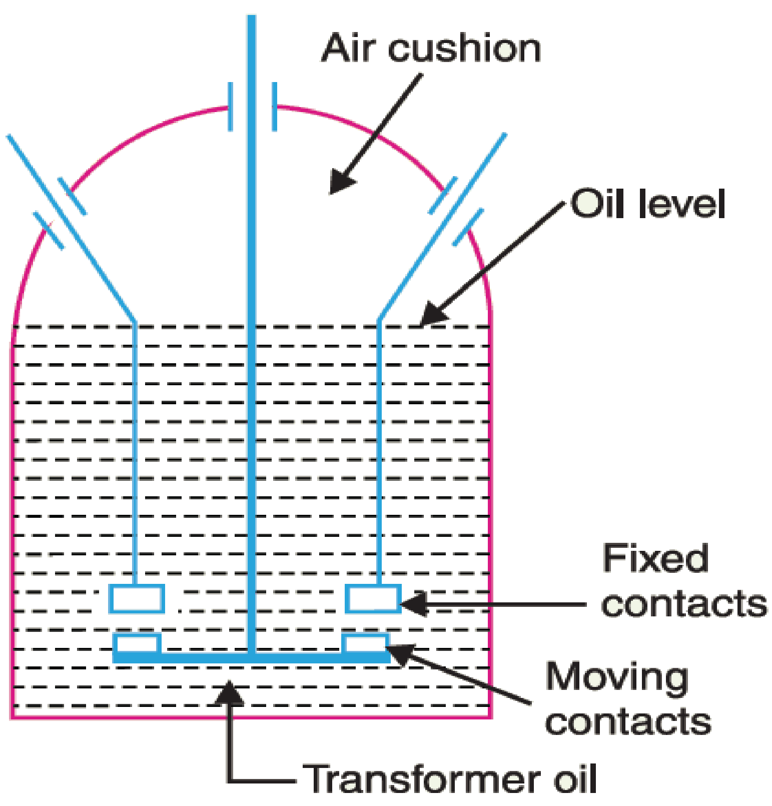
Typesofoilcircuitbreakers: Therearetwotypesofoilcircuitbreakers,

- Bulkoilcircuitbreaker.
- Lowoilcircuitbreaker.

Againbulkoilcircuitbreakeraretwotypes

- Plainbreakoilcircuitbreaker
- Arccontroloilcircuitbreaker

Plainbreakoilcircuitbreaker:



Oil Circuit Breaker

Construction:

- Ithasastrongweather tighttank.
- Thetankcontainstransformeroiluptoacertainlevel.
- Theaircushionpresentabovetheoillevel.
- Thefixedcontactandmovingcontactenclosedinthetank.

Operation: Under normal operating conditions, the fixed contact and moving contacts remain closed andthe breakercarriesthe normalcircuitcurrent.Whenfaultoccurs ,the movingcontactsare pulled downbythe protectivesystemandanarcisstruckwhichvapouriestheoilmainlyintohydrogen,The hydrogen plays vital rule to extinguished the arc and the circuit current is interrupted.

Disadvantages:

- Thereisnospecialcontroloverthearc.
- Thesebreakershavelongandinconsistentarcingtimes.
- Thesebreakersdonotpermithighspeedinterruption.

Arccontroloilcircuitbreakers:

Inarccontroloilcircuitbreakersspecialarccontroldevices are employed for arc extinction purposes efficiently as possible.

Thesearetwotypesofsuchbreakersnamely:

- Self-blastoilcircuitbreakers.
- Forced-blastoilcircuitbreakers.

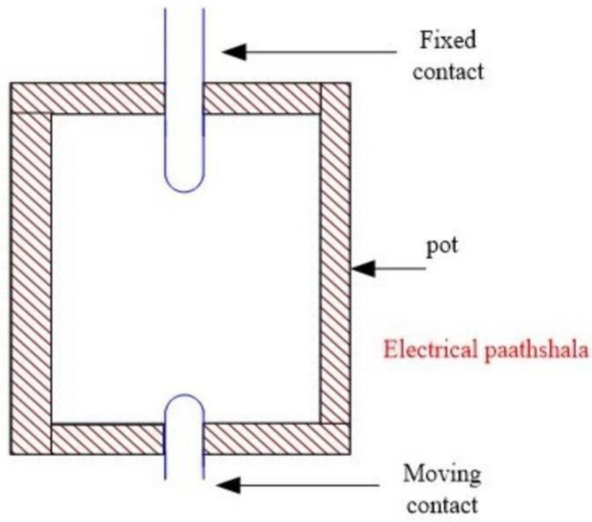
Self-blast oil circuit breakers:

- Inself-blastoilcircuitbreakersarccontrolisprovidedbyinternalmeansi.ethearcitselfis employed for its own extinction efficiently.
- Aninsulatingrigidpressurechamberorpotisinstalledsurroundingthecontacts.
- Herethearcgasesisrestrictedbythe chamber,a veryhighpressureisdevelopedtoforcethe oil and gas through or around the arc to extinguish it .
- Themagnitudeofpressuredevelopeddependsuponthevalueoffaultcurrenttobe interrupted

Several design of pressure chamber are described below :

- Plainexplosionpot
- Cross-jetexplosionpot.
- Self-compensatedexplosionpot.

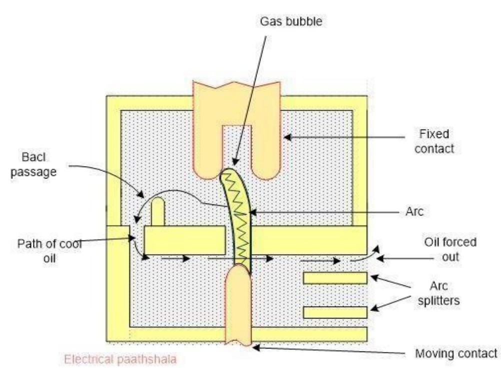
Plain explosion pot:



PLAIN EXPLOSION POT

- Itisarigidcylinderofinsulatingmaterialandenclosedthefixedandmovingcontacts.
- Themovingcontactisacylindricalrodpassingthroughathroatatthebuttom.
- Whenfaultoccurs,thecontactgetseparatedandanarcisstruckbetweenthem.
- Theheatofthearcdecomposesoilintoagasataveryhighpressureinthepot.
- Thishighpressureforcestheoilandgasthroughand aroundthearctoextinguishedit. Cross-

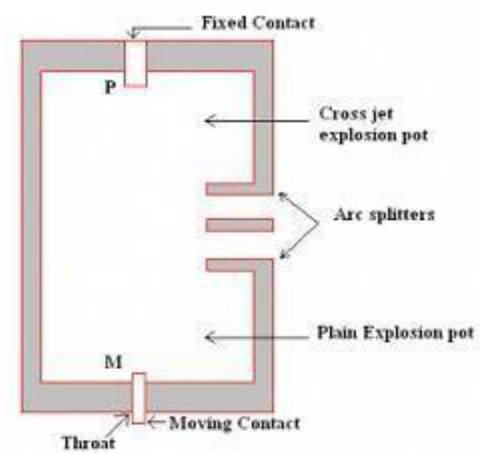
jet explosion pot:



Cross jet explosion pot

- Itismadeofinsulatingmaterial.
- Ithaschannelsononesidewhichactsasarcsplitters.
- Thearcsplittershelpsinincreasingthearclength,thusfacilitatingarcextinction.
- Bybackpassage(arcgases)thecooloilflowrightangletothearc.
- Thusthearcdrivensidewaysintothearcsplitterswhichincreasethearclength ,causingarc extinction.
- Itisusedforinterruptingheavyfaultcurrent.

Self-compensatedexplosionpot:

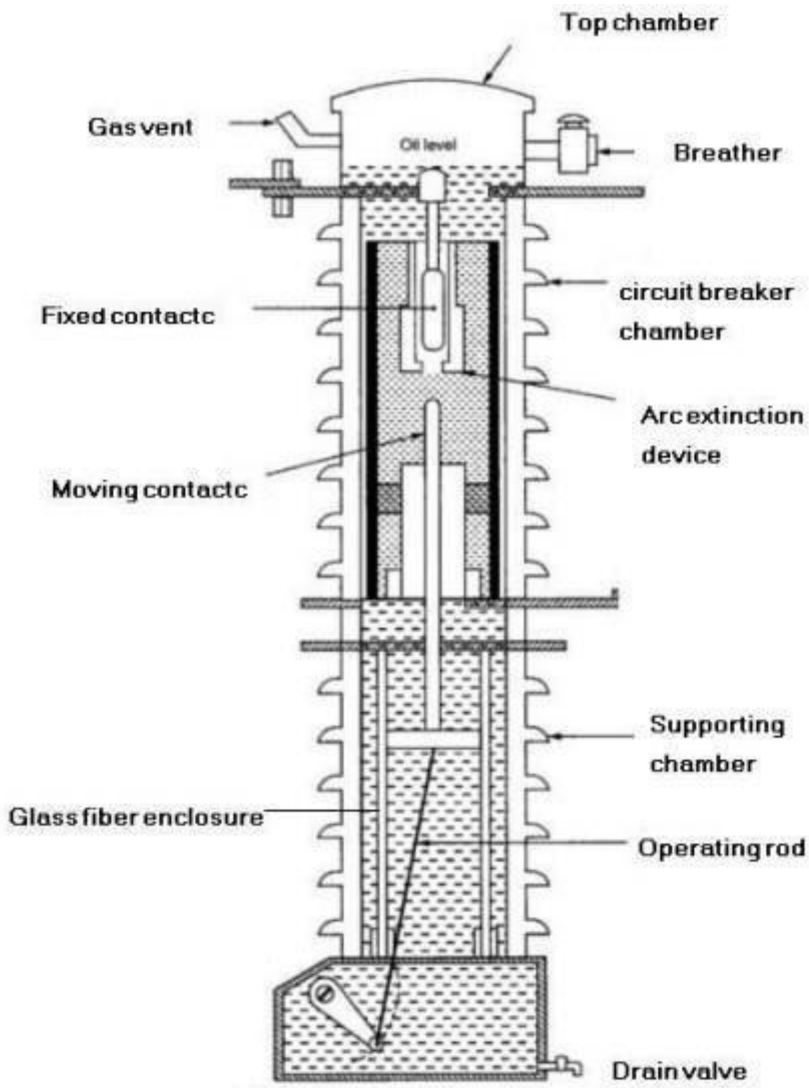


- Thispotiscombinationofplainexplosionpotandcross-jetexplosion pot.
- Thispotisusedtointerruptedlowaswellasheavyshortcircuitcurrent.
- Thispotconsistsoftwochamber.
- Lowerchamberistheplainexplosion pot.
- Upperchamberisthecross-jetexplosionpot.
- Whenshortcircuitcurrentisheavythedevicebehavesasacross-jetexplosion pot.
- Whenshortcircuitcurrentislow,thedevice behavesasaplainexplosionpot.

Forced blast oil circuit breaker:

- Herepressureisgeneratedbymechanically.
- Thatmeansoilpressureiscreatedbythepistoncylinderarrangement.
- Whenfaultoccurs ,the contactgetseparatedbytheprotectivesystemand anarcisstuck between the contact.
- Thenthepistonforcesajetofoiltowardsthecontactgapextinguishthe arc.

Lowoilcircuitbreakers:



Construction:Thelowoilcircuitbreakerhasthefollowingparts :

supportingchamber:

- Itisaporcelainchambermountedonametal chamber.
- Itisfilledwithoilwhichisphysicallyseparatedfromtheoilinthecircuitbreakingcompartment.
- Theoilinsidethesupportingchamberisemployedfor insulationpurposesonly.

Circuit breaking chamber:

- Itisaporcelainenclosuremountedonthetopofthesupporting compartment.
- Itisfilledwithoil. It

has following parts

- upperandlowerfixedparts.
- moving contacts.
- turbulator.

Topchamber:

- Itisametalchamber.
- Itismountedonthecircuit-breakingchamber.
- Itprovidesexpansionspacefortheoilinthe circuitbreakingcompartments.

Operation:

- Undernormaloperatingconditionthemovingcontactareclosedwitheachother.
- Whenafaultoccurs,themovingcontactispulleddownbythe trippingspringandanarcis struck.
- Thearcvaporizestheoilandproducesgasesunderhighpressure.
- Thehighpressuregasissprayedserieslytothearcby turbulator,thusarcisextinguished.Then the circuit current is interrupted.

Advantages:Alowoilcircuitbreakerhasthefollowingadvantagesoverabulkoilcircuitbreaker.

- Itrequireslessquantityof oil.
- Itrequiressmallerspace.
- Thereisreducedriskof fire.
- Maintenanceproblemsarereduced.

Disadvantages:Alowoilcircuitbreakerhasthefollowingdisadvantagesascomparedtobulkoilcircuit breaker.

- Duetosmallerquantityofoil,thedegreeofcarbonizationisincreased.
- Thereisdifficultyofremovingthegasesfromthecontactspaceintime.
- Thedielectricstrengthoftheoildeterioratesrapidlyduetohighdegreeofcarbonization.

Maintenanceofoilcircuitbreakers:

- Checkthecurrentcarryingpartsandarcingcontacts.Ifthe burningissevere,thecotactsshould be replaced.
- Check the dielectric strength of the oil.If the oil is badly discoloured ,it should be changed or reconditioned.Theoilingoodcondtitionshouldwithstand30KVfor oneminuteinastandardoil testing cup with 4 mm gap between electrodes.
- Checktheinsulationpossibledamage.
- Cleanthesurfaceandremovecarbondepositswithastronganddryfabric.
- Checktheoil level.
- Checkclosingandtrippingmechanisim.

Air-blastcircuitbreakers:

- Thesebreakersemployahighpressureairblastasanarcquenchingmedium.
- Theairblastcoolsthearcandkeepsawaythearcingproductstotheatmosphere.
- Thisrapidlyincreasesthedielectricstrengthofthemediumbetweencontactsandprevents from re-establishing the arc.
- Consequentlythearcisextinguishedandflowofcurrentisinterrupted.

Advantages:Anairblastcircuitbrakerhasthefollowingadvantagesoveranoilcircuitbreaker.

- Theriskoffireiseliminated.
- Thearcingtimeisverysmall.
- Thesizeofthecircuitbreakerisreduced.
- Thearcingproductiscompletelyremovedbytheblast.

Disadvantages:

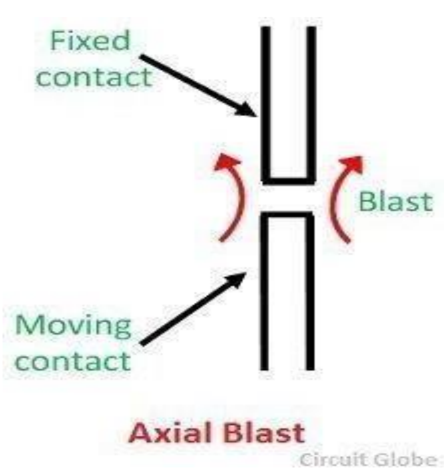
- Maintenanceisrequiredforthecompressorplant.
- Ithassensitivetotherateofriseofrestrickingvoltage.
- Theairhasaninferiorarcextinguishingproperties.

Classificationofair-blastcircuitbreakers:

Dependinguponthedirectionofairblastin relation to the arc,air blast circuit breakers are classified into:

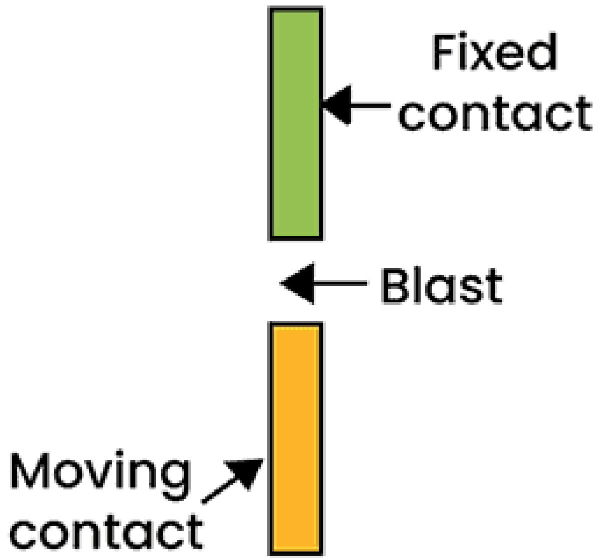
- Axial-blasttype.
- Cross-blasttype.
- Radial-blasttype.

Axialblasttype:



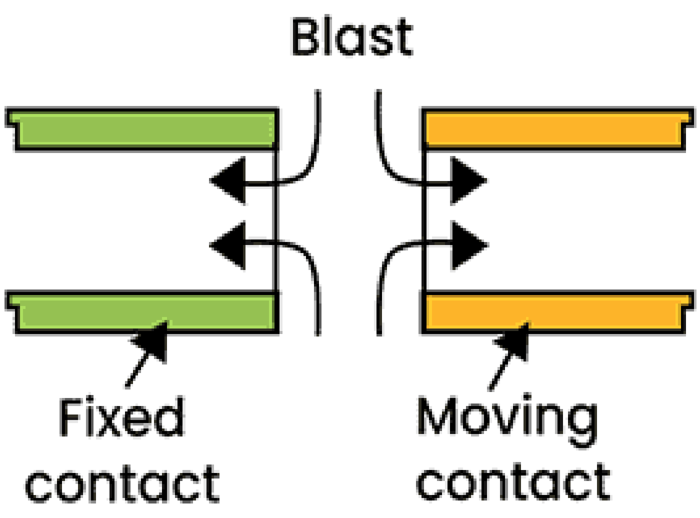
Heretheairblastdirectedalongthearcpath.

Cross-blasttype:



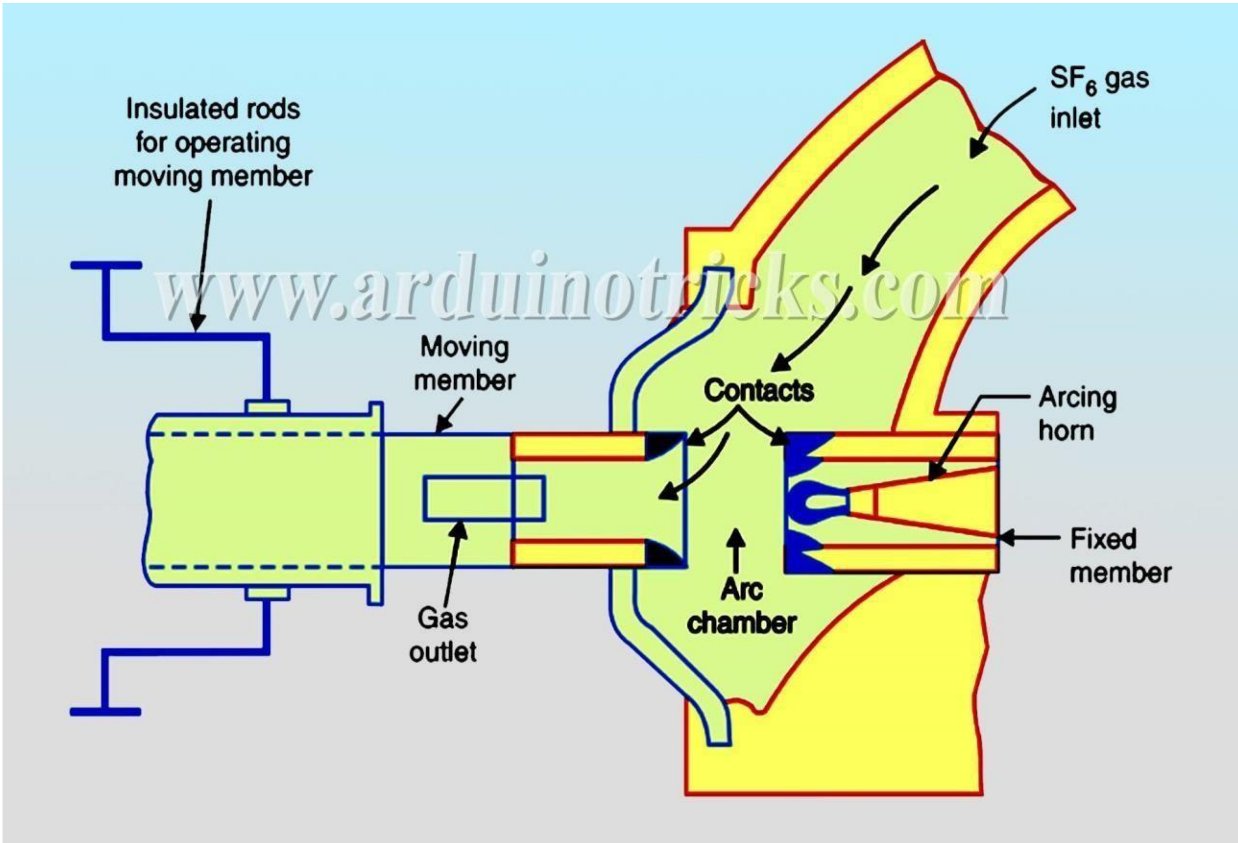
Heretheairblastisdirectedatrightanglestothearcpath.

Radial-blasttype:



Heretheair-blastisdirectedradiallytothearcpath.

Sulphurhexafluoride(SF_6)circuitbreaker:



Construction:

- Itconsistsoffixedandmovingcontactsenclosedinachamber.
- Fixedcontactisahollowcylindricalcurrentcarryingcontactfittedwithanarchorn.
- Themovingcontactisalsoahollowcylinderwithrectangularholes.
- Thetipsoffixedcontact,movingcontactandarcing hornarecoatedwithcopper-tungstenarc resistant material.
- TheenclosedchambercalledarcinterruptionchambercontainingSF_6gas.
- ThischamberisconnectedtoaSF_6gasreservoir.

Working:

- UndernormaloperatingconditionthecontactremainclosedbySF_6gasatapressureofabout 2.8kg/cm^2.
- Whenbreakeroperates,themovingcontactispulledapartandan arcisstruckbetweenthe contacts.
- Themovementofthemovingcontactisconnectedwiththeopeningofavalvewhichpermits SF_6gas at 14 kg/cm^2 pressure from the reservoir to the arc interruption chamber .
- ThehighpressureflowofSF_6rapidlyabsorbsthefreeofelectronsinthearcpathtoform immobilenegativeionswhichareineffectiveaschargecarriers.

- Theresultisthatthemediumbetweenthecontacts quicklybuildsuphighdielectricstrength and causes the extinction of the arc.

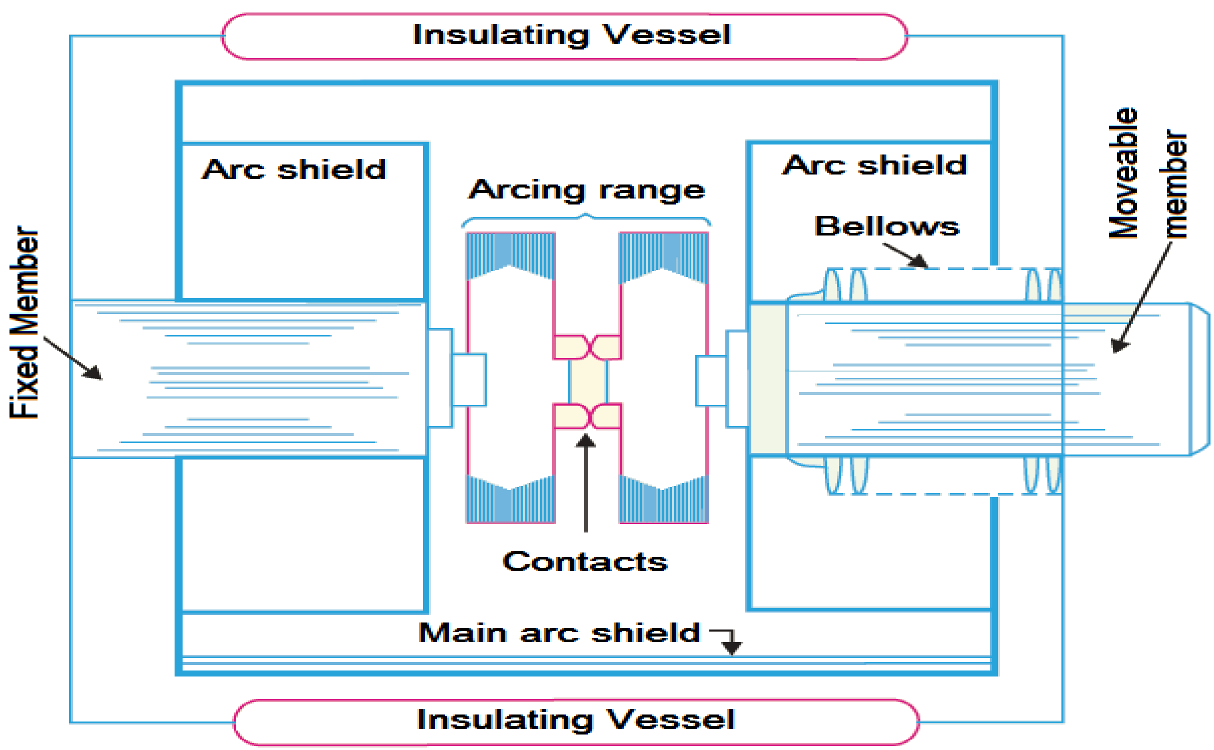
Advantages:SF_6circuitbreakerhavemanyadvantagesoveroiloraircircuitbreakerasfollowsbelow:

- Ithasveryshortarcingtime.
- Itcaninterruptmuchlargercuurent.
- Ithasgivesnoiselessoperation.
- ThereisnoriskoffireinsuchbreakersbecauseSF$_6$gasisnon-inflammable.
- Therearenocarbondepositssothattracingandinsulationproblemsareeliminated.
- TheSF_6 breakershavelowmaintenancecost,lightfoundationrequirement.

Disadvantages:

- SF_6breakersarecostlyduetohighcostof SF_6.
- ImperfectjointsleadtoleakageofSF$_6$gas.
- ArcedSF$_6$gasispoisonousandshouldnotbeinhaledorlet-out.

Vaccumcircuitbreakers(VCB):



Vacuum Interupter Unit of VCB

Construction:

- Itconsistsoffixedcontact,movingcontactandarcshieldmountedinsideavaccumchamber.
- Themovablememberisconnectedtothecontrolmechanisimbystainlesssteelbellows.
- Thisenablesthepermanentsealingofthevaccumchambersoastoeliminatethepossibilityof leak .
- Aglassvesselorceramicvesselisusedastheouterinsulatingbody.
- Thearcshieldpreventsthedeteriorationof theinternaldielectricstrengthbypreventing metallic vapours falling on the inside surface of the outer insulating cover.

Working:

- Undernormalconditionfixedcontactandmovingcontactareinclosed.
- Whenbreakeroperatesthemovingcontactseparates fromthefixedcontactandanarcisstruck between the contacts.
- Theproductionofarcisduetoionizationofmetalions anddependsverymuchuponthe material of the contact.
- Thearcisquicklyextinguishedbecausethemetallicvapours,electronsandionsproducedduring arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields.

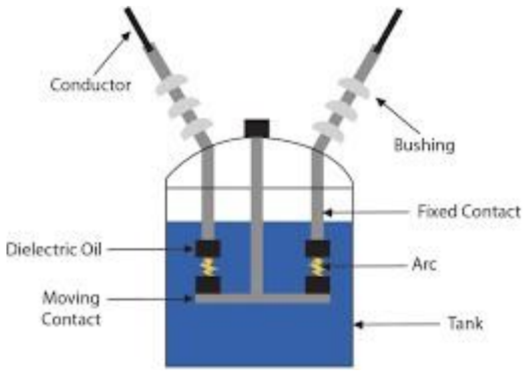
Advantages:Vaccumcircuitbreakerhasthefollowingadvantages:

- Theyarecompact,reliableandhavelongerlife.
- Therearenofirehazards.
- Thereisnogenerationofgasduringafteroperation.
- Theycaninterruptanyfaultcurrent.
- Theyrequirelittlemaintenanceandarequietinoperation.
- Theycansuccessfullywithstandlighteningsurges.
- Theyhavelowarcenergy.
- Theyhavelowinertiaandhencerequiresmallerpowerforcontrolmechanisim.

Switchgearcomponents:Thefollowingaretheimportantcomponentscommontomostof the circuit breakers:

- Bushings
- Circuitbreakercotacts
- Instrumenttransformers
- Bus-barsandconductors

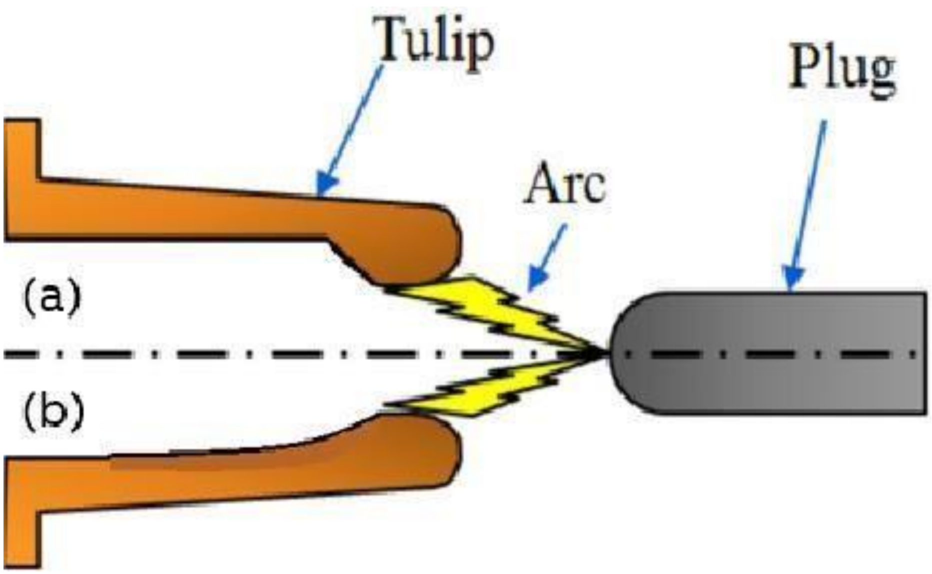
Bushings:Whenahighvoltagepassesthroughametalsheetorframewhichisatearth potential,the necessary insulation is provided in the form of bushing.



Circuitbreakercontacts :The circuitbreakercotacts arerequiredtocarrynormalaswellasshortcircuit current.

Circuitbreakercontactsarefollowingtypes:

Tulip type contact:



Fingerandwedgecontactandbuttcontact:

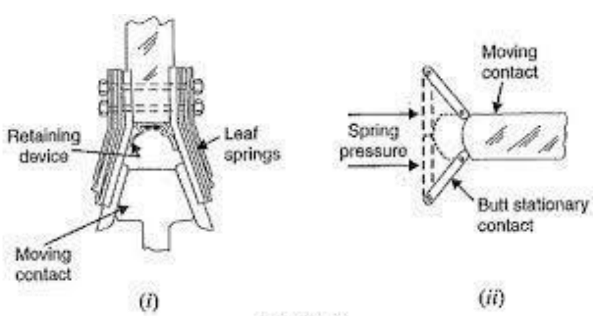


Fig. 19.15

- Thistypeofcontactislargelyusedforlowvoltageoilcircuitbreakersowningtothegeneral unsuitability for use with arc control devices.
- Buttcontactsareusefulinsinglebreakoilcircuitbreakersandairblastcircuitbreakers.
- Thereisnogripforcesothat thistypeofcontacttospeciallysuitableforhighershortcircuit rating.

Instrumenttransformer:Formeasuringhighvoltage,highcurrentandfor relayoperationthe instrument transformer is connected to circuit breakers.

Theinstrumenttransformersaretwotypes:

- Currenttransformer
- Potentialtransformer

Bus-bars and conductors:

- Thecurrentcarryingmembersinacircuitbreakerconsistsoffixedandmovingcontacts andthe conductors connecting these to points external to the breaker.
- Iftheswitchgearisofoutdoortype ,theseconnectionsareconnecteddirectlytotheoverhead lines.
- Incaseofindoorswitchgear,theincomingconductorstothe circuitbreakerareconnected to the bus-bars.

Problemsofcircuitinterruption:

Rateofriseofrestrickingvoltage(RRRV):

- Itistherateofincreaseofrestrikingvoltage.
- TheunitofRRRVisKV/µsec.
- IfRRRVgreaterthantherate ofriseofdielectricstrengthbetweenthe contacts ,thearcwill restrike.
- HoweverthearcwillfalltorestrikeifRRRVislessthantherateof increaseofdielectricstrength between the contact of the breaker .

Currentchopping:

- Itisthephenomenonofcurrentinterruptionbeforethenaturalcurrentzeroisreached.
- Currentchoppingmainlyoccursinairblastcircuitbreakersbecausetheyretainthesame extinguishing power irrespective of the magnitude of the current to be interrupted.

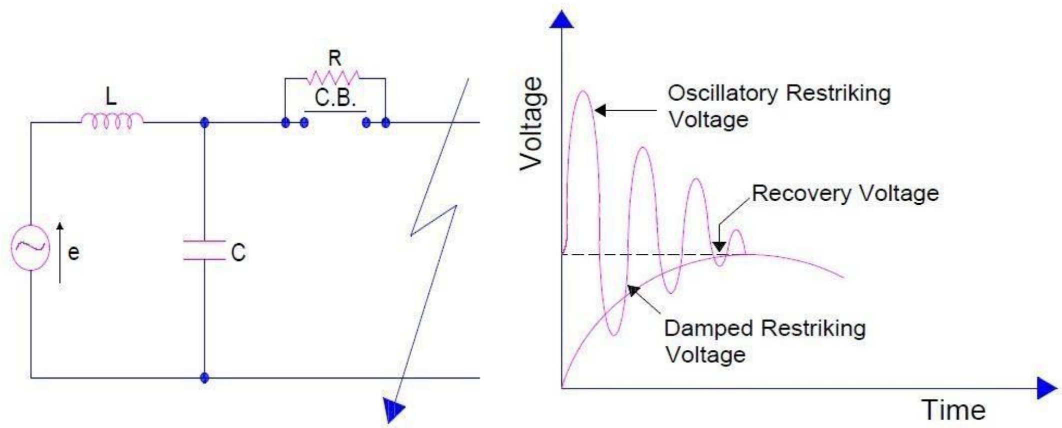
Capacitivecurrentbreaking:

- Anothercauseofexcessivevoltagesurgesinthecircuitbreakersistheinterruptionof capacitive current

- Examplesofsuchinstancesareopeningofanunloadedlongtransmissionline,disconnectinga capacitior bank used for power factor improvement.

Resistanceswitching:

- Inpowersystemduetocurrent chopping,capacitivecurrentbreakingetcgiverisetosevere voltageoscillations.
- Theseexcessivevoltagesurgesduringcircuitinterruptioncanbe preventedbythe use ofshunt resistance Rconnected across the circuit breaker contacts is known as resistance switching.



- Whenafaultoccurs,thecontactof thecircuitbreakeropenedandanarcisstruck betweenthe contacts
- SincethecontactsareshuntedbyresistanceRapartofarccurrentflowsthroughthisresistance.
- Thisresultsinthedecreaseofarccurrentandan increaseintherateof de-ionisationofarcpath and consequently the arc resistance is increased.
- Theincreasedarcresistanceleadstofurtherincreaseincurrentthroughshuntresistance.
- Thisprocesscontinuesuntilthearccurrentbecomesosmallthatitfallstomaintainthe arc.
- Nowthearcisextinguishedandcircuitcurrentisinterrupted.

Circuitbreakerratings:

Thecircuitbreakershavethreeratingsi.e

- BreakingcapacityinMVA.
- MakingcapacityinKA,MA.
- Short-timecapacityinsec.

Breakingcapacity:Itiscurrent(rms) thata circuitbreakeriscapableofbreakingatgivenrecovery voltage and under specified conditions (e.g power factor,rate of rise of restricking voltage).

Makingcapacity:Thepeakvalueofcurrent(includingdccomponent)duringthefirstcycleof current wave after the closure of circuit breaker is known as making capacity .

Shorttimerating:Itistheperiodforwhich thecircuitbreakerisabletocarryfaultcurrentwhile remaining closed.

PROTECTIVERELAYS

Definitionofprotectiverelay:Aprotectiverelayisadevicethatdetectsthefaultandinitiatesthe operation of the circuit breaker to isolate the defective system.

Fundamentalrequirementofprotectiverelay:Thefollowingarethemainfunctionoftheprotective relay:

Selectivity:Itistheabilityoftheprotectivesystemtoselectcorrectlythatpartof thesystemintrouble and disconnect the faulty part without disturbing the rest of the system.

Speed: The relay system should disconnect the faulty section as fast as possible.

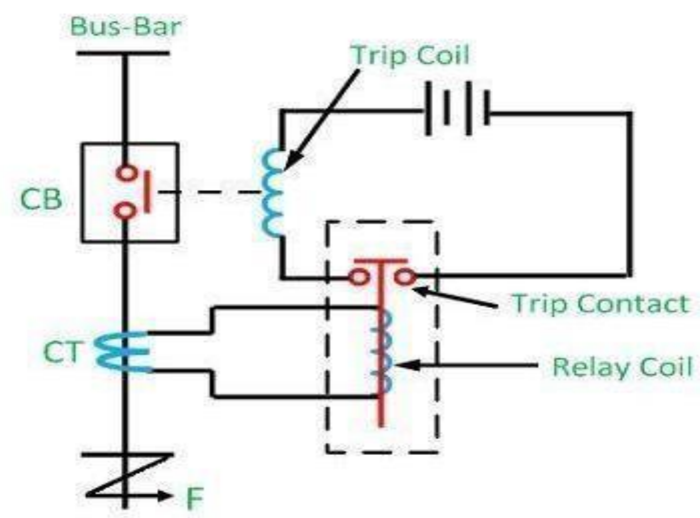
Sensitivity:Itistheabilityofthesystemtooperatewithlowvalueofactuatingquantity.

Reliability:Itistheabilityoftherelaysystemtooperateunderthepre-determinedconditions. Simplicity: The

relaying system should be simple so that it can be easily maintained.

Economy:Theprotectiverelaysystemismustbeinlowcost. Fault

clearing process/Basic relay operation of relay:



Basic Connection Diagram of Protective Relay

Asimplerelaycircuitisshowninabovediagram.Therelaycircuitconnectionisdividedintothreeparts:

- Firstpartistheprimarywindingofacurrenttransformer(C.T)whichisconnectedinserieswith the line to be protected.
- SecondpartconsistsofsecondarywindingofCTandrelayoperatingcoil.

- Thirdpartisthetrippingcircuitwhichmaybeeitheracordc.Itconsistsofasource ofsupply ,thetripcoilofthe circuitbreakerandrelaystationarycontact.

Whenashortcircuitoccursatpoint Fon thetransmissionline,thecurrentflowingonthe lineincreases to an enormous value .This result in a heavy current flow through the relay coil ,causing the relay to operate by closing its contacts .This is in turn closes the trip circuit of the breaker,making the circuit breaker open and isolating the faulty section from the rest of the system.

Basicrelayoperation:Thebasicrelaysareworkonthefollowingtwomainoperating principle:

- Electromagneticattractiontype:
- Electromagneticinductiontype:

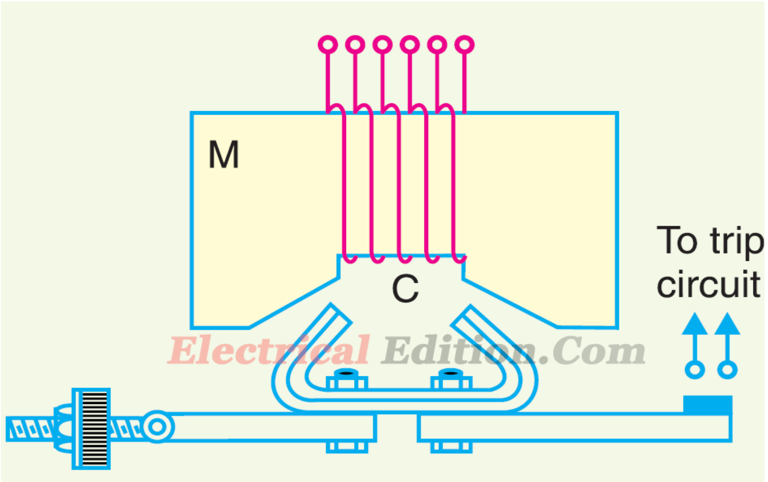
Electromagnetic attraction type:

- Electromagneticattractionrelaysoperateonthe principleofanarmaturebeingattractedtothe poles of an electromagnet .
- This relays may be actuated by dc or ac quantities.

Theimportanttypesofelectromagneticattractionrelaysare:

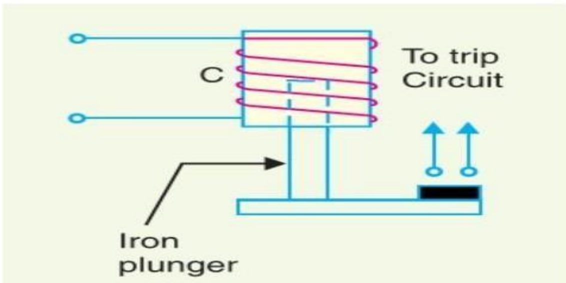
- Attractedarmaturetyperelay
- Solenoidtyperelay
- Balancedbeamtyperelay

Attracted armature type relay:



- ItconsistsofalaminatedelectromagnetMcarryingacoilCandapivotedlaminatedarmature.
- Undernormalconditionthecurrentthrough therelaycoilCissuchthatcounter weightholds the armature in the position.
- Underfaultcondition,therelayarmatureisattracted upwardsandthiscompletesthe trip circuit which results in the opening of the circuit breaker.

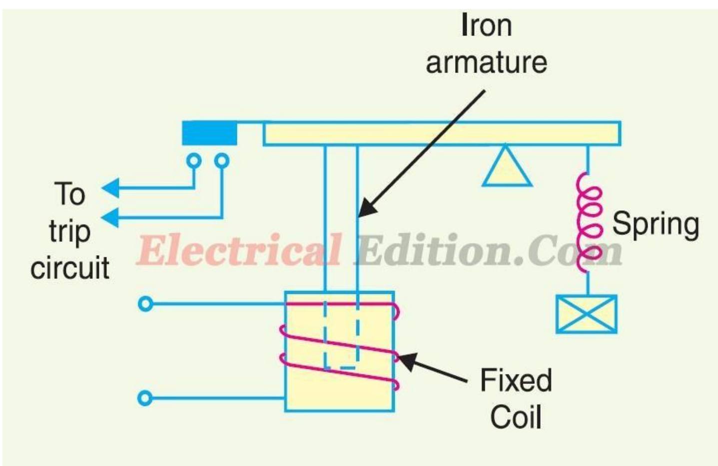
Solenoidtyperelay:



Solenoid type relay

- Itconsistsofasolenoidandmovableironplunger.
- Undernormaloperatingcondition,thecurrentthroughtherelaycoilCissuchthatitholdsthe plunger in the position shown.
- Underfaultcondition,theplungerismovedupwardandclosesthe tripcircuit,thusopeningthe circuit breaker.

Balancedbeamtyperelay:



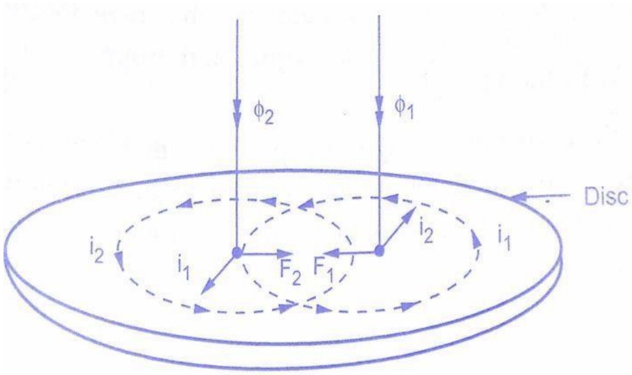
- Itconsistsofan ironarmaturefixedtoabalancedbeam.
- Undernormaloperatingcondition,the currentthroughtherelaycoilissuchthatthe beamis held in the horizontal position by the spring.
- Underfaultconditionthebeamisattracted toclosethetripcircuitthus openingthecircuit breaker.

Inductionrelay:

Electromagneticinductionrelaysoperateontheprincipleofmutualinduction.

Thisrelayoperateontheacquantites.

Aninductionrelaycanbeconsistsofapivotedaluminiumdiscplacedinthemagneticfield.



From above fig,

$\phi_1=\phi_{1max}\sin\omega t$

$\phi_2=\phi_{2max}\sin(\omega t+\alpha)$

WeknowfromFaradayslawsofelectromagneticinduction

$i_1 a \frac{d\emptyset 1}{dt} a \frac{d\emptyset}{dt}(\emptyset_1 max\sin\omega t)$

$i_2 a \phi_{1max}\cos\omega t$

and$i_2 a \emptyset_{2max}(\cos\omega t+\alpha)$

$\therefore F_1 a \phi_1 i_2$ and $F_2 a \phi_2 i_1$

HencenetforceFattheinstantis, F a

$F_2 - F_1$

$a \emptyset_2 i_1 - \emptyset_1 i_2$

$a \emptyset_{2max}\sin(\omega t+\alpha)\emptyset_{1max}\cos\omega t - \emptyset_{1max}\sin\omega t \emptyset_{2max}\cos(\omega t+\alpha)$

$a \emptyset_{1max}\emptyset_{2max}[\sin(\omega t+\alpha)\cos\omega t - \sin\omega t\cos(\omega t+\alpha)]$

$a\ \emptyset_{1max}\emptyset_{2max}\sin\alpha$

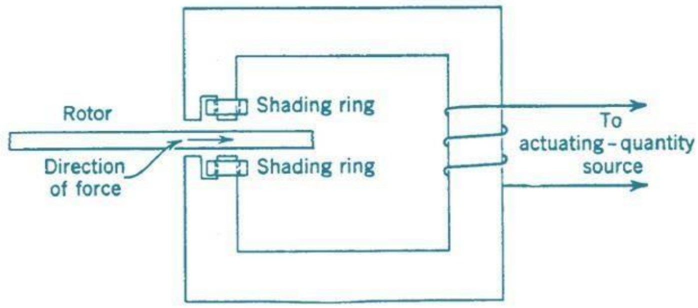
$a \emptyset_1\emptyset_2\sin\alpha$ ---------- (1)

$F a \emptyset_1\emptyset_2 \sin a$

Thefollowingthreetypesofstructure arecommonlyusedforobtaining thephasedifferenceinthe fluxes and the operating torque in induction relays.

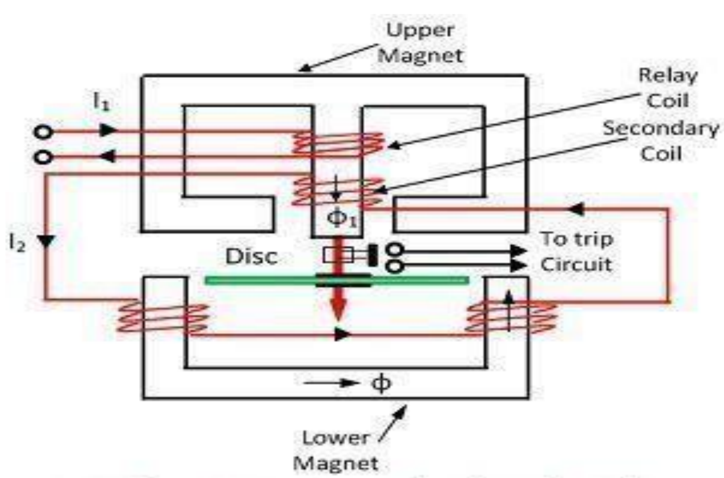
- Shadedpolestructure
- Watthourmeterordoublewinding structure
- Inductioncupstructure

Shaded pole structure:



- Itconsistsofapivoteddiscfreetorotateintheairgap ofanelectromagnet.
- Onehalfofeachpoleofthemagnetissurroundedbyacopperbandknownasshading ring.
- The alternating flux $\emptyset_s$ inthe shadedportionof the pole will,owing tothe reaction of the currentinducedinthering,lagbehindtheflux$\emptyset_\mu$intheunshadedportionbyananglеα.
- Thesetwoacfluxesdifferinginphasewillproducethenecessarytorquetorotatethedisc.
- ThedrivingtorqueTisgivenby,Ta$\emptyset_s\emptyset_\mu$sinα.
- Assumingthefluxes$\emptyset_s$and$\emptyset_\mu$tobeproportionaltothecurrentIintherelaycoil,TaI^2sin α.Thisshowsthedrivingtorqueisproportionaltothesquareofcurrentintherelaycoil.

Watthour-meterstructure:

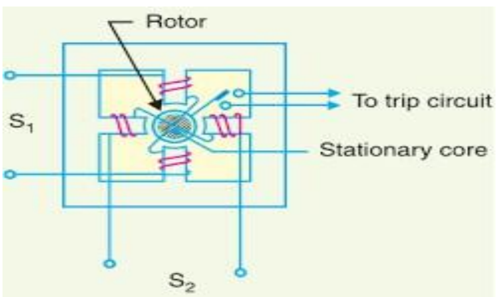


Watt-hour Meter Type Induction Disc Relay

- Itconsiststwomagnetstwomagnetsoneislowermagnetanotherisuppermagnet.
- Uppermagnetconsistsofprimarywindingandsecondarywinding.
- Apivotedaluminiumdiscarrangedtorotatefreelybetweenthepolesoftwoelectromagnets.

- TheprimarywindingcarriesrelaycurrentI_1 whilethesecondarywindingisconnectedtothe winding of the lower magnet .
- TheprimarycurrentinducesemfinthesecondaryandsocirculatesthecurrentI_2 init.
- Theflux$\emptyset_2$ inducedinthelowermagnetbythecurrentin thesecondarywindingoftheupper magnet will lag behind $\phi_1$by an angle α .
- The two fluxes ϕ_1 and ϕ_2 differingin phase by α will produce a driving torque on the disc proportionalto$\phi_1$and$\emptyset_2$differinginphasebyαwillproducea drivingtorqueonthedisc proportional to $\emptyset_1\emptyset_2\sin\alpha$.

Inductioncupstructure:

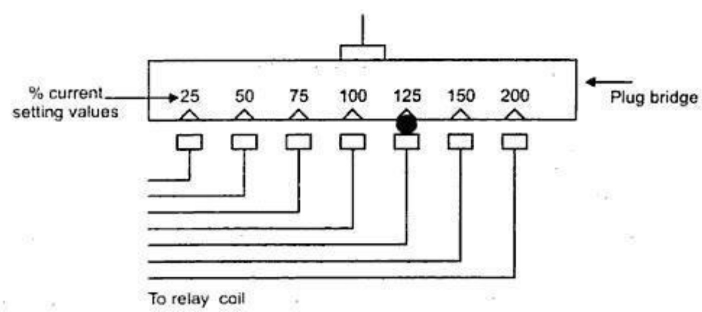


- Itmostcloselyresemblesaninductionmotor ,exceptthattherotorironisstationary,onlythe rotor conductor portion being free to rotate.
- Themovingelementisahollowcylindricalrotorwhichturnsonitsaxis.
- Therotatingfieldisproducedbytwopairsofcoilswoundonfourpolesasshown.
- Therotatingfieldinducescurrentinthecuptoprovidethenecessarydrivingtorque.

Definition of following important terms:

Pick-upcurrent:Itistheminimumcurrentintherelaycoilatwhichtherelaystartstooperate.

Currentsetting:Theadjustmentofthepick-upcurrenttoanyrequiredvalueisknownascurrentsetting.



Example:Supposethatan overcurrentrelayhavingcurrentsetting of125%isconnectedtosupplycircuit through a CT of 400/5. Find pick-up current.

Ans:Pick-upcurrent=5×1.25=6.25A.

Plug-settingmultiplier(PSM):Itistheratiooffaultcurrentinrelay coiltothepick-upcurrent. PSM

$$=\frac{\text{Fault current in relay coil}}{\text{Pick-upcurrent}}$$

$$=\frac{\text{Faultcurrentinrelaycoil}}{\text{RatedsecondarycurrentofCT}\times\text{currentsetting}}$$

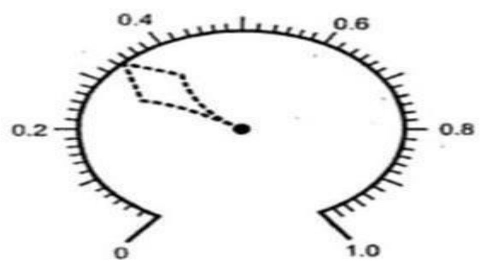
Example:Supposethata relayisconnected toa 400/5CTandsetof 150%,witha primaryfault current of 2400 A. Find PSM.

Solution:Pick-upcurrent= Ratedsecondarycurrentof CT$\times$currentsetting=5$\times$1.5=7.5A Fault

current in relay coil =2400 $\times$ (5/400) = 30 A .

plugsettingmultiplier=30/7.5=4.

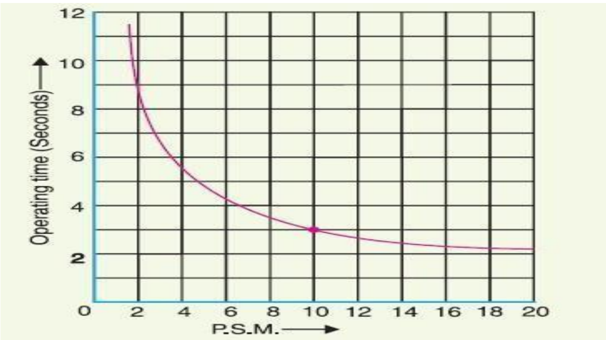
Timesettingmultiplier:Theadjustmentofcontrolof timeoperationintherelayisknownastimesetting multiplier.



Example:Inanovercurrentrelaythetimesettingis0.1andtimeobtainedfrom thetime/PSMcurvein3 sec.Find the actual relay operating time.

Solution:Actualrelayoperatingtime=3$\times$0.1=0.3sec.

Time/PSMcurve:Thecurvebetweentimeofoperationandplugsettingmultiplierofatypicalrelayis known as Time/PSM curve.



Example:Determinethetimeofa5-ampere,3-second overcurrentrelayhavingacurrentof125%and a time setting multiplier of 0.6 connected to supply circuit through a 400/5 current transformer when the circuit carries a fault current of 4000 A .Use the curve as shown in fig .

Solution:RatedsecondarycurrentofCT=5A.

Pick-up current = 5 × 1.25 =6.25 A

Faultcurrentinrelaycoil=4000×$(5/400)$=50A

∴Plug-settingmultiplier(PSM)=50/6.25=8

Correspondingtotheplug-settingmultiplierof8(Seefig),thetimeofoperationis3.5seconds.

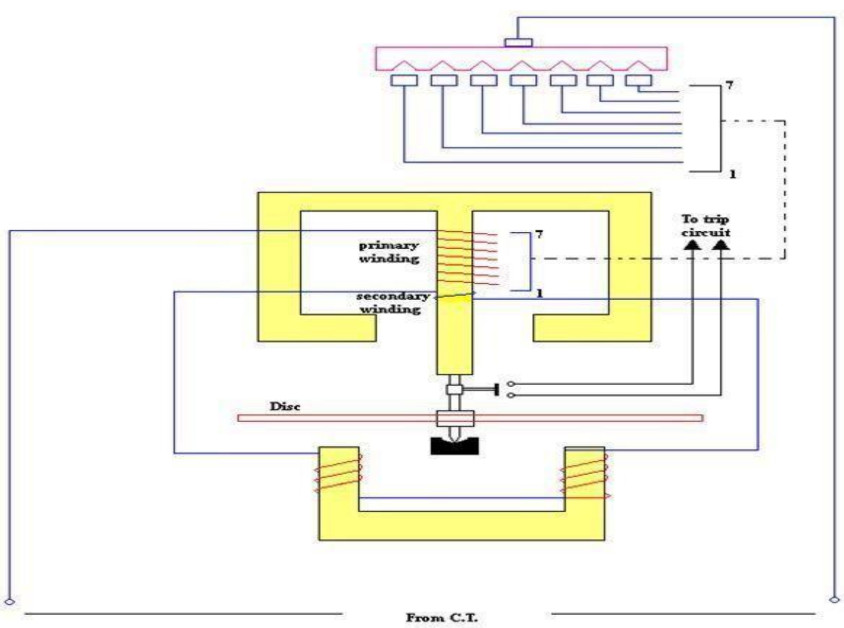
∴Actualrelayoperatingtime=3.5×Time-setting=3.5×0.6=2.1seconds.

Classificationoffunctionalrelays:Accordingtothefunctionofpowersystemrelaysarefollowingtypes:

- Inductiontypeovercurrentrelays.
- Inductiontypereversepowerrelays.
- Distancerelays.
- Differential relays.
- Translayscheme.

Inductiontypeovercurrentrelay(non-directional):

Construction:



- Thisrelayworksontheprincipleofmutualinduction.

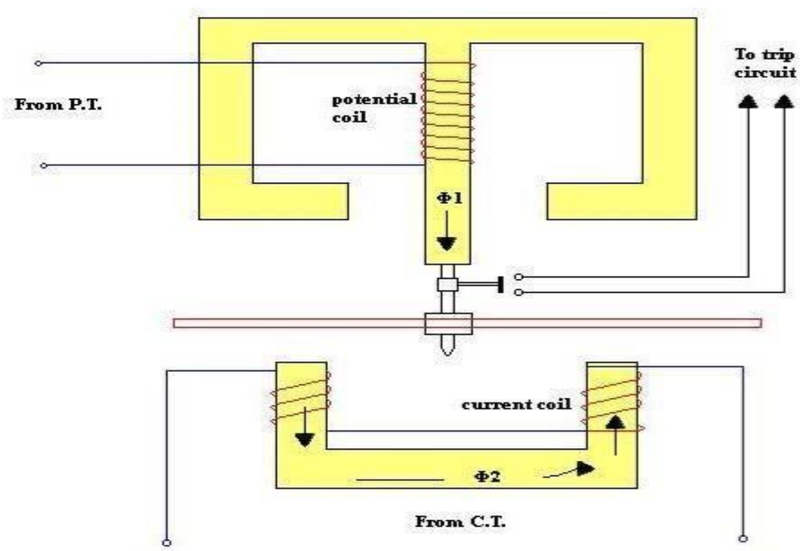
- Theactuatingsourceisafaultcurrent.
- Ithastwoelectromagnetcalledasupperandlowerelectromagnet.
- Upperelectromagnethasaprimaryandsecondarywinding.
- Secondarywindingisconnectedserieswiththelowerelectromagnetwinding.
- Tappingareprovidedontheprimarywindingwhichareconnected to aplug-bridgeorplug-setting and CT.
- Ametallic(aluminiumn)discwhichisfreetorotateinbetweenthepolesoftwoelectromagnet.
- Time-settingisprovidedbyadjustingthemovingcontactofdisc.
- Thecontrollingtorqueisprovidedbyaspiralspring.

Operation:

- Undernormaloperatingconditions,restrainingtorqueisgreaterthanthedrivingtorque produced by the relay coil current. Therefore the aluminum disc remains stationary .
- Whenfaultoccurs ,the currentintheprotected circuitsexceedsthepre-setvalue,the driving torque become greater then restraning torque.
- Hencethediscrotateandthe movingcontactbridgesthefixedcontacts.
- Afterthatthetripcircuitoperatesthecircuitbreaker.

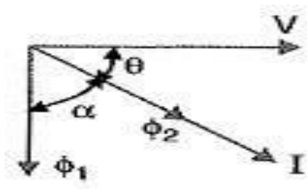
Induction type directional power relay:

Construction:



- Itworksontheprincipleofmutualinduction.
- Itconsistsoftwoelectromagnetcalledasupperandlowerelectromagnet.
- Upperelectromagnet´swindingenergisedthroughaPT(calledpotentialcoil).
- Lowerelectromagnet´swindingenergisedthroughaCT(calledcurrentcoil).
- Itconsistsofaaluminiumdiscfreetorotateinbetweentwopolesofelectromagnet.
- ThetappingsareprovidedonCC,whichareconnectedtoplug-settingbridge.

Operation:



Fromvectordiagram,weseethat T

α VI sin ($90^0 - \theta$)

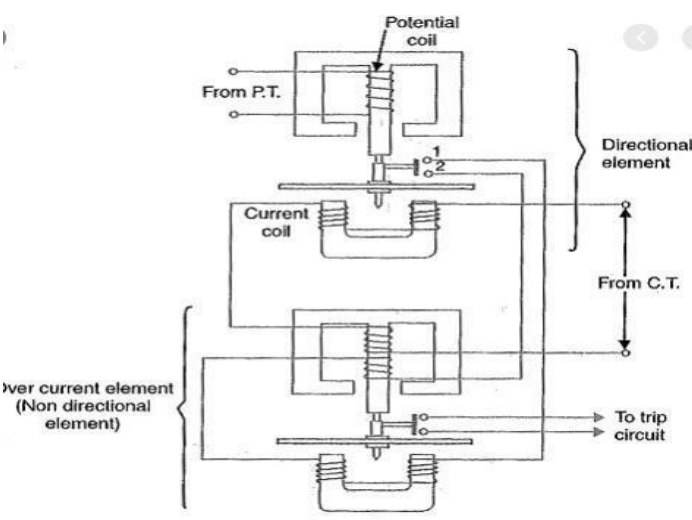
TαVI cosθ

αpowerinthecircuit

- Undernormalcondition,thepowerwillflowin thenormaldirectionandthealuminiumdisc remain stationary .
- Inabnormalcondition,thediscrotatesandthemovingcontactclosesthe tripcircuit.
- Thiscausestheoperationofcircuitbreakerwhichdisconnectthefaultysection.

Induction type direction overcurrent relay:

Construction:



- Itconsistsof tworelayelementsmountedonacommoncaseviz(i)directionalelementand(ii) non-directional element.
- Thedirectionalelementconsistsofupperandlowerelectromagnetofaluminiumdisc.
- ThedirectionalelementenergisedfromPTand CT.
- Thenon-directionalelementconsistsofuppermagnet(primarywindingandsecondary winding),lower magnet and an aluminium disc.
- Thenon-directionalelementenergisedfromCTandthetripcontactofdirectionalelement.
- Thenon-directionalelement´saluminiumdisctripcontactconnectedtotripcircuit.
- Thetappingofcurrentsettingprovidedonnon-directionalelementsprimarywindings.

Operation:

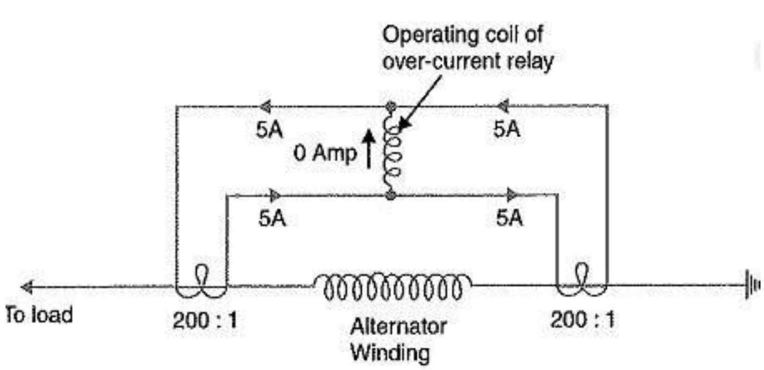
- Undernormalconditionthetwoaluminiumdiscremainstationary.
- Whenfaultoccursthe tripcontactofdirectionalelementclosesthe circuitoflowermagnet´s winding of non-directional element .
- Afterthataluminiumdiscofnon-directionalelementtripthecircuitandhenceoperate the circuit breaker which isolate the faulty section.

Differentialrelays:Adifferentialrelayisonethatoperateswhenthephasor differenceoftwo ormore similar electrical quantites exceeds a pre-determined value .

Therearetwofundamentalsystemsofdifferentialorbalancedprotection.

- Currentbalanceprotection
- Voltagebalanceprotection

Current differential relay :

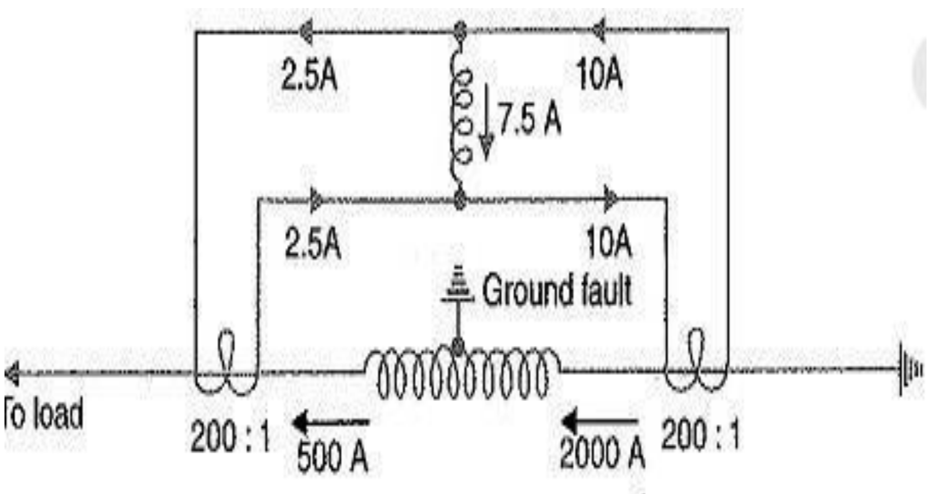


- Apairofidenticalcurrenttransformersarefittedoneitherendofthesectiontobeprotected.
- Thesecondaryof CT´sareconnected inseriesinsuchawaythattheycarryinduced currentsin the same direction.
- TheoperatingcoiloftheovercurrentrelayisconnectedacrosstheCTsecondarycircuit.

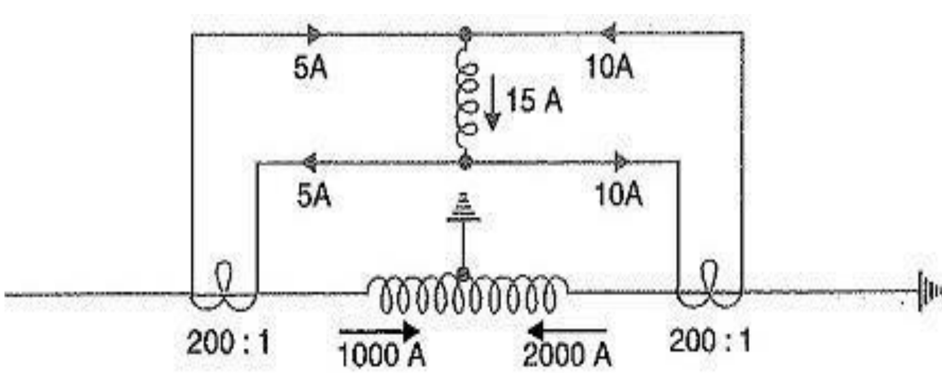
Operation:

- Undernormaloperatingconditions,supposethe alternatorwindingcarriesanormalcurrentof 1000 A. Then the currents in the two secondaries are equal.These currents will circulate between the two CT´s and no current will flow through the differential relay.
- Ifagroundfaultoccursonthealternator winding,thetwosecondarycurrents willnotbeequal and the current flows through the operating coil of the relay causing the relay to operate.

I. Ifsomecurrent(500Ainthis case)flowsoutof onesidewhilealargercurrent(2000A) enters theothersideasshowninbelow,then thedifference ofCTsecondary currentsi.e10—2.5=7.5 A will flow through the relay coil .



II. Ifcurrentflowsto thefaultfrombothsidesasshown inbelowdiagram,thenthesumofCT secondary currents i.e 10+5 = 15 A will flow through the relay.

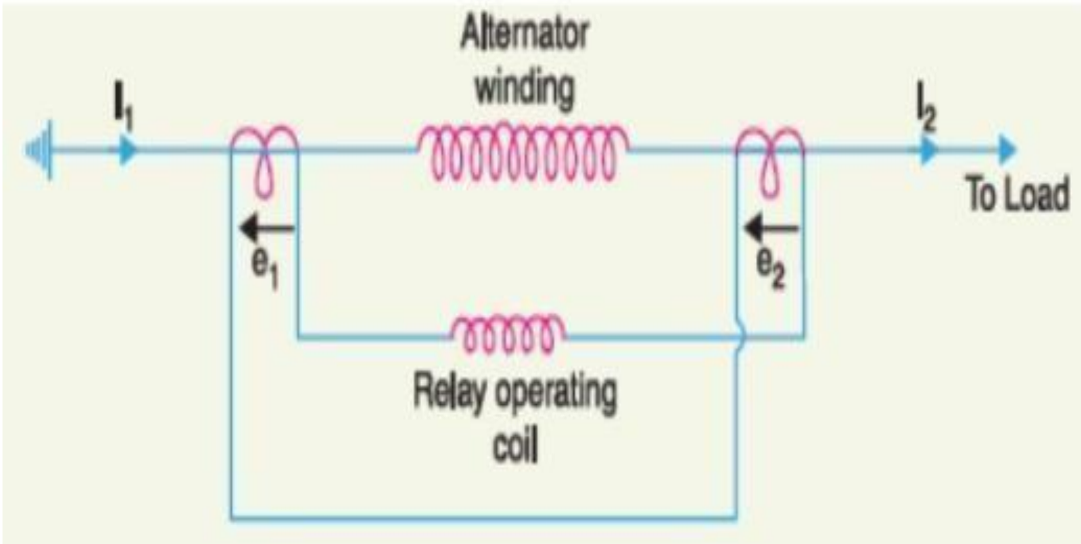


Disadvantages:

Pilotcapacitancecausesincorrectoperationoftherelaywhenalargecurrentflows.

Accurate matching of CT´s cannot be achieved due to pilot circuit impedance.

Voltagebalancedifferentialrelay:



- Inthisschemeofprotectiontwo similarcurrenttransformersareconnectedateitherendof the element to be protected (e.g an alternator winding) by means of pilot wires.
- Thesecondariesofcurrenttransformersare connnetedinserieswithrelayinsuchawaythat under normal conditions ,their induced emfs are in opposition .

Operation:

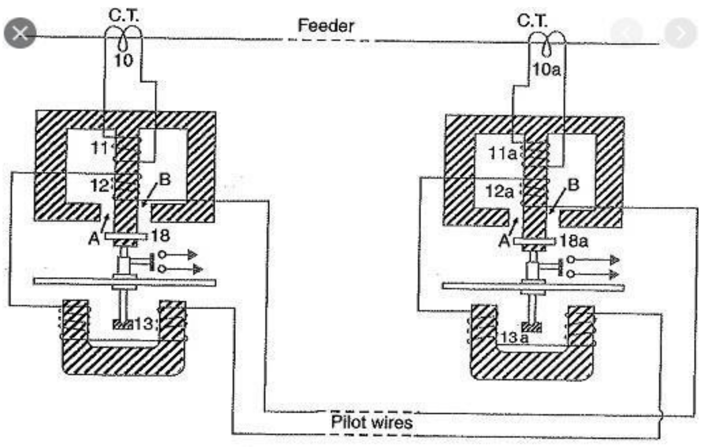
- Underhealthyconditionsequalcurrents(I_1=I_2)flowinbothprimarywindings.
- Thereforethesecondaryvoltagesoftwotransformers arebalancedagainsteachotherandno current will flow through the relay operating coil.
- Whenfaultoccurs intheprotected zone,thecurrentinthetwo primarieswilldifferfrom($I_1 \neq I_2$) and their secondary voltages no longer be in balance.
- Thisvoltagedifferencewillcauseacurrentto flowthroughtheoperatingcoiloftherelaywhich close the trip circuit .

Disadvantages:

- Amultigaptransformerconstructionisrequiredtoachivetheaccuratebalancebetweencurrent transformerpairs.
- Thesystemissuitableforprotection ofcablesofrelativelyshortlengthduetocapacitanceof pilot wires.
- Onlongcables,thechargingcurrentmaybesufficienttooperatetherelayevenifaperfect balance of current transformer is attained.

Traslaysystem:

Constructionaldetails:



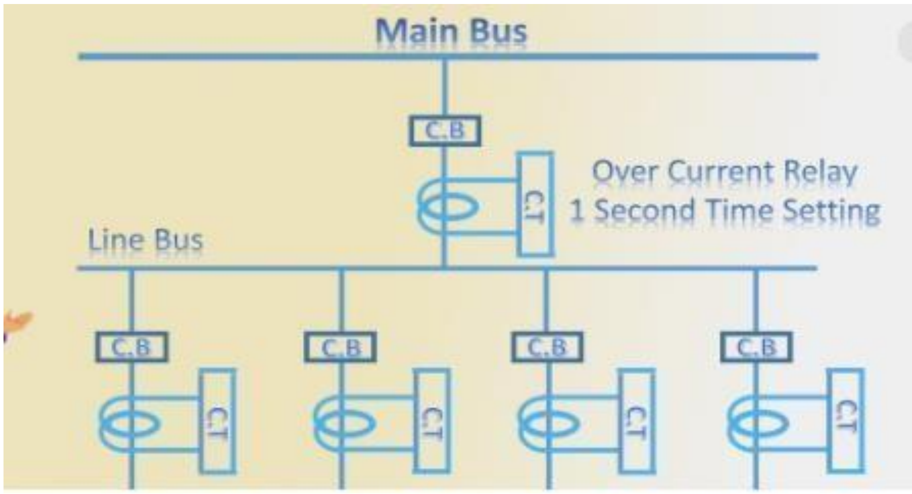
- Itconsistsof twoidenticaldoublewindinginductiontyperelaysfittedateitherendof the feeder to be protected.
- Theprimarycircuits(11,11a)oftheserelaysaresuppliedthroughapairofcurrenttransformers.
- Thesecondarywindings(12,13and12a,13a)ofthetworelaysareconnectedinseriesbypilot wires in such a way that voltages induced in the former opposes the other.
- Thecompensatingdevices(18,18a)neutralizetheeffectsofpilot-wirecapacitancecurrents.

Operation:

- Underhealthyconditions,the currentatthe twoendsoftheprotectedfeederisthe sameand the primary windings (11,11a) of the relays carry the same current.
- Thewindings11and11ainduceequalemfsinthesecondarywindings12,12aand13,13a.
- As these windings are soconnected that their induce voltages are in opposition ,nocurrentwill flowthroughthepilotsor operatingcoilsandhence notorquewillbeexertedon thedisceither relay.
- Whenfaultoccurs,ontheprotectedfeeder,currentleavingthefeederwilldifferfromthe current entering the feeder.
- Consequently unequal voltages will be induced in the secondary windings of the relays and currentwillcirculatebetweenthetwowindings,causingthetorque tobe exertedonthediscof each relay.
- Asthedirectionofthesecondary currentwillbetendtoclosethetripcircuitwhiletheother relay ,the torque will hold the movement in the normal unoperated position.
- Closedcopperrings(18.18a)inneutralizingtheeffectsofpilotcapacitivecurrents.

Types of protection: Protection schemes are two types :

- Primaryprotection
- Back-upprotection



Primaryprotection:

- Itistheprotectionschemewhichisdesignedtoprotectthe componentpartsof thepower system.
- Inabovefigureeachlinehasanovercurrentrelaythatprotectes theline.
- Iffaultoccursonanyline,itwillbeclearedbyitsrelayandcircuitbreaker.
- Thisformstheprimaryormainprotectionandservesasthefirstlineofdefence Back-

up protection:

- Itisthesecondlineofdefenceincaseof failureoftheprimaryprotection.
- Itisdesignedtooperatewithsufficienttimedelaysothatprimaryrelayingwill begivenenough time to function if it is able to .
- InabovefigurerelayAprovidesback-upprotectionfor eachoffourlines.
- Ifalinefaultisnotclearedbyitsrelayandbreaker,therelayAonthegroupbreakerwill operate after a definite time delay and clear entire group of lines.

PROTECTIONOFELECTRICALPOWEREQUIPMENTANDLINES

Protectionofalternator:Therearesomeimportantfaultsoccuronanalternatorarefollowsbelow:

- Failureofprime-mover
- Failureoffield
- Overcurrent
- Overvoltage
- Unbalancedloading
- Statorwindingsfaults

Failure of prime-mover:

- Thefailureofprime-moverinanalternatormechanicallycoupledtoturbine.
- Primemoverfailureoccurs,themachinecansafelyisolatedbythecontrolroomattendant.
- Thereforetheautomaticandelectricalprotectionisnotrequired.

Failure of field:

- Thechanceoffieldfailureofalternatorareundoubtedlyveryrare.
- Iffieldfailureoccur,thenalternatorcanrunforashortperiod.
- Thisshortperiodallowedcontrolroomattendanttodisconnectthefaultyalternatormanually from the system bus-bars.

Over-current:

- Theovercurrentoccurs onanalternatordue tooverloadonthe supplysystemandpartial breakdown of winding insulation.
- Forprotectionofalternator fromovercurrent,the m/cshouldbedesignedwithhighvaluesof internal impedance and can be disconnect manually.

Overspeed:

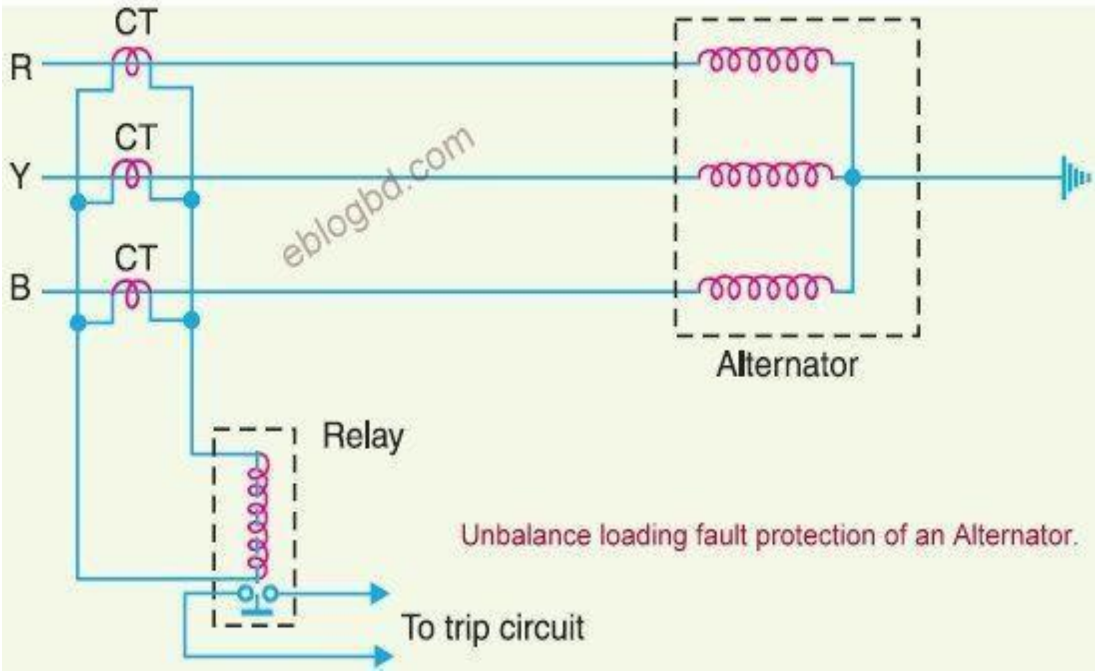
- Thechiefcauseofoverspeedisthesuddenlossofallorthemajorpartofloadonthealternator
- Modernalternatorareusuallyprovidedwithmechanicalcentrifugaldevicesmountedontheir driving shafts totripthe main valveof the primemover whena dangerous overspeedoccurs.

Overvoltage:

- Overvoltageinanalternatoroccurs whenthespeed oftheprimemoverincreasesdueto sudden loss of the alternator load.
- Controlgovernors(systemturbine)exerciseacontinuouscheckonoverspeedandthusprevent the occurrence of over voltage on generating unit.

Unbalancedloading:

- Unbalancedloadingmeansthattherearedifferentphasecurrentsinthealternator.
- Unbalancedloadingarisesfromfaultstoearthor faultsbetweenphasesonthe circuitexternal to the alternator.
- Thecircuitdiagrambelowshowstheprotectionofalternatoragainstunbalancedloading.



- Threecurrenttranformers,onemountedoneachphasehavingtheirsecondariesconnectedin parallel .
- Arelayisconnectedinparallelacrossthetransformer secondaries.
- Underthenormaloperatingconditions,equalcurrent flowthroughthedifferentphasesofthe alternator and their algebraic sum is zero.
- Thereforethesumof currentflowinginthesecondariesisalsozeroandnocurrentflows through the operating coil of the relay.
- Howeverifunbalancingoccurs,thecurrentsinducedinthesecondarieswillbedifferentandthe resultant of the currents will flow through the relay.
- Theoperationoftherelaytripthe circuitbreakertodisconnectthealternatorfromthesystem.

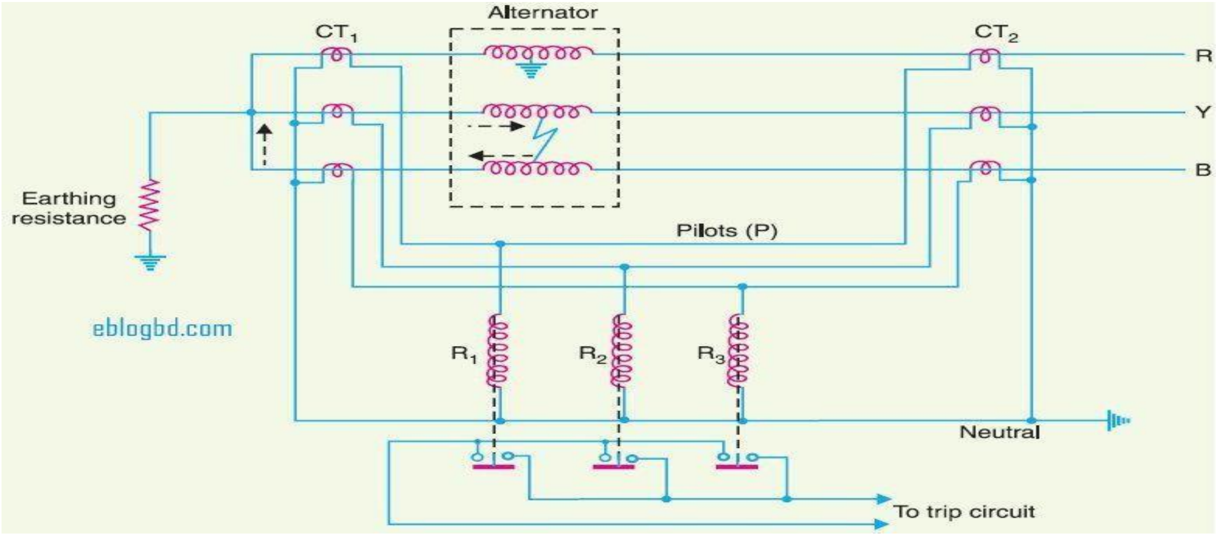
Stator winding faults:

- Thesefaultsoccurredmainlyduetotheinsulationfailureofthestatorwindings.
- Themaintypesofstatorwindingfaults are:
  - Faultbetweenphaseandground.
  - Faultbetweenphases.
  - Inter-turnfaultinvolvingturnsofthesamephasewindings.

- Forprotectionofalternatoragainstsuchabovefaultsdifferentialmethodofprotection(also known as Merz-Prize System) is employed.

Differentialprotectionofalternators(Merz-Prizecirculatingcurrentscheme):

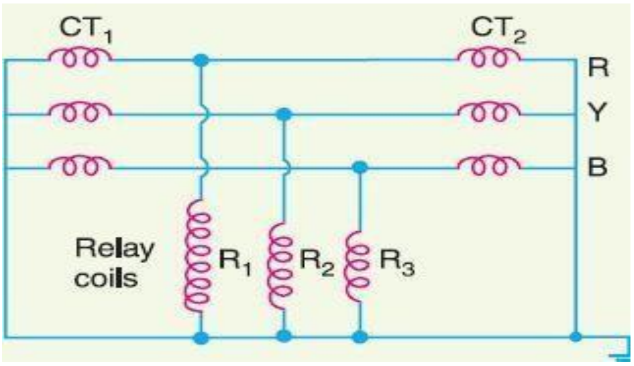
Schematic arrangement:



- Abovefigureshowstheschematicarrangementofcurrentdifferentialprotectionfora 3-Ø alternator.
- IdenticalcurrenttransformerpairsCT_1andCT_2areplacedeithersideofeachphaseofthestator windings.
- Thesecondariesofeachsetofcurrenttransformersareconnectedinstar.
- Thereistwostargroupsi.eisstator windingandCTsecondaries.Hencethereis twoneutral points.
- Thetreminalsoftwostargroups beingconnected togetherbymeansofafourcore pilotcable.

Operation:

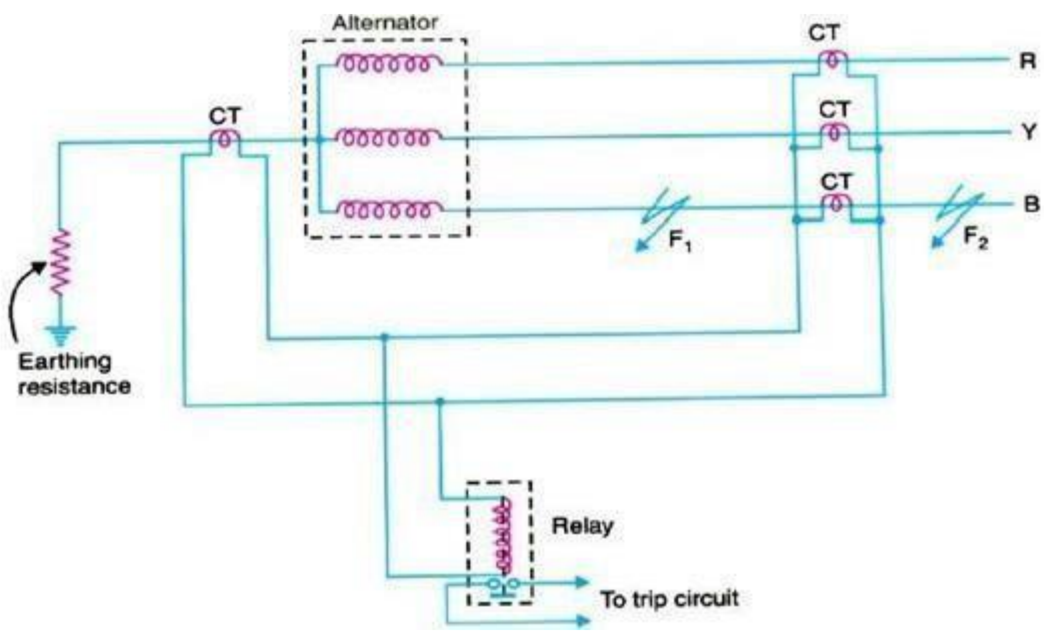
Theabovecircuitdiagramcanberedrawninthesimpleformasfollowbelow:



- Undernormaloperatingconditions,thecurrentatbothendsofeachwindingwillbeequal.
- Hencethecurrentsin thesecondariesof thetwo CTsareconnected inanyphasewiialsobe equal.
- Therefore,thereisbalancedcirculatingcurrentinthe pilot wiresandnocurrentflowsthrough the operating coils (R_1,$R_2$and R_3) of the relays.
- Whenanearthfault orphase-to-phase faultoccurs,thisconditionsnolongerholdsgoodand the differential currentflowing throughthe relay circuitoperates the relay totrip the circuit breaker.

Balancedearthfaultprotection:

Schematicarrangement:



- Itconsistsofthreelinecurrenttransformers,onemountedineachphase.
- AnotherCTconnectedinthestarpointofthealternatortoeach.
- Thesecondariesofthree currenttransformersareconnectedinparallelwiththatofasingle current transformer .
- Arelayisconnectedacrossthetransformerssecondaries.

Operation:

- Undernormalconditions,equalcurrentsflowthroughthedifferentphasesofthealternatorand their algebraic sum is zero.
- Thereforethesumof currentsflowinginthesecondariesisalsozeroandnocurrentflow through the operating coil of the relay.
- Undertheseconditions,the currentintheneutralwireiszeroandthe secondaryofneutral current transformer supplies no current to the relay.

- If an earth fault develops at F_2 external to the protected zone,the sum of the currents at the terminalsofthealternatorisexactlyequaltothe currentintheneutralconnectionsandhence current flows through the relay.
- WhenanearthfaultoccursatF$_1$orwithintheprotectedzone,these currentsarenolonger equal and the currents flows through the relay to operate the circuit breaker.

ProtectionsystemsforTranformers:Thecommontransformerfaultsare:

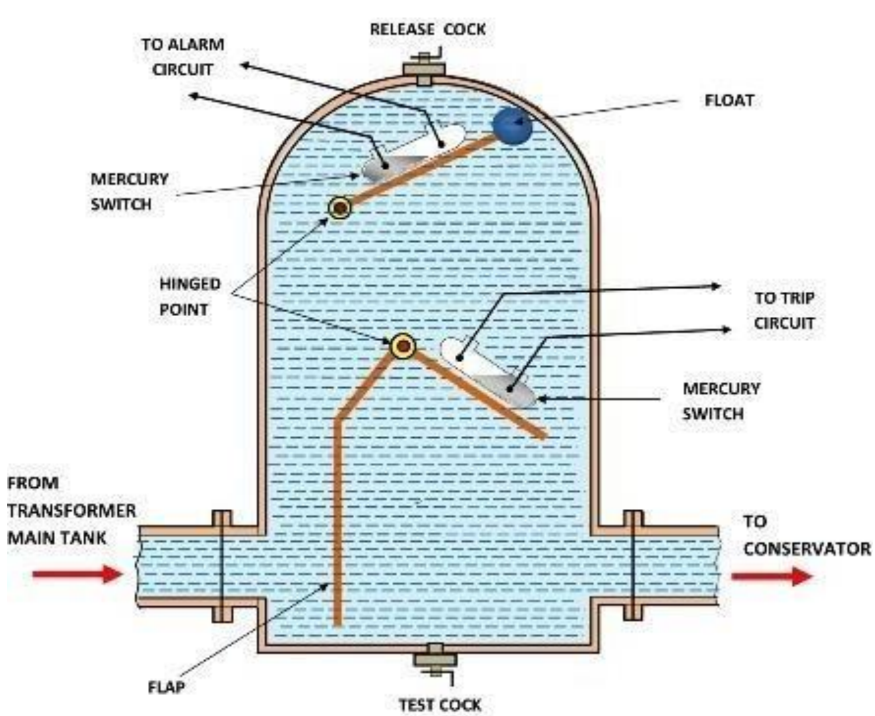
- Opencircuits
- Overheating
- Windingshort-circuitse.gearth-faults,phasetophase faultsandinterturnfaults. The

principal relays and systems used for transformer protection are :

- Buchholzdevicesprovidingprotectionagainstallkindofincipientfaultssuchasinsulation failure of windings, core heating , fall of oil level due to leakage joints etc.
- Earthfaultsrelaysprovidingprotectionagainstearth-faultonly.
- Overcurrentrelaysprotectionmainlyagainstphase-to-phasefaultsandoverloading.
- Differentialsystem(orcirculating-currentsystem)providingprotectionagainstbothearthfault and phase faults.

Buchholzrelay:Buchholzrelayisagasactuated relayinstalled inoilimmersedtransformersagainstall kinds of faults.

Diagram:



Construction:

- Ittakestheformof domedvesselplacedintheconnectingpipebetweenthemaintankand conservator.
- Thedevicehastwoelementsi.eupperandlower.
- Theupperelementconsistsofamercurytypeswitchattachedtoa float.
- Thelowerelementcontainsamercuryswitchmountedonahingedtypeflaplocated inthe direct path of the flow of oil from transformer to the conservator.
- Theupperelementclosesanalaramcircuitduringincipientfaults.
- Thelowerelementisarrangedtotripthecircuitbreakerincaseofseverefaults.

Operation: The operation of Buchholz relay is as follows below:

- In case of incipient faults within the transformers the heat due to fault causes the decompositionofsometransformeroilinthemaintank.Theproductofdecompositioncontains morethan70 %ofhydrogengasbeinglighttriestogo intotheconservator.Atthat momentthe gas get deposited in the upper part of the relay chamber .When a high amount of gas gets accumulated,itexertssufficientpressureon thefloat tocauseit totiltand closethe contacts of mercury switch attached to it. This completes the alaram circuit to sound on the alaram.
- If a serious fault occurs in the transformer, an enoromous amount of gas is generated in the main tank. The oil in the main tank.The oil in the main tank rushes towards the conservator throughBuchholzrelayandindoingsotiltstheflapto closethecontacts ofmercuryswitch.This completes the trip circuit to open the circuit breaker controlling the transformer .

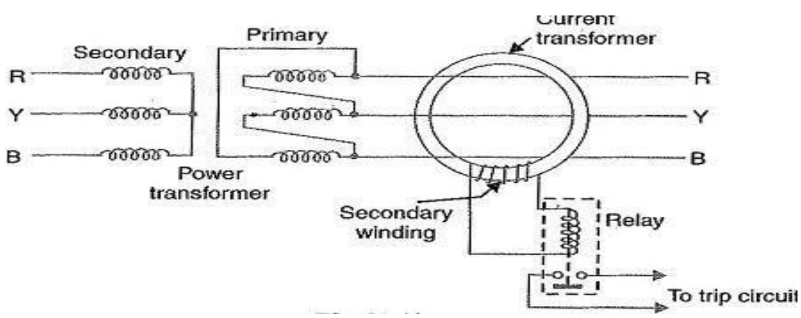
Advantages:

- Itissimplestformoftransformerprotection.
- Itdetects theincipientfaultsata stagemuchearlierthanispossiblewithotherformsof protection.

Disadvantages:

- Itcanonlybeusedwith oilimmersedtransformersequippedwithconservatortank.

Earth-fault or leakage protection:

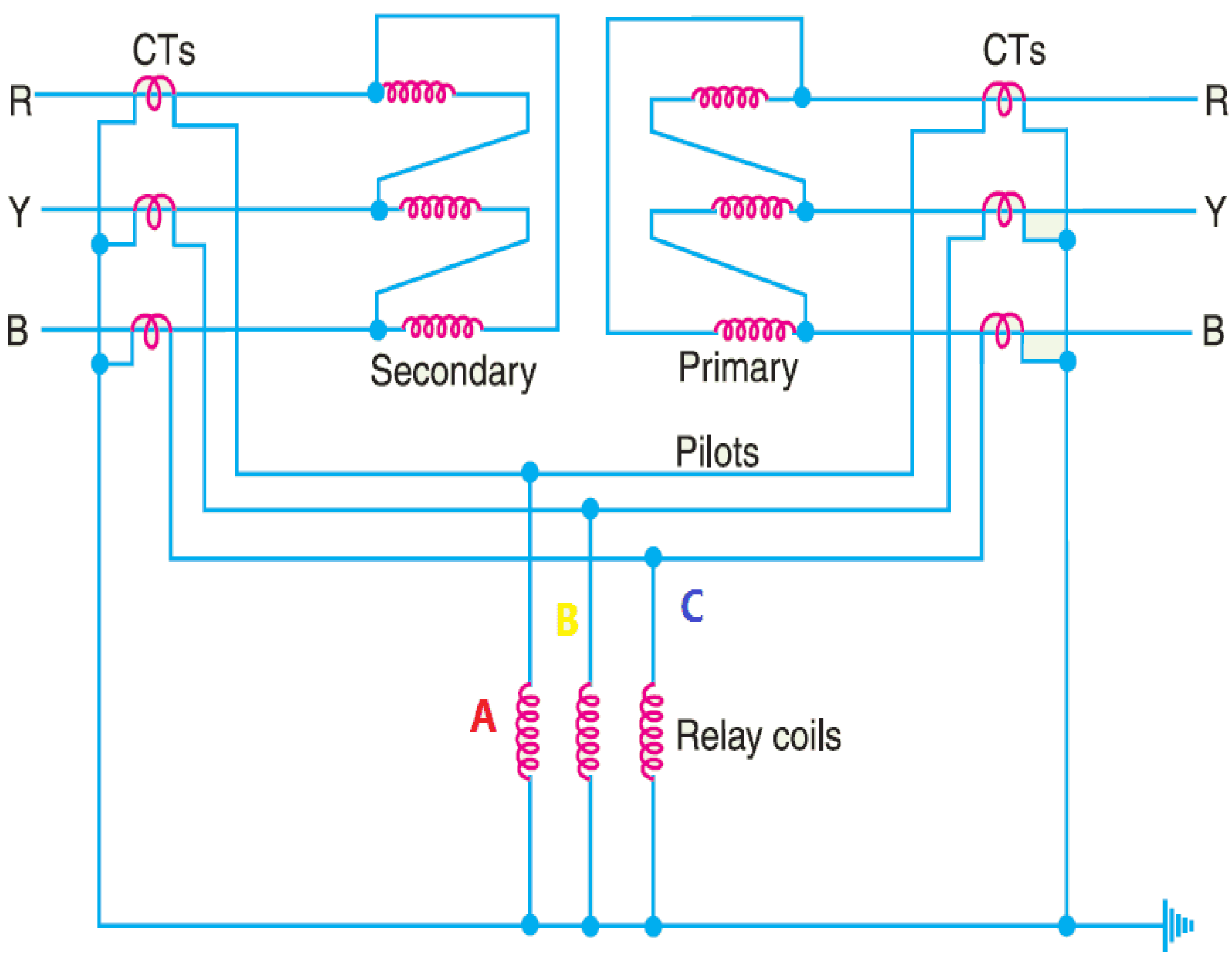


Operation:

- Undernormaloperatingcondition(i.enofaultcurrenttoearth),thevectorsumof thethree phase currentis zero and there is no resultant flux in the core of the current transformer.
- Consequentlynocurrentflowsthroughtherelayanditremainsinoperative.
- Whenearthfaultoccursthevectorsumof threephasecurrentisnolongerzero.
- Theresultantcurrentssetupfluxinthecoreof theCT,whichinduces emfinthesecondary winding.
- Thisenergiestherelaytotripthecircuitbreakeranddisconnectthefaulty transformerfromthe system.

Circulating-currentschemefortransformerprotection:

Diagram:



- Inabovediagrama3-Ødelta/deltapowertransformerconnected.
- CTsonthetwosidesofthetransformerareconnectedinstar.
- TheCTsonthetwosidesareconnectedbypilotwiresandonerelayisusedforeachpairofCTs.

Operation:

- Undernormaloperatingconditions,thesecondariesofCTscarryidentical currents.
- Therefore,the currents enteringandleavingthepilotwiresofbothendsare thesameandno current flows through the relays.
- Ifagroundorphase tophasefaultoccurs ,thecurrent inthesecondariesofCTswillnolongerbe the same and the differential current flowing through the relay circuit will clear the breaker on both sides of the transformer.

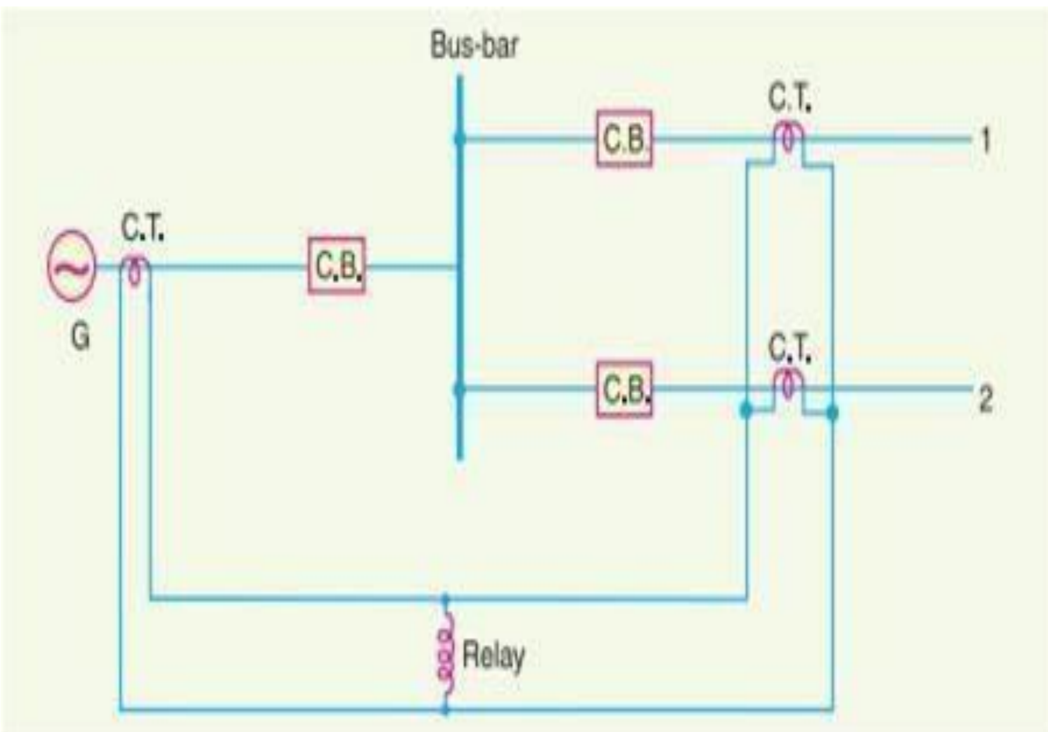
Protectionofbus bar:Bus-bars inthegeneratingstationsandsubstationformimportantlinkbetween the incoming and outgoing circuits.

Thetwomostcommonlyusedschemeforbusbarprotectionare:

- Differential protection
- Faultbusprotection

Differentialprotection:Thebasicmethodforbus-bar protectionisthe differentialschemeinwhich currents entering and leaving the bus are totalized.

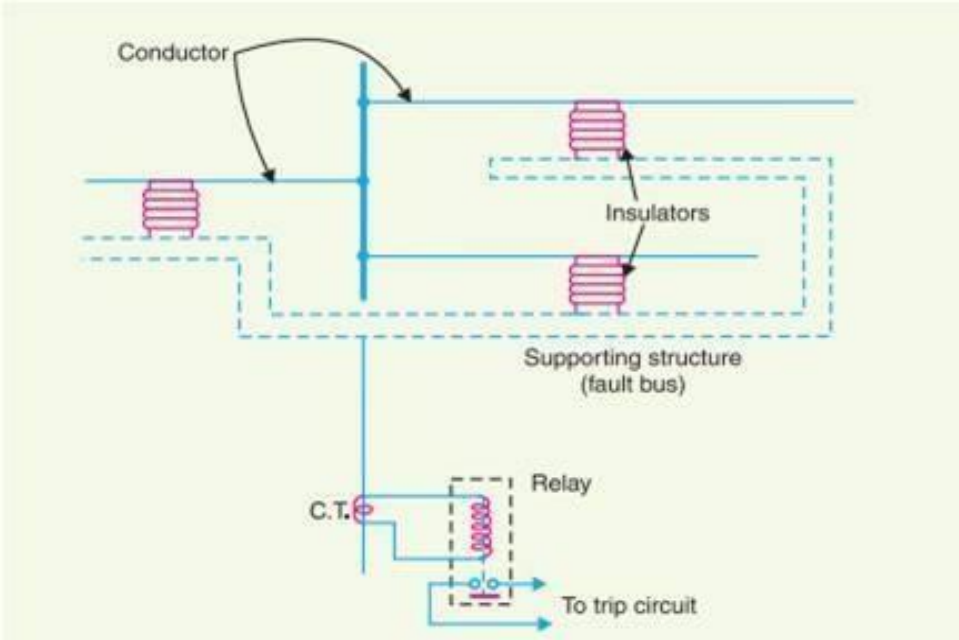
Diagram:



- Duringnormalloadcondition,the sumofthesecurrentsisequaltozero.
- Whenafaultoccurs,thefaultcurrentupsetsthe balanceandproducesadifferentialcurrentto operate a relay.

Faultbusprotection:

Schematicarrangement:



- Themetalsupportingstructureorfaultbusisearthedthrougha CT.
- Arelayisconnectedacrossthesecondaryofthiscircuit.

Operation:

- Undernormaloperatingconditions,thereisnocurrentflowfromfaultbus togroundandthe relay remains inoprerative.
- Afaultinvolvingaconnectionbetweena conductorandearthsupportingstructurewillresultin current flow to ground through the fault bus , causing the relay to operate .
- Theoperationof therelaywilltripallbreakersconnectingequipmenttothebus.

Protection of transmission lines: The common methods of line protection are:

- Time-gradedovercurrentprotection
- Differential protection
- Distanceprotection

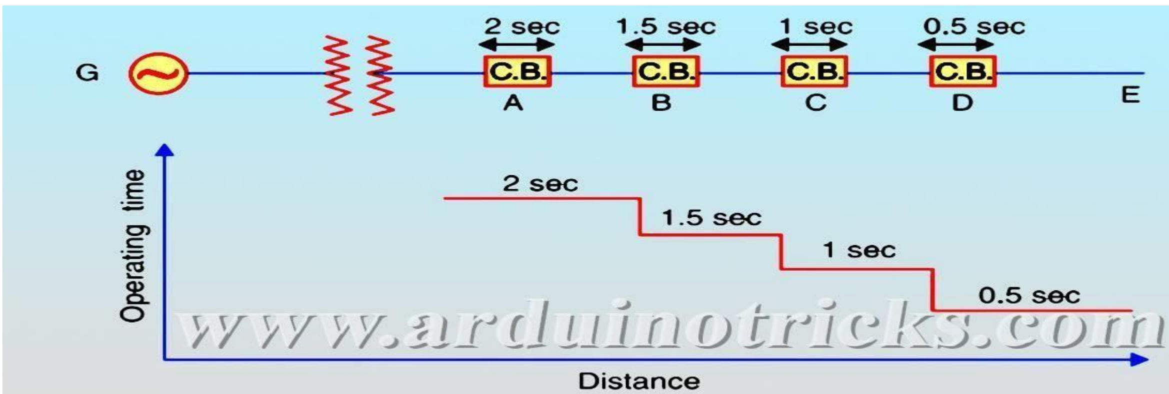
Timegradedovercurrentprotection:

- Hereovercurrentnondirectionalrelaysareused.
- Therelaysemployedareoperatedundersomedefinitetimeofoperation.
- Time-gradedovercurrentprotectionarethreetypes:

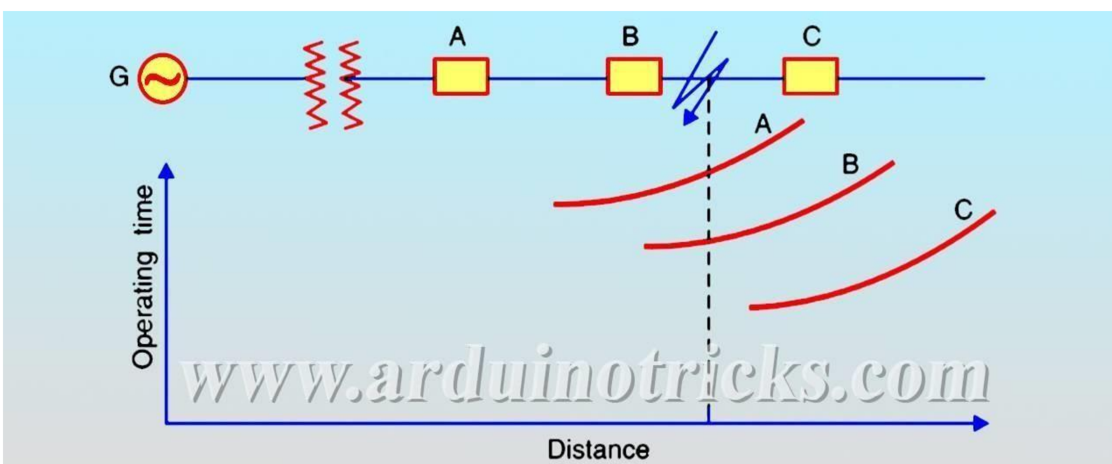
- Radial feeder
- Parallelfeeder
- Ringmainsystem

Radialfeeder:

- Herepowercanflowonlyinonedirectionfromgeneratororsupplyendtotheload.
- Time-gradedprotectionofaradialfeedercanbeachivedbyusing:
  - Definitetimerelays
  - Inversetime relays
- Definitetimerelays:

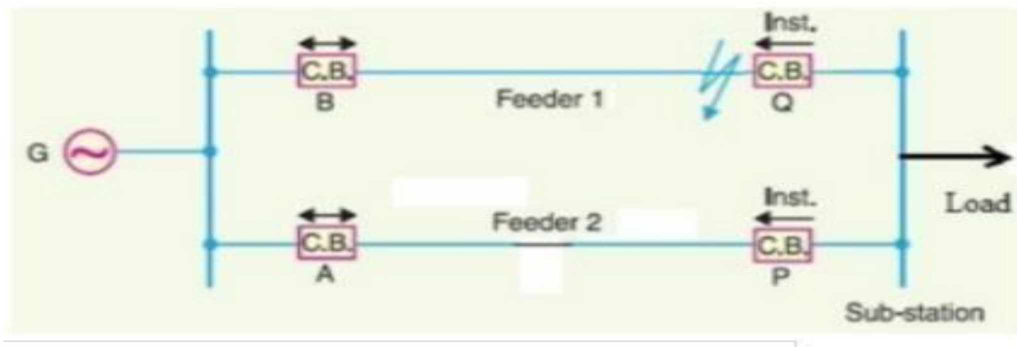


  - Herenon-directionalovercurrentrelaysareused.
  - Hereallrelaysaresetwithdefinitetime.
  - Ifafaultoccurs inthesectionDE,itwillclearedin0.5secbytherelayandcircuit breaker at D because all other relays have higher operating time .
- Usinginversetimerelays:



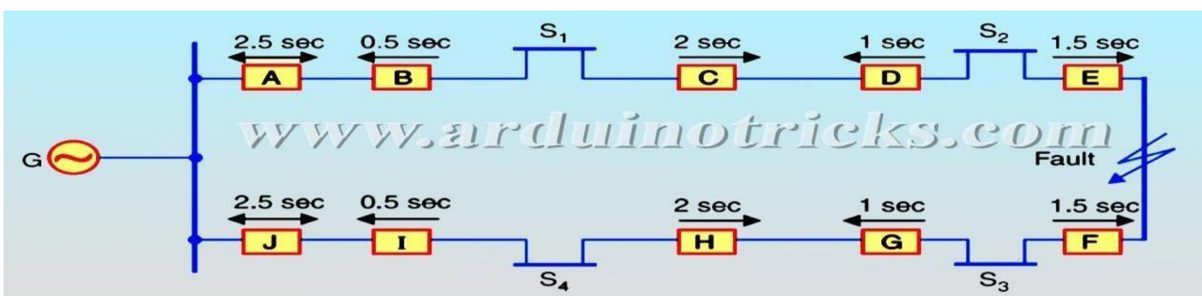
  - Herealsonon-directionalover-currentrelaysareused.
  - Allrelaysoperatingtimeisinverselyproportionaltotheoperatingcurrent.

Parallelfeeder:



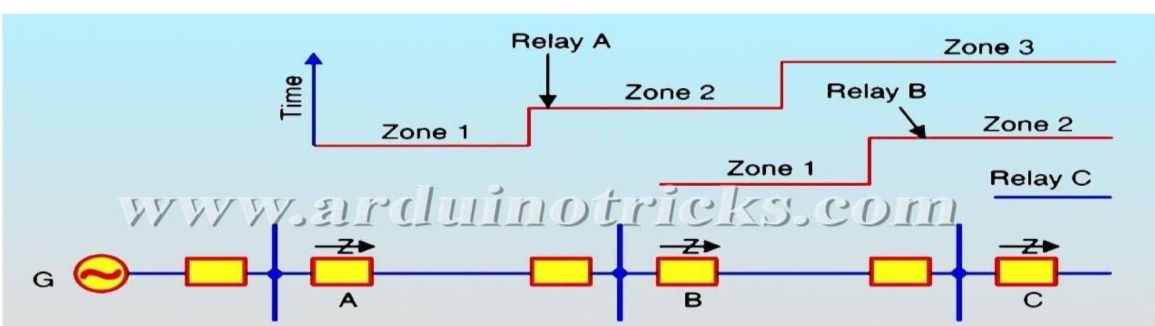
- Herenon-directionalandareversepowerordirectionalrelayused.
- Atgeneratorendnon-directionalrelayandatthesubstationendreversepowerrelayused.
- Iffaultoccursatfeeder-1 onlyBandQshouldisolatethefaultysection. Ring

main system:



- Inthissystemvariouspowerstationsorsubstationsareinterconnectedbyalternateroutesthus forming a closed ring.
- Incaseofdamagetoanysectionof thering,thatsectionmaybedisconnectedforrepairsand powerwill be supplied from both endsat the ring ,there by maintaining continuity of supply ‘
- Iffaultoccurs onsection EF thenonlyEandFwilloperatesbecauseof theirlowertimesetting.

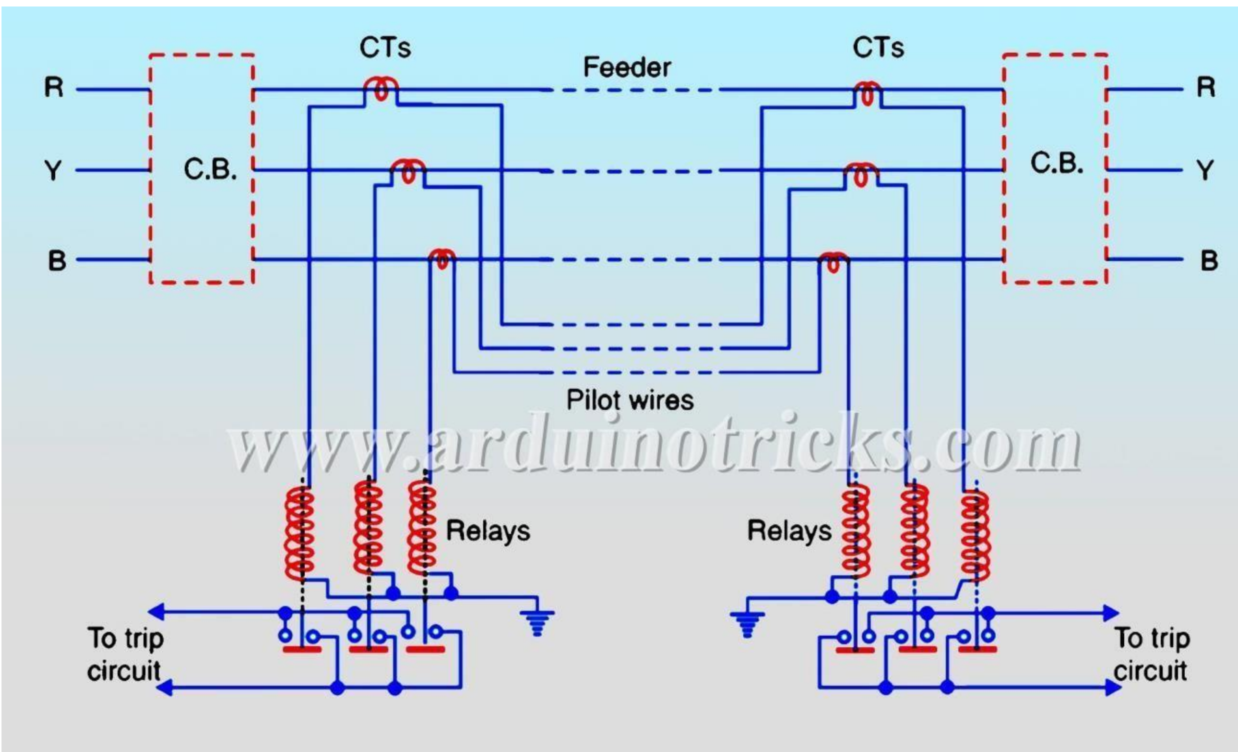
Distance protection:



- Abovefigureshowsasimplesystemconsistingoflinesinseriessuchthatpowercanflowonly from left to right .
- TherelaysatA,BandCaresettooperateforimpedancelessthanZ_1,Z_2andZ_3respectively.
- SupposeafaultoccursbetweensubstationsB andCthefaultimpedanceatpowerstationand s/s A and B will be $Z_1$and Z respectively.
- Itisclearthatfor theportionshownonlyrelayatBwilloperate.
- SimilarlyifafaultoccurswithinsectionAB,then onlyrelayatAwilloperate.

Differential pilot wire protection (Merz-price Voltage Balance system):

Schematicarrangement:



- Aboveshowsthesinglelinediagramof Merz-pricevoltagebalancesystemforprotectionofa3- ϕ line.
- Identicalcurrenttransformersareplacedineachphaseatbothendsofthe line.
- ThepairsofCTsineachlineisconnectedinseries witharelay.

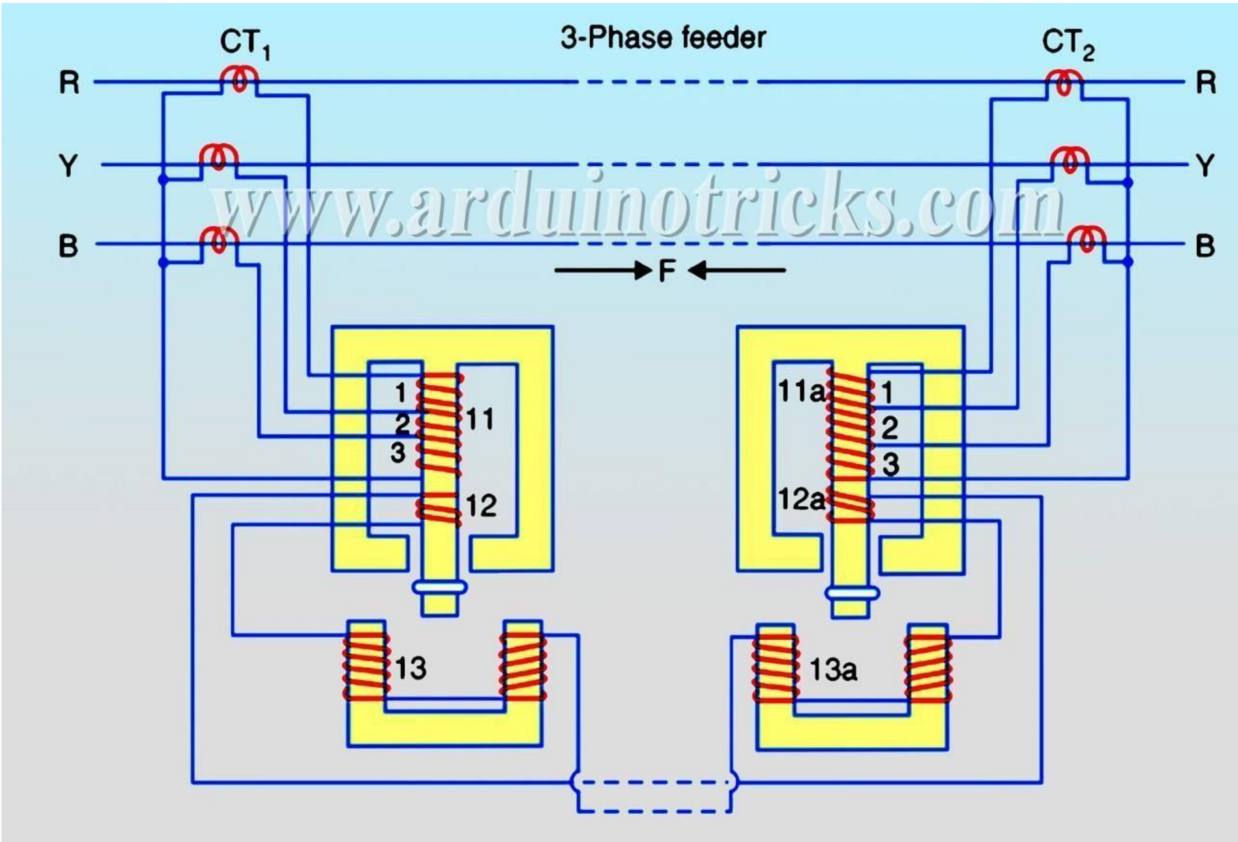
Operation:

- Undernormalcondition,currententeringthelineatone-endisequaltothatleavingitatthe other end.
- ThereforeequalandoppositevoltagesareinducedinthesecondariesoftheCTsatthe twoends of the line.
- Theresultisthatno-currentflowsthroughtherelays.

- Suppose a fault occurs at point F on the line, this will cause a greater current to flow through CT_1 then through CT_2.
- Finally, their secondary voltages becomes unequal and circulating current flows through the pilot wires and relays.
- The circuit breakers at both ends of the line will trip out and the faulty line will be isolated. Explain

protection of feeder by over current and earth fault relay:

Schematic arrangement:



- The relays used in the scheme are essentially overcurrent induction type relay.
- Each relay has two electromagnetic elements.
- The upper element carries a winding (11 or 11a) which is energised as a summation transformer from the secondaries of the line CTs connected in the phases of the line to be protected.
- The upper element also carries a secondary winding (12 or 12a) which is connected in series with the operating winding (13,13a) on the lower magnet.
- The secondary windings 12,12a and operating windings 13,13a are connected in series.

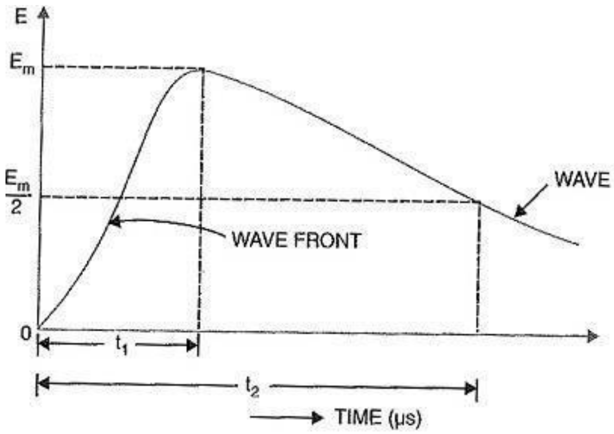
Operation:

- When the feeder is sound, the currents at its two ends are equal so that secondary curren on both sides of CTs are equal.

- Finallythecurrentsflowingintherelayprimarywindings11and11awillbeequalandthey induce equal voltages in secondary windings 12 and 12a.
- Sincethesewindingsareconnectedinopposition ,nocurrentflowsinthemorinthe operating windings 13 or 13a.
- Whenfaultoccurs on theprotectedline,unequalcurrentswillflow,asaresultthetorquewill developed to rotate the disc.
- Hencethecircuitbreakershouldopenthefaultysection.

PROTECTIONAGAINSTOVERVOLTAGEANDLIGHTING:

Voltagesurge:Asuddenriseinvoltageforaveryshortdurationon thepowersystemisknownasa voltage surge or transient voltage.



Abovefigureshowsthewaveformofatypicallightningsurge.

Causesofovervoltages:Thecausesofovervoltagesonapowersystemdividedintotwomaintypese.g Internal

causes:

- Switchingsurges.
- Insulationfailure.
- Arcing ground.
- Resonance.

Externalcauses

- i.elightning.

Internalcausesofovervoltages:

Switchingsurges:Theovervoltagesproducedonthepowersystemduetoswitchingoperationsare known as switching surges.

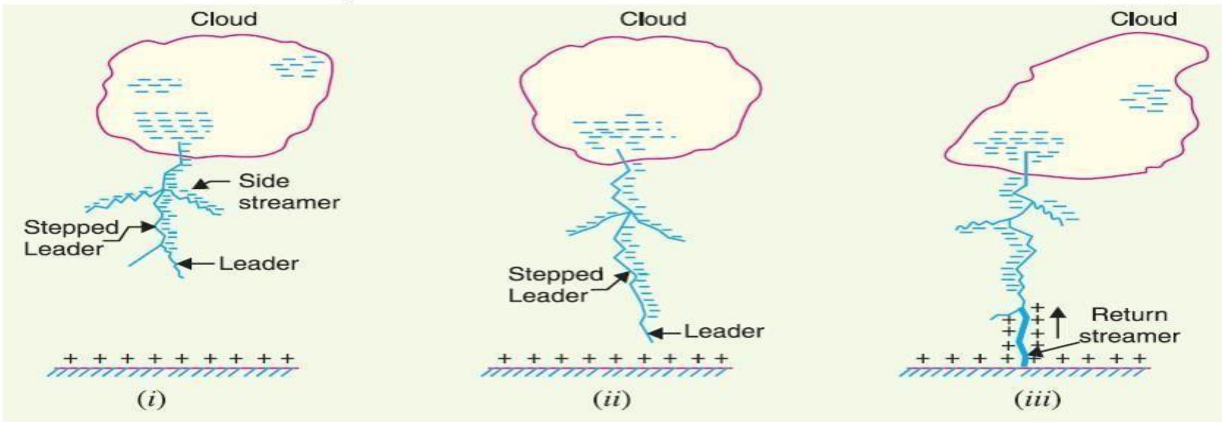
Insulationfailure:Theovervoltagesproducedon thepowersystemduetoinsulationfailurebetween line earth.

Arcingground:Thephenomenonofarctaking placein linetogroundfaultofa 3-ϕsystemwith consequent production of transients is known as arcing ground.

Resonance:Theovervoltagesproducedonthepowersystemduetoresonancecondition.

Externalcausesofovervoltage(lightning):Anelectricdischargebetweencloudandearthbetween clouds or between the charge centers of the same cloud is known as lightning.

Mechanisimoflightningdischarges:

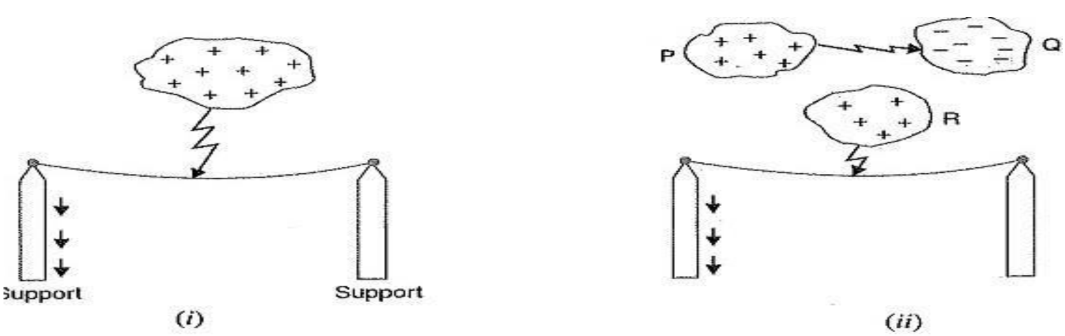


- Inatmospherethedropsofwateraccumulatetoformclouds.
- Cloudmaypossesseitherapositiveornegativedependinguponthechargeof dropsof water they contain.
- Whenachargedcloudpassesovertheearth ,itinducesequalandoppositechargeonearth below it.
- Assoonastheairnear thecloud breaksdown,astreamercalledleaderstreamerorpilot streamer starts flowing from the cloud towards the earth as shown in above figure.
- Afterthatareturnstreamerstartsflowingfromearthtocloud.
- Atthatmomentthereturnstreamerandleaderstreamercollidewitheachother.
- Thisphenomenoncausesasuddensparkwhichwecalledlightning.

Typesoflightningstrokes:Therearetwomainswaysinwhichalightningmaystrikethepowersystem (e.g over head lines ,towers,substations etc) namely:

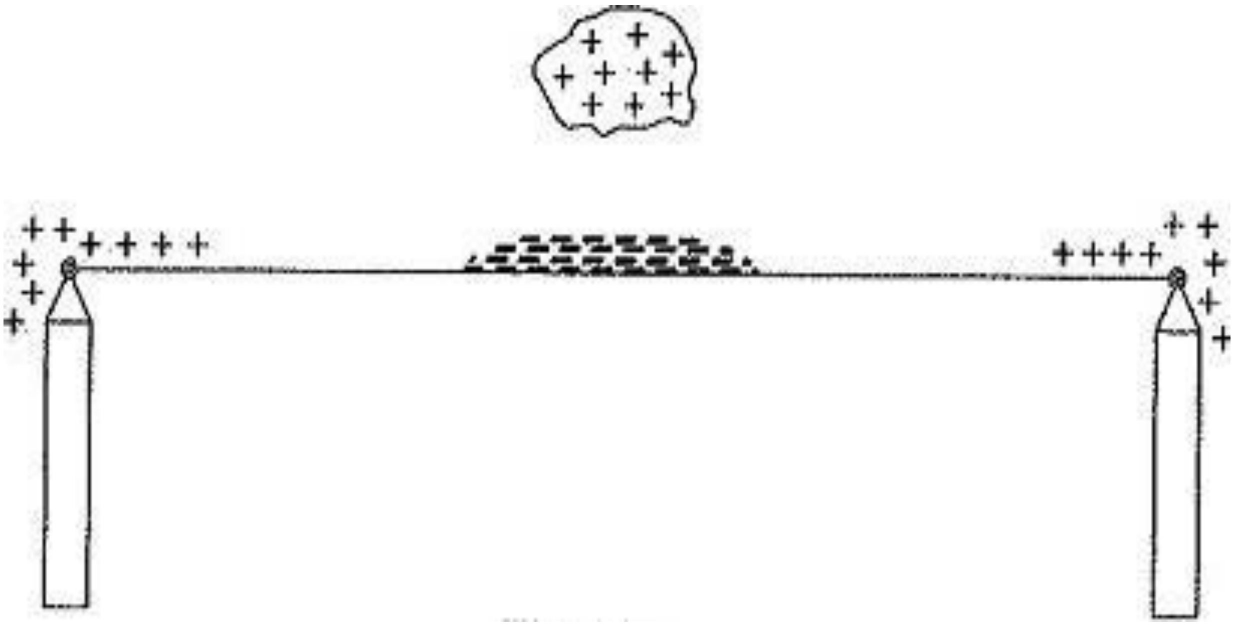
- Directstroke
- Indirectstroke

Direct stroke:



- Inthedirectstroke,thelightningdischarge(i.ecurrentpath)isdirectlyfromthecloudtothe subject equipment e.g an over head lines.
- DirectstrokesaretwostrokeAandstrokeBwhichare showninfigabove.
- Directstrokesareveryrare.
- StrokeAwillalwaysoccursontallobjectsandhenceprotectioncanbeprovidedagainstit.
- StrokeBcompletelyignorestheheightoftheobjectandcan evenstriketheground andhence protection against stroke B cannot be provided.

Indirectstroke:



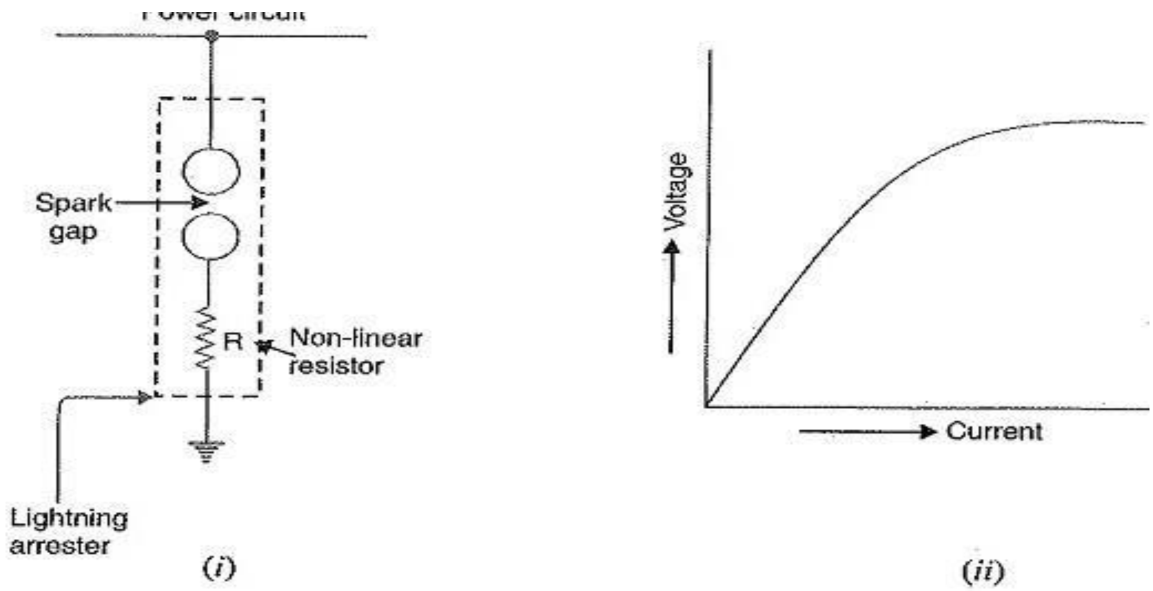
- Intheindirectstrokethe lightningdischarge(i.ecurrentpath)isnotdirectlyfromthe cloud the subject equipment.
- Theindirectstrokeisshowninfigabove.
- Themajorityofsurgesinatransmissionlinearecausedbyindirectlightningstrokes,which moves as travelling waves in the powe lines.

Harmfuleffectsoflightning:

- Crackstheinsulatorsandpoles.
- Damagethewindingsoftransformersandgenerators.
- Theinsulationpropotiesofoildecreasesinthepower equipment,resultingintheproductionof arc.
- Theproductionofthearcwillset-upverydisturbingoscillationsintheline.

Lightning arresters:Alightningarresterorasurgediverterisaprotectivedevicewhichconductsthehigh voltage surge on the power system to the ground.

Circuitdiagram:



- Abovefigureshowsthebasicformofasurgediverter.
- Itconsistsofasparkgapinserieswithanon-linearresistor.
- Oneendof thediverterisconnectedtothe terminaloftheequipmenttobeprotectedandthe other end is effectively grounded.
- Thelengthofthegapisso setthatnormallinevoltageisnotenoughto causean arc acrossthe gap but a dangeriously high voltage will break down the air insulation and form an arc.

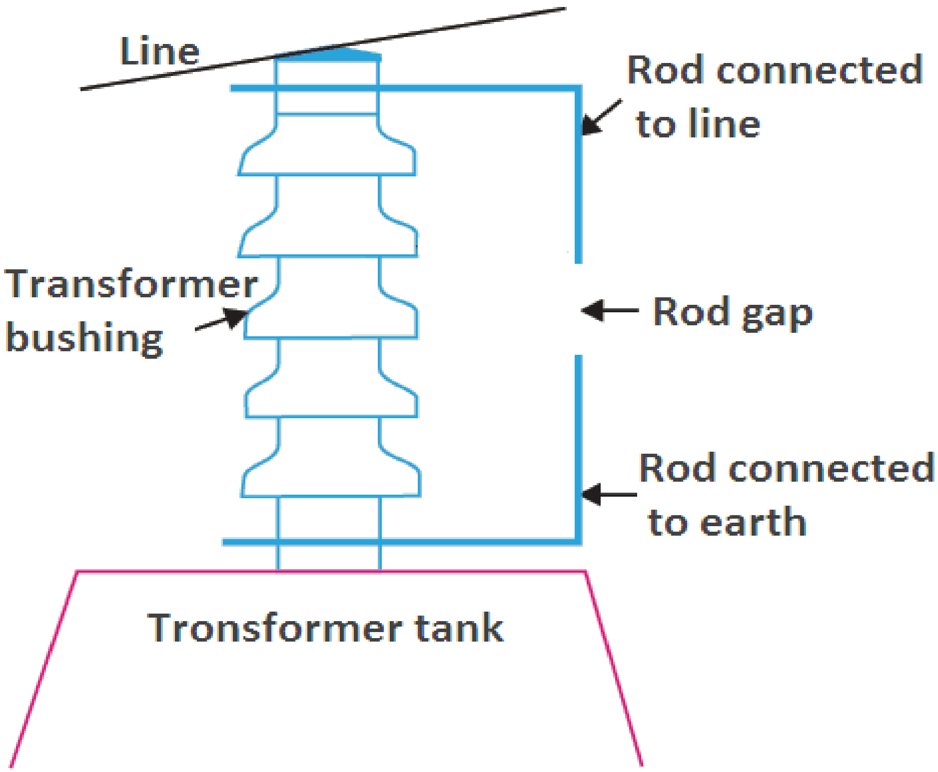
Operation:

- Undernormaloperation,thelightningarresterisoffthelinei.eitconductno currenttoearth or the gap is non-conducting.
- Onthe occurrenceofovervoltage,theairinsulationacrossthegapbreaksdown andanarcis formed ,providing a low resistance path for the surge to the ground.
- Inthisway,theexcess chargeon thelineduetothesurgeisharmlesslyconductedthrough the arrester to the ground instead of being sent back over the line.

Typesoflightningarresters:Thesearethefollowingtypesoflightningarresters:

- Rod-gaplightningarrester.
- Horn-gaparrester.
- Valvetypearrester.

Rod-gap lightning arrester:



Construction:

- Itconsistsoftwo1.5cmrodswhicharebentatrightangleswithagapinbetweentwo.
- Onerodoflightningarresterisconnectedtothelinecircuit.
- Otherrodisconnectedtoearth.
- Thedistancebetweengapandinsulator(i.edistanceP)mustnotbelessthanone thirdof the gap length.

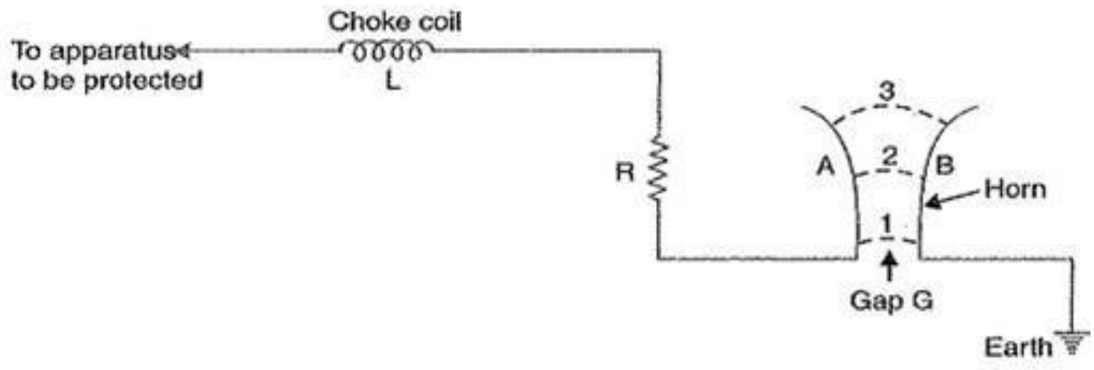
Operation:

- Undernormaloperatingconditions,thegapremainsnon-conducting.
- Onthe occurrenceofa highvoltagesurgeonthelineduetothesurgeisharmlesslyconducted to earth.

Limitations:

- Afterthesurgeisover,thearcinthegapismaintainedbythenormalsupplyvoltageleadingtoa short circuit on the system.
- Therodmaymeltorgetdamagedduetoexcessiveheatproducedbythe arc.
- Theclimaticconditions(e.grain,humidity,temperatureetc.)affecttheperformanceofrodgap arrester.
- Thepolarityofthesurgealsoaffectstheperformanceofthisarrester.

Horngaplightning arrester:



Construction:

- ItconsistsoftwohornshapedmetalrodsAandBseparatedbyasmall airgap.
- Thehornsaresoconstructed thatdistancebetweenthengraduallyincreasestowardsthetopas shown.
- Thehornsaremountedonporcelaininsulators.
- Oneendofhornisconnected tothelinethrougharesistanceRandchokeLwhiletheotherend is effectively grounded.

Operation:

- Undernormalconditions,thegapisnon-conductingi.enormalsupplyvoltageisinsufficientto initiate the arc between the gap.
- Ontheoccurrenceofanovervoltage,spark-overtakesplaceacrossthesmallgapG.
- Theheatedairaroundthearcandthemagneticeffectofthearccausethearctotravelupgap.
- Thearcmovesprogressivelyintopositions1,2and3 atsomepositionofthearc(perhaps position 3) the distance may be too great for the voltage to maintain the arc.
- Finallythearcisextinguished.
- Theexcesschargeonthe lineisthusconducted throughthearrestertotheground.

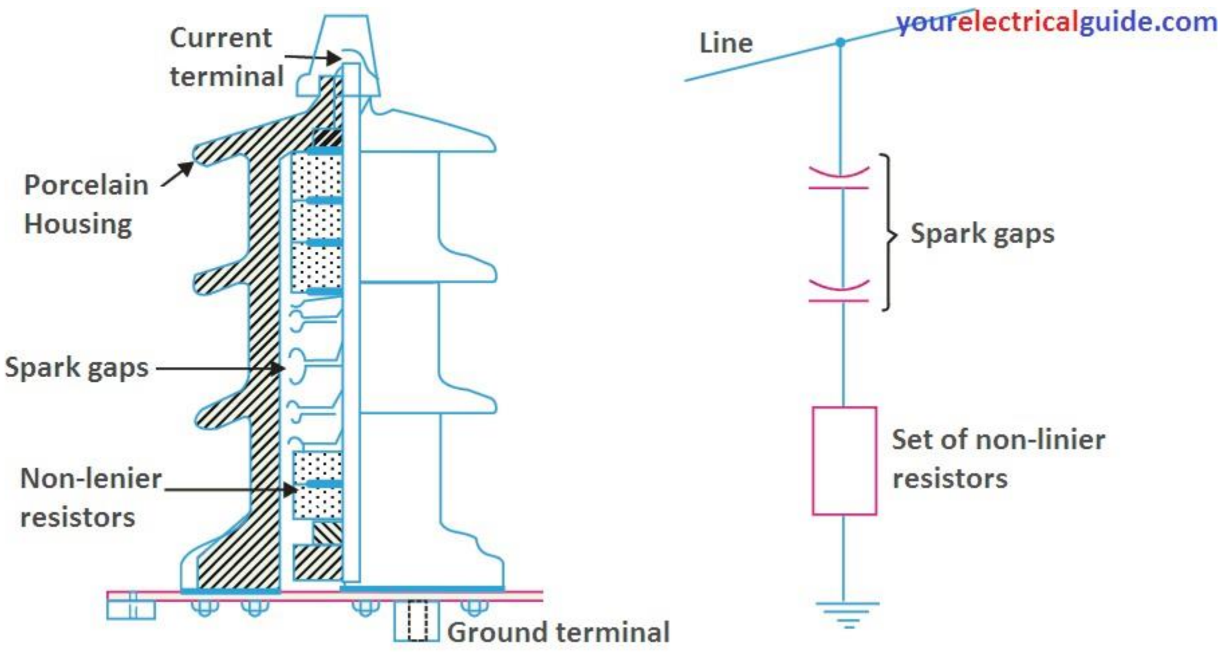
Advantages:

- Thearcisselfclearing.Thereforethistypeofarresterdoesnotcauseshort-circuitingofthe system after the surge is over as in the case of horn-gap.
- Seriesresistancehelpsinlimitingthefollowcurrenttoasmallvalue.

Limitations:

- Thebridgingofgapbysomeexternalagency(e.gbirds) canrenderthedeviceuseless.
- Thesettingofhorn-gaplikelytochangeduetocorrosionorpitting.Thisadverselyaffectsthe performance of the arrester.
- Thetimeofoperationiscomparativelylongsay about3seconds.

ValveTypeArrester:



Valve type arrester

Equivalent Circuit

Construction:

- Itconsistsof twoassembles(i)seriessparkgapsand(ii)non-linearresistordiscs(madeof material such as thyrite or metrosil) in series.
- Thenon-linearelementsareconnectedinserieswiththesparkgaps.
- Boththeaboveassemblesareaccommodatedintightporcelaincontainer.

Working:

- Undernormalconditionsthesystemvoltagesisinsufficienttocausethe breakdownofairgap assembly.
- Onthe occurrenceofanovervoltagethebreakdown ofseriessparkgaptakesplaceandthe surge current is conducted to earth through the non-linear resistors.
- Sincethemagnitudeofsurgecurrentisverylarge,the non-linearelementswillofferaverylow resistance to the passage of surge.
- Theresultisthatthesurgewillrapidlygotoearthinsteadofbeingsentbackover theline.

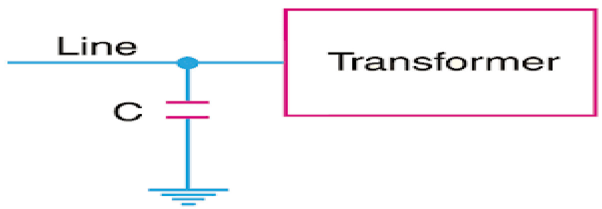
Advantages:

- Theyprovideveryeffectiveprotectionagainstsurges.
- Theyoperateveryrapidlytakinglessthanasecond.
- Theimpulsiveratioispracticallyunity.

Limitations:

- Theymayfailtocheckthesurgesofverysteepwavefrontfromreachingtheterminal apparatus.This calls for additional steps to check steep-fronted waves.
- Theirperformanceisadverselyaffectedbytheentryofmoistureintotheenclosure.This necessitates effective sealing of enclosure at all times.

Surgeabsorber:



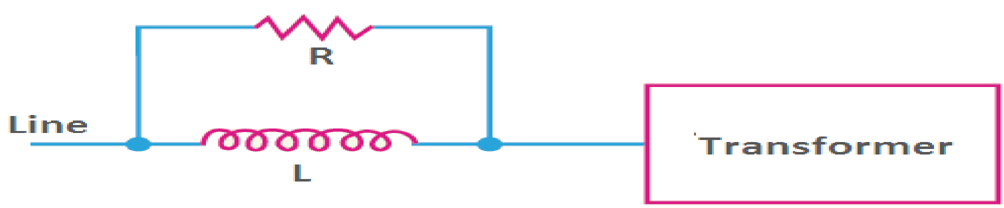
Asurgeabsorberisaprotectivedevicewhichreduces thesteepnessofwavefront ofasurgeby absorbing surge energy.

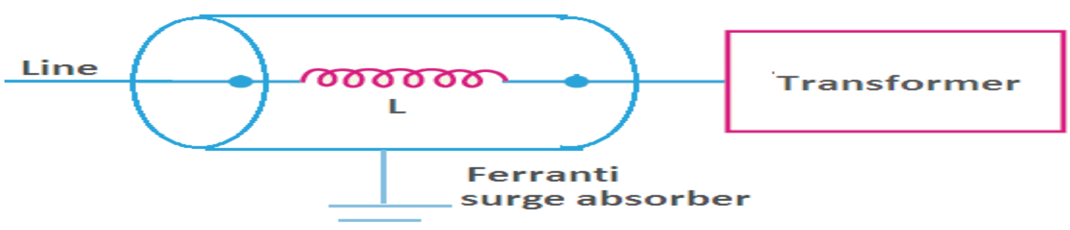
Thesurgediverterdivertsthesurgetoearthbutthesurgeabsorberabsorbsthesurgeenergy. A few

cases of surge absorption are discussed below :

As shown in above diagram a condenser is connected across the line and earth can acts as a surge absorber .Since the reactance of a condenser is inversely proportional to frequency , it will be low at highfrequencyandhighatlowfrequency.Sincethesurgesareofhighfrequency,the capacitorsactsas a short circuit and passes them directly to earth.However for power frequency , the reactance of the capacitor is very high and practically no current flow to the ground.

- Anothertypeofsurgeabsorberdiagramshowninfig below:





STATICRELAY:

Definitionofstaticrelay:Arelayusingcombinationofbothstaticandelectromagneticunitsisalsocalled as static relay.

Advantagesofstaticrelay:

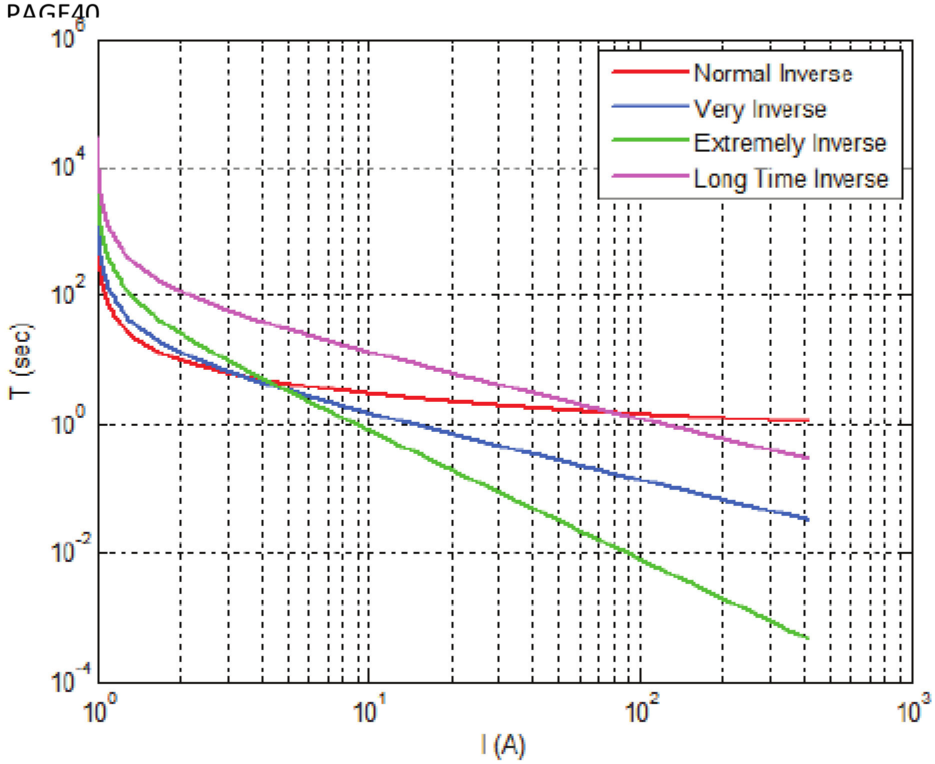
- Lowpowerconsumption.
- Quickresponse.
- Longlife.
- Shockproof.
- Fewerproblemsofmaintenance.
- Highreliabilityandahighdegreeofaccuracy.
- Astaticrelaycanperformseveralfunctionssuchasprotections,monitoring,data acquisition,measurement,memory indication,data communication etc.
- Staticrelayscanbedesignedforrepeatedoperations.
- Theriskofunwantedtrippingislesswithstaticrelays.
- Staticrelaysarevery compact.
- Thecharacteristicsofstaticrelaysareaccurateandsuperior.

Instantaneous overcurrent relay:

- Thereisnotimedifferencebetweentheoccurrenceoffaultandtheoperationsoftherelay.
- Therelayoperateswhenthecurrentintherelaycoilexceedsthepick-upvalue.
- Theoperatingtimeofthistypeofrelayislessthan0.1 sec
- Aninstantaneousovercurrentrelayisoneinwhichnointentionaltimedelayisprovidedfor operation.
- Insucharelaytherelaycontacts closeimmediatelyafterthecurrentintherelaycoilexceedsfor which it is set.
- Althoughtherewillbeashorttimeintervalbetweentheinstantofpick-up and theclosingofthe relay contacts,no intentional time delay is provided.

PrincipleofIDMTrelay:

- Inversedefiniteminimumtimerelays.
- Such a relay is one in which operating time is approximately inversely proportional to fault currentnearpick-up valueandbecomessubstantiallyconstantslightlyabovethepick-upvalue of the relay as shown in below figure.
- Thisisachivedbyusingacoreofthe electromagnetwhichgetssaturatedfor currents thanthe pick-up currents.


Normal Inverse
Very Inverse
Extremely Inverse
Long Time Inverse
T (sec)
I (A)
10^6
10^4
10^2
10^0
10^-2
10^-4
10^0
10^1
10^2
10^3

CHAPTER-1

SHORT QUESTIONS WITH ANSWERS :

1 .Whataretheessentialfeaturesofswitchgear?

2 ANS:Theessentialfeaturesofswitchgearare

- completereliability
- absolutecertaindiscrimination
- quickoperation
- provisionformanualcontrol
- provisionforinstrument

3 Inwhichvoltagebus-baroperates?

ANS:Bus-baroperatesatconstantandvariablevoltage.

4 Whichtypeoffaultinpowersystemismostfrequent.

- ANS:Themostcommontypeoffaultinpowersystemissinglelinetogroundfault.

5 Whatarethedifferenttypeofbusbararrangementinpowersystem? ANS:

The different bus-bar arrangements are

- singlebus-bararrangement
- singlebusbarwithsectionalisation
- duplicatebus-barsystem

LONGQUESTIONS:

Stateessentialfeaturesofswitchgear.

Explainaboutswitchgearaccommodation.

Explainaboutvarioustypesofbus-bararrangements.

CHAPTER-2

SHORTQUESTIONSWITHANSWERS:

1. Whatissymmetricalfault?

ANS:Thatfaultonthe powersystemwhichgivesrisetosymmetricalfaultcurrents(i.eequalfault currents in the lines with 120^0displacement) is called a symmetrical fault.

2. Definepercentagereactance.[2010(s),2012(s),2018(w),2019(s)]

ANS:Itisthepercentageofthe totalphase-voltagedroppedinthecircuitwhenfullloadcurrentis flowing.

3. Defineshortcircuitkva.[2015(s),2018(w)]

ANS:Theproductof normalsystemvoltageandshortcircuitcurrentatthepointoffaultexpressedin KVA is known as short circuit KVA.

4. Whatisreactor?

ANS:Theadditionalreactance(a coilofnumberofturnsdesignedtohavealargeinductance)as compared to its ohmic resistance is known as reactor .

5. Writethefunctionofreactor.

ANS:

- Reactorslimittheflowofshortcircuitcurrent.
- Reactorspermittheinstallationofcircuitbreakersoflowerrating.
- Reactorsareconnectedinserieswiththesystem.

LONGQUESTIONS:

Withneatsketchexplainaboutfeederreactors

Whatarethetypesofreactorsusedinsubstationas perlocation?Explainrelativeadvantages.

Explaindifferenttypesofreactors.

CHAPTER-3

SHORT QUESTIONS WITHANSWERS:

1. Writedifferencebetweenfuseandcircuitbreaker?

ANS:Fuse:Itisthevoltagethatappearsacrossthe cotactsof thecircuitbreaker duringthearcing period.

Circuitbreaker:Acircuitbreakerisapieceofequipmentwhichcan makeorbreakacircuiteither manually or by remote control under normal condition ,break a circuit automatically under fault conditions ,make a circuit either manually or by remote control under fault condition.

2. Definefusingfactor .
ANS:Itistheratioofminimumfusingcurrenttothecurrentratingofthe fuseelement.

$$\text{Fusingfactor} = \frac{\text{minimumfusingcurrent}}{\text{currentratingoffuse}}$$

3. Whatarethecommonmaterialsusedforfuseelement ?

ANS:Thecommonmaterialsusedforfuseelementsarelead,tin,copper,zincandsilver.

LONGQUESTIONS:

1. WithneatsketchexplainaboutHRCtypeoffuse
2. Writeshortnotesondifferencebetweenafuseandcircuitbreaker 3

.Define prospective current and cut-off current

4. ExplainHRCfusewithtrippingdevice

5. Drawwavediagramofcurrentandexplainbrieflycut-offcurrent,pre-arcingtime,arcing time

CHAPTER-4

Shortquestionswithanswer:

Q-1Whatiscircuitbreaker?

ANS:Acircuitbreakerisapieceofequipmentwhichcanmakeorbreakacircuiteithermanuallyorby remote control under normal condition ,break a circuit automatically under fault conditions ,make a circuit either manually or by remote control under fault condition

Namethequenchingmediumusedincircuitbreaker
ANS:Quenchingmediumusedincircuitbreakerare transformer,air,vaccum,SF_6 . Q-3

Why AC circuit is more easily interrupted than DC circuit

ANS:ACcircuitismoreeasilyinterruptedthanDCcircuitbecauseinanACsystemcurrentdrops to zero after every half cycle.

Definerestrickingvoltage.

ANS:Itisthetransientvoltagethatappearsacrosscontactsat ornearcurrentzeroduringarcingperiod. Q-5

What is short time rating of circuit breaker ?

ANS:Itistheperiodforwhich thecircuitbreakerisabletocarryfaultcurrentwhile remainingclosed. Q-6

Define recovery voltage ?

ANS:Itisthenormalfrequency(50Hz) rmsvoltagethatappearsacross thecontactsof thecircuit breaker after final arc extinction ,It is approximately equal to the system voltage.

Q7Whatisarcvoltage?
ANS:Itisthevoltagethatappearsacrossthecotactsofthecircuitbreakerduringthearcingperiod.

LONGQUESTIONS:

Explainthephenomenonofarcformation.

Explainplainbreakoilcircuit-breaker.

Withneatsketchexpaincostructionandoperatingdetailsof VCB.
Discusstheconstructionaldetailsandoperation ofatypicallowoilcircuitbreaker? Q-5
Explain low resistance method of Arc extinction ?
WriteshortnotesonSF₆circuitbreaker.
Withneatsketchexplainaboutrestrickingandrecoveryvoltage.

Explainhighresistancemethodof Arc extinction . Q-9

Explain rating of circuit breaker .

Q-10Discussthearcphenomenonandvariousmethodsofarcextinctioninacircuitbreaker.

CHAPTER-5

Shortquestionswithanswer:

DefinePSM.

ANS:Itistheratiooffaultcurrentinrelaycoilto thepick-upcurrent. PSM

$$=\frac{\text{Fault current in relay coil}}{\text{Pick-upcurrent}}$$

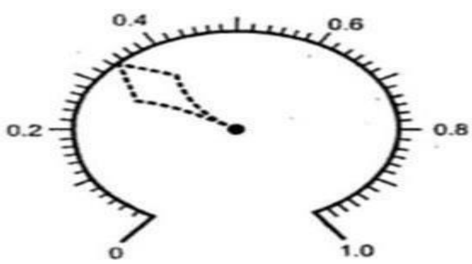
$$=\frac{\text{Faultcurrentinrelaycoil}}{\text{Ratedsecondary currentof CT} \times \text{currentsetting}}$$

Q-2Whatispick-upcurrent?[2015(S),2018(S),2019(S)]

ANS:Itistheminimumcurrentintherelaycoilatwhichtherelaystarts tooperate . Q-3

Define TSM .[2018(S)]

ANS:Theadjustmentofcontroloftimeoperationintherelayisknownastimesettingmultiplier.



Longquestions:

Q-1Explaincurrentdifferentialrelay.

Explainbasicoperationofinductionrelay.

Explainessentialqualityofgoodprotectiverelay.

Writeshortnoteonelectromagneticattractionrelay.

Describetheconstructionandprincipleofaninductiontypedirectionalovercurrentrelay.

CHAPTER-6

SHORTQUESTIONSWITHANSWERSANDLONGQUESTIONSWITHHINTS:

Whatisdifferentialprotection?

ANS:Thedifferentialprotectionisthatwhichrespondstothephasordifferencebetweentwo ormore electrical quantites.

WhichtypeofrelaysareusedinMerz-priceprotection systemforalternator?

ANS:TherelaysusedinMerz-priceprotectionsystem ofalternatorareinstantaneous electromagnetic type .
InwhichtypeoftransformerBuchholzrelaysareused?

ANS:Buchholzrelayareusedonoilimmersedpowertransformerspfratingabove750kva. Q-4

Buchholz relay is a -------

ANS:Buchholzrelayisagasactuatedrelay.

WritedownthepositionofBuchholzrelay?

ANS:Buchholzrelayisconnectedinthe pipeconnectingmaintankoftransformerand conservator. Q-6 A

transmission line is protected by ….

ANS:Atransmissionlineisprotectedbydistanceprotectionandinrushcurrentprotection. LONG

QUESTIONS:

Writeshortnotesondifferentialprotectionofalternator.

Q-2 Explain about protection scheme of power

system ?

Explainearth-faultprotectionfortransformer.

ExplainwithneatdiagramtheworkingofaBuchholzrelay.

CHAPTER-7

Shortquestionswithanswerandlongquestionswithhints: What is

lightning arrester ?

ANS:Alightningarresterorasurgediverterisaprotectivedevicewhichconducts thehighvoltagesurge on the power system to the ground.

Definevoltagesurge.

ANS:Asuddenriseinvoltagefora veryshortduration onthepowersystemisknownasa voltagesurge or transient voltage.

Whatissurgeabsorber?

ANS:Asurgeabsorberisaprotectivedevicewhichreducesthesteepnessof wavefrontof asurgeby absorbing surge energy.

Whatisarcingground?

ANS:Thephenomenonofintermittentarctakingplaceinlinetogroundfaultof a3-ϕsystemwith consequent production of transients is known as arcing ground.

Stateharmfuleffectoflightning?

ANS:

- Crackstheinsulatorsandpoles.
- Damagethewindingsoftransformersandgenerators.
- Theinsulationpropotiesofoildecreasesinthepower equipment,resultingintheproductionof arc.
- Theproductionofthearcwillset-upverydisturbingoscillationsintheline.

Whatarethecausesofovervoltage? ANS:

Internal causes:

- Switchingsurges.
- Insulationfailure.
- Arcing ground.
- Resonance.

Externalcauses

i.e lightning

Longquestions:

Q-1WhatisHorn-gaplightningarrester?Explainhowitworks. Q-2

Explain valve type arrester .

ExplainsurgeAbsorber.

Explainharmfuleffectsoflightning.

WriteshortnotesonRod-Gaplightningarrester.

Whatislightning?Describemechanisimoflightningdischarge.

CHAPTER -8

Shortquestionswithanswer:

Whatisstaticrelay?

ANS:Arelayusingcombinationofbothstaticand electromagneticunitsisalsocalledasstatic relay. Q-2

Write advantages of static relays.

ANS:Longlife,efficiencyhigh,lowpowerloss,quickresponse,ithasshockproof. Long

questions:

Writeshortnotes onIDMTrelay.

Writeadvantagesofstaticrelays.