SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
(Approved by AICTE, New Delhi & Affiliated to Pondicherry University)
(Accredited by NBA-AICTE, New Delhi, ISO 9001:2000 Certified Institution & Accredited by NAAC with "A" Grade)
Madagadipet, Puducherry - 605 107

**DEPARTMENT OF MECHANICAL ENGINEERING**

**Subject Name:** Electrical and Electronics Engineering **SubjectCode:**MET35

**Prepared by:**

Dr.K.Suresh, Professor / EEE
Mr.B.Parthiban, Assistant Professor / EEE
Mr.R.Ragupathy, Assistant Professor/ EEE

**Verified by:** **Approved by:**

## 3. ALTERNATOR

*Alternators - construction - Operating principle - alternators on No load – Alternators on Load - Phasor diagram - Losses – Efficiency-voltage regulation by EMF method – Parallel operation of alternators*

## Part- A (2 Marks)

1. **Write down the equation for frequency of emf induced in an alternator** (NOV/2014)

   Frequency of emf induced in an Alternator,f,expressed in cycles per second or Hz, is given by the following equation

   F = (PN) / 120 Hz,

   Where P- Number of poles

   N-Speed in rpm

2. **Name the types of alternator based on their rotor construction**(NOV/2014)

   Based on the alternator rotor construction
   - Salient pole (or) Projected pole type
   - Non- salient Pole (or) Smooth Cylindrical type

3. **Calculate the synchronous speed of a four pole 50Hz alternator.**(APRIL/2014)

$$N_s = \frac{120\,f}{P}$$

$$N_s = \frac{120 * 50}{4}$$

$$\mathbf{N_s = 1500\,rpm}$$

4. **Write the emf equation of an alternator.**( APRIL/2014)

$$\mathbf{E_{ph} = 4.44 K_C K_d f \Phi T_{ph}}\text{volts}$$

   Where ,$K_c$ =Pitch factor

   $K_d$ = Distribution factor

5. **Differentiate salient pole rotor and smooth cylindrical type rotor of an alternator**(NOV/2013)(APRIL/2012)

| Salient Pole Rotor | Cylindrical Rotor |
|---|---|
| Large diameter and short axial length | Small diameter and long axial length |
| Used for low speed alternators | Used for high - speed turbo-alternators |
| Has projecting poles | No projecting poles |
| Needs damper windings | Does not need damper windings |
| Windage loss is more | Windage loss is less |

6. **List the various losses in an alternator**(NOV/2013)(or) **What are the losses in an alternator?**(NOV/2012)

The various losses occur in an alternators are

- Iron loss
  - Hysteresis loss
  - Eddy current loss
- Mechanical loss
  - Frictional loss
  - Windage loss
- Copper loss (or) Variable Loss

(Iron loss and Mechanical loss: Constant losses)

7. **Define voltage regulation.**(APRIL/2013)(or)**Define voltage regulation of an alternator.**(APRIL/2012)

Thevoltageregulationofanalternatorisdefinedasthechangeinitsterminalvoltagewhenfull load is removed, keeping field excitation and speed constant, divided bytherated terminal voltage.

So if $V_{ph}$=Rated terminal voltage

$E_{ph}$=No load induced e.m.f.

Thevoltageregulationis defined as,

$$Regulation\ \% = \frac{Eph - Vph}{Vph} X\ 100$$

8. **What is meant by synchronous reactance?** (NOV/2012)

It is the sum of the leakage reactance X1 and armature reactance Xa.

$$X_s = X_1 + X_a$$

9. **Why emf method called Pessimistic method?**

The value of voltage regulation obtained by EMF method is always more than the actual value; therefore it is called Pessimistic method

10. **Why are Alternators rated in kVA and not in kW?**

The continuous power rating of any machine is generally defined as the power the machine or apparatus can deliver for a continuous period so that the losses incurred in the machine gives rise to a steady temperature rise not exceeding the limit prescribed by the insulation class.Apart from the constant loss incurred in Alternators is the copper loss, occurring in the three phase winding which depends on $I^2R$, the square of the current delivered by the generator. As the current is directly related to apparent – power delivered by the generator, the Alternators have only their apparent power in VA/kVA/MVA as their power rating.

11. **What is the necessity for predetermination of voltage regulation?**

Most of the alternators are manufactured with large power rating and large voltage ratings. Conduction load test is not possible for such alternators. Hence other indirect methods of testing are used and the performance can be predetermined at any desired load currents and power factors.

**12. What are the main parts of Alternator?**

- Stator core
- Salient or non salient rotor field winding
- Rotor shaft
- Bearings
- Internal cooling Fan etc.

**13. Write down conditions for parallel operation of two Alternators?**

Both the Alternator should have same

- Voltage
- Frequency
- Phase sequence of three phase supply

**Part –B (11 Marks)**

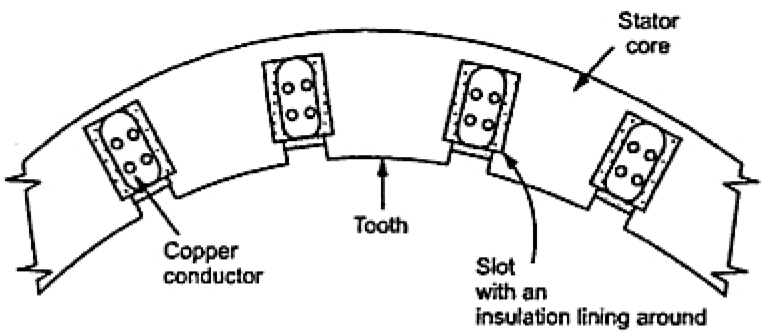
**1. Write in details about the construction and working of an alternator?**

*Constructionof SynchronousGenerator*

Mostofthealternatorspreferrotating fieldtypeoftheconstruction.Incaseofalternatorsthe windingterminology isslightly differentthanincaseofDC generators.Inalternatorsthestationary windingis called'Stator' while therotating windingis called'Rotor'.

*Stator*

Thestatorisastationary armature.Thisconsistsofacoreandtheslotstoholdthearmature winding similartothe armatureofaDCgenerator.Thestatorcore usesa laminatedconstruction.Itis builtupofspecialsteel stampingsinsulatedfromeachotherwithvarnishorpaper.Thelaminated constructionisbasicallytokeepdowneddycurrentlosses.Generallychoiceofmaterialissteelto keep down hysteresislosses.




***Section ofanalternatorstator***

Theentire coreisfabricatedina framemadeofsteelplates.Thecorehasslotsonitsperiphery for housingthearmatureconductors.Framedoesnotcarryany fluxandservesasthesupporttothecore. Ventilation is maintainedwith thehelpof holes cast in the frame. Thesection of analternators statoris shown in the above figure.

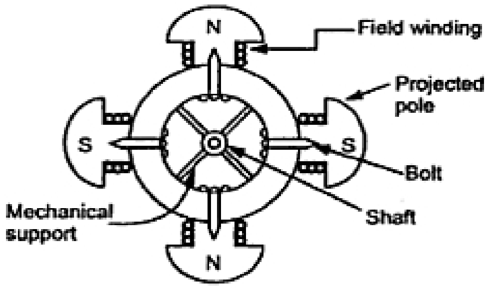
*Rotor:*

There aretwo typesof rotors used in alternators,

- Salient pole type
- Smooth cylindrical type.

*Salient Pole Type*

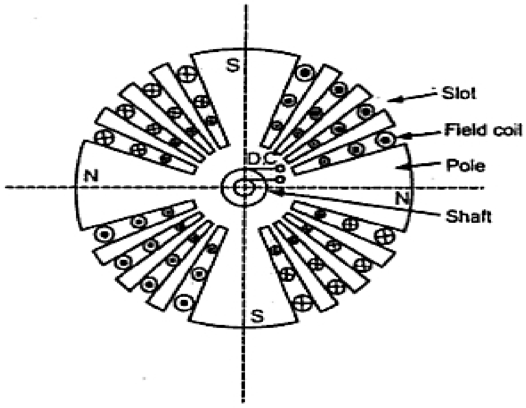
Thisisalsocalledprojectedpoletypeasallthepolesare projectedoutfromthesurfaceofthe rotor. The polesare builtupof thicksteellaminations.The polesare boltedtothe rotorasshown inthe Figure.The pole face hasbeengivena specificshape.Thefieldwindingisprovidedonthepoleshoe. These rotorshave large diameterandsmallaxiallength.The limitingfactor for thesize of therotor is thecentrifugalforceacting ontherotating memberofthemachine.As mechanicalstrengthof salient poletypeisless,thisispreferredforlowspeedalternatorsranging from125r.p.m.to500r.p.m.The primemovers used to drivesuch rotorare generallywaterturbinesandI.C.engines.




*Salient poletyperotor*

*Smooth Cylindrical Type*

Thisisalsocallednon-salienttypeornon-projectedpoletypeorroundrotorconstruction.The below figure shows smooth cylindrical typeof rotor.




***Smooth cylindrical rotor***

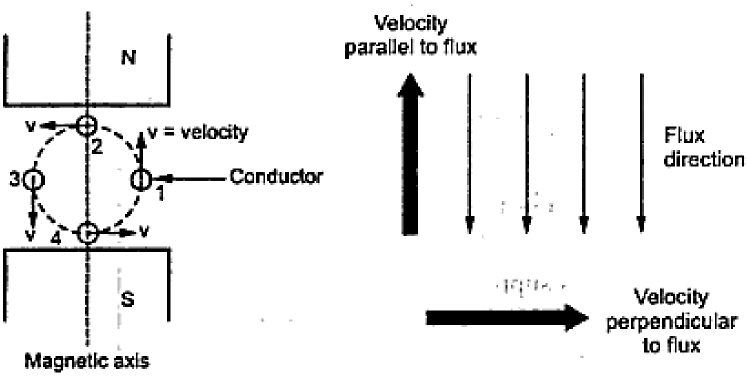
Therotorconsistsofsmallsolidsteelcylinder,having numberofslotstoaccommodatethefield coil.Theslotsarecoveredatthetopwiththehelpofsteelormanganesewedges.Theunslotted portionsofthe cylinderitselfactasthepoles.Thepolesarenotprojecting outandthesurfaceofthe rotor issmoothwhichmaintainsuniformairgapbetweenstator andtherotor.These rotorshave small diametersandlargeaxiallengths.Thisistokeepperipheralspeedwithinlimits.Themainadvantage ofthistypeisthatthesearemechanically very strongandthuspreferredforhighspeedalternators rangingbetween 1500 to 3000 r.p.m. Such highspeed alternatorsarecalled'turbo alternators'.The primemovers used to drivesuch typeofrotors aregenerallysteam turbines, electricmotors.

*WorkingPrinciple of SynchronousGenerator*

Thealternatorsworkontheprincipleofelectromagneticinduction.Whenthereisarelative motionbetweentheconductorsandtheflux,e.m.f.getsinducedintheconductors.The DCgenerators alsoworkonthesameprinciple.Theonly differenceinpracticalalternatorandaDCgeneratoristhat inanalternatortheconductorsarestationaryandfieldisrotating.Butforunderstandingpurposewe canalwaysconsiderrelativemotionofconductorswithrespecttothefluxproducedby thefield winding.

Considerarelativemotionofasingleconductorunderthemagneticfieldproducedby two stationarypoles.Themagneticaxisofthetwopolesproducedby fieldisvertical,showndottedinthe below Figure.

Letconductorstartsrotatingfromposition1.Atthisinstant,theentirevelocity componentis paralleltothefluxlines.Hencethereisnocuttingoffluxlinesby theconductor.SodΦ/dtatthis instant is zero and henceinduced e.m.f. in the conductor is also zero.




***Two pole alternator***

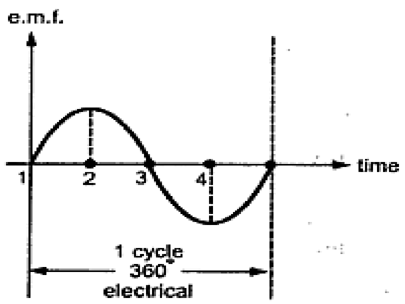
Astheconductormovesfromposition1towardsposition 2,thepartofthevelocity component becomes perpendicular tothe fluxlinesand proportionaltothat, e.m.f. getsinduced inthe conductor.Themagnitudeofsuchaninducede.m.f.increasesastheconductormovesfromposition 1 towards 2.

Atposition2,theentirevelocity component isperpendiculartothefluxlines.Hencethereexists maximum cutting ofthefluxlines.Andatthisinstant,theinducede.m.f.intheconductorisatits maximum.

Asthepositionofconductorchangesfrom2towards3,thevelocity componentperpendicularto the fluxstartsdecreasingandhence inducede.m.f.magnitudealsostartsdecreasing.Atposition3, againtheentirevelocitycomponentisparalleltothefluxlinesandhence atthisinstantinducede.m.f. in the conductor is zero.

Astheconductormovesfrom3towards4,thevelocity componentperpendiculartothefluxlines againstartsincreasing.Butthe directionof velocitycomponentnow isopposite tothe directionof velocity componentexistingduringthemovementoftheconductorfromposition1to2.Hencean induced e.m.f. in the conductor increases but in theopposite direction.

Atposition4,itachievesmaximainthe oppositedirection,astheentirevelocity component becomes perpendicular to thefluxlines.Againfrom position4 to 1, induced e.m.f.decreasedandfinallyatposition 1, again becomeszero. This cycle continues asconductor rotates atacertain speed. Soifweplot themagnitudesoftheinducede.m.f.againstthetime,wegetanalternating natureof the induced e.m.f.as shown in the Fig.This is the workingprincipleof an alternator




***Alternating natureofthe inducede.m.f***

**2. Explain about the winging terminology used in alternator and brief its types**

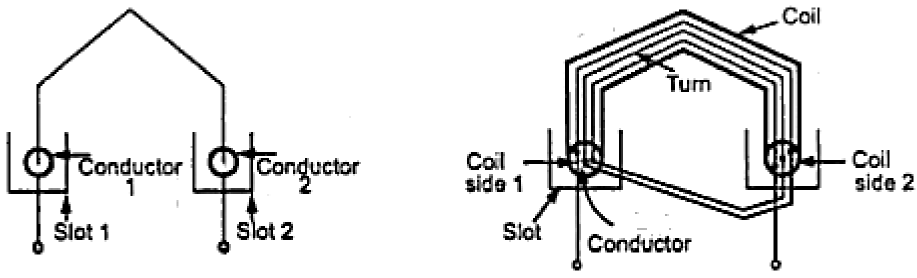
*Armature Windingof SynchronousGenerator*

Armaturewindingofalternatorsisdifferentfromthatof DCmachines.Basically threephase alternatorscarry threesetsofwindingsarrangedintheslotsinsuchawaythatthereexistsaphase differenceof120$^0$betweentheinducede.m.f.inthem.InaDCmachine,winding isbroughtout.In threephasealternators winding isopeni.e.twoendsofeachofsetofwinding isbroughtout.Inthree phase alternators, thesixterminals arebrought outwhich are finallyconnected in star ordeltaand then thethreeterminalsare broughtout.Eachsetofwindingsrepresentswinding perphaseandinduced e.m.f.ineachsetiscalledinducede.m.f.perphasedenotedas$E_{ph}$.Allthe coilsusedfor one phase mustbeconnectedinsuchaway thattheire.m.fhelpseachother.Andoveralldesignshouldbein such awaythat thewaveform of an induced e.m.f.is almost sinusoidal in nature.

*Winding Terminology*

**1)Conductor:**The partof thewire,whichisunder theinfluence of themagnetic fieldand responsible fortheinducede.m.f.iscalledactivelengthoftheconductor.Theconductors are placedinthe armatureslots.

**2) Turn:** A conductorinone slot,whenconnectedtoaconductorinanother slotformsa turn. Sotwo conductors constitute aturn. This is shown in the Fig. (a).



(a)Turn (b)Multiturn coil

**3)Coil:**Astherearenumberofturns,forsimplicitythenumberofturnsaregroupedtogethertoform acoil.Suchacoiliscalledmultiturncoil.Acoilmayconsistofsingleturncoil.TheFig.(b)shows amultiturncoil.

**4)Coilside:**Coilconsistsofmany turns.Partofthecoilineachslotiscalledcoilsideofacoilas shown in the Fig. (b).

**5) PolePitch:**Itiscentretocentre distance betweenthetwoadjacentpoles. We have seenthatfor one rotationoftheconductors,2polesare responsiblefor $360^0$electricalofe.m.f.,4polesare responsible for$720^0$electrical of e.m.f. and so on. So 1 pole is responsible for $180^0$electrical of induced e.m.f. So $180^0$electricalis also called onepole pitch. Practicallyhowmanyslotsare underonepolewhicharereresponsiblefor$180^0$electrical,are measured to specifythe pole pitch.e.g.Consider2pole,18slotsarmatureofanalternator.Thenunder1polethere are 18/2i.e.9 slots.Sopolepitchis9slotsor$180^0$electrical.Thismeans9slotsare responsibletoproduceaphase differenceof 180between the e.m.f. induced in differentconductors.

This number ofslots/poles isdenoted as'n'.

**Pole pitch = $180^0$ electrical**
**= slots per pole (no. of slots/P) =n**

**6) Slotangle(β):**Thephasedifferencecontributed byoneslotindegreeselectricaliscalledslotangle β.

As slots per pole contributes $180^O$electrical which is denoted as'n', wecan write,

1 slot angle =$180^O$/n

$$\beta = \frac{180^0}{n}$$

In the aboveexample, n =18/2 = 9, while β =$180^O$/n =$20^O$

*Typesof ArmatureWindings:*

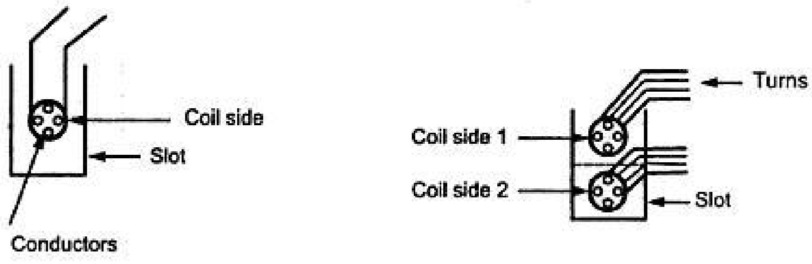
Ingeneral armaturewindingis classifiedas,

- Single layer and doublelayer winding.
- Fullpitch and short pitchwinding.

- Concentratedand distributed winding.

*1. Single LayerandDouble LayerWinding*

Ifaslotconsistsofonly onecoilside,winding issaidtobesinglelayer.ThisisshownintheFig.(a). Whilethearetwocoilsidesperslot,oneatthebottomandoneatthetopthewindingiscalled double layer as shown in the Fig. (b).




(a) Single layer (b) Double layer

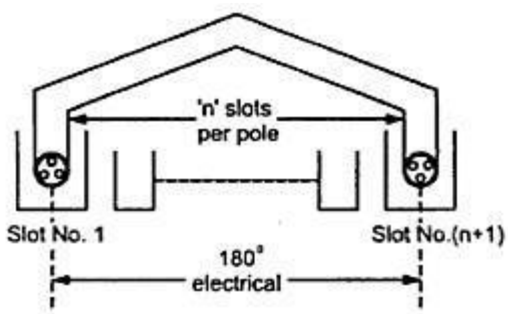
Alotofspacegetswastedinsinglelayerhenceinpracticegenerallydoublelayerwindingis preferred.

*2. FullPitchand Short PitchWinding*

Asseenearlier,onepolepitchiselectrical.Thevalueof'n',slotsperpoleindicateshowmany slots arecontributingelectrical phasedifference.So if coilside in oneslotis connected toa coilsidein anotherslotwhichisonepolepitchdistanceaway fromfirstslot,thewindingissaidtobefullpitch windingandcoilis called full pitch coil.

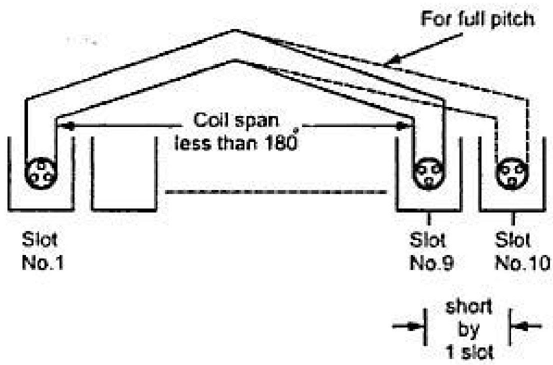
*Coil Span*

Itisthedistanceontheperiphery ofthearmaturebetweentwocoilsidesofacoil.Itisusually expressedin termsofnumberofslotsordegreeselectrical.Soifcoilspan is'n' slotsor180$^0$electrical the coilis called full pitch coil.




***FullPitchCoil***

Asagainstthisifcoilsare isslightlylessthanapolepitchi.e.lessthan180electrical,thecoilsare called, short pitchedcoils or fractional pitched coils. Generallycoils areshorted byoneor two slots. Soin18slots,2pole alternatorinsteadof connectinga coilsideinslotNo.1toslotNo.10,it is connectedtoa coilsideinslotNo.9or slotNo.8,coilissaidtobe shortpitchedcoilandwindingis called short pitch winding. This is shown in the below figure.



### *ShortPitchCoil*

*Advantages ofShortPitchCoils*

Inactual practice, short pitch coils areusedasithas followingadvantages,

- Thelengthrequiredfortheendconnectionsofcoilsislessi.e.inactivelengthofwindingisless.So less copper is required. Hence this is economical.
- Shortpitchingeliminateshighfrequencyharmonicswhichdistortthesinusoidalnatureofe.m.f. Hencewaveform of aninduced e.m.f. is moresinusoidal dueto short pitching.
- Ashighfrequencyharmonicsgeteliminated,eddycurrentandhysteresislosseswhichdependon frequencyalsoget minimized. This increases theefficiency.

*3. ConcentratedandDistributedWinding*

Inthreephasealternators,wehaveseenthattherearethreedifferentsetsofwindings,eachfor a phase.So depending uponthetotalnumberofslotsandnumberofpoles,wehavecertainslotsper phase availableundereach pole. This is denoted as 'm'.

m = Slots perpole per phase=n/numberof phases

=n/3 (generallyno. ofphases is3)

For examplein 18 slots, 2 pole alternator

wehave, n =18/2 = 9 and m = 9/3 =3

Sowehave3slotsperpoleperphaseavailable.Nowlet'x' numberofconductors perphaseareto beplacedunderonepole.Andwehave3slotsperpoleperphaseavailable.Butifall'x'conductors perphaseareplacedinoneslotkeepingremaining2slotsperpoleperphaseempty thenthewindingis called **concentratedwinding.**Soinconcentratedwindingallconductorsorcoilsbelongingtoaphaseareplacedinoneslot under everypole.

Butinpractice,anattemptisalwaysmade touseallthe'm' slotsperpoleperphaseavailablefor distributionofthewinding.Soif'x' conductorsperphasearedistributedamongstthe3slotsperphase availableunderevery pole,thewindingiscalled**distributedwinding.**Soindistributedtypeof windingallthecoilsbelonging toaphasearewelldistributedoverthe'm' slotsperphase,underevery pole.Distributedwinding makesthewaveformoftheinducede.m.f.moresinusoidalinnature.Alsoin concentrated windingdueto largenumber of conductors per slot, heat dissipation is poor. Soinpractice,doublelayer,shortpitchedanddistributed typeofarmaturewindingispreferred forthe alternators

3. Derive an expression for the induced EMF of an alternator. (APRIL/2013)

*E.M.F.Equation ofan Alternator:*

Let $\Phi$ = Fluxper pole, in Wb

P=Numberof poles

$N_S$=Synchronous speed in r.p.m.

f =Frequencyof induced e.m.f. in Hz

Z =Total numberof conductors

$Z_{ph}$=Conductors per phase connected in series

$Z_{ph}$=Z/3 as number ofphases =3.

Consider asingleconductor placed inaslot.

The average value of emf induced in a conductor $=\frac{d\varphi}{dt}$

For one revolution of a conductor,

$$e_{avg} per conductor = \frac{flux cut in one revolution}{time taken for one revolution}$$

Total flux cut in one revolution = φ * P

Time taken for one revolution = $\frac{60}{N_S}$ $seconds$

$$= \frac{\varphi P}{\left(\frac{60}{N_S}\right)} = \frac{\varphi P N_S}{60}$$

But $f = \frac{PN_S}{120}$

Substituting in (1),

$$e_{avg} \text{ per conductor } = 2f\phi \text{ volts}$$

Assumefullpitchwindingforsimplicityi.e.thisconductorisconnectedtoaconductorwhich is $180^o$electricalapart.Sotheretwoe.m.f.swilltrytosetupacurrentinthesamedirectioni.e.the twoe.m.f.arehelpingeachotherandhenceresultante.m.f.perturnwillbetwicethee.m.f.inducedin a conductor.

∴ e.m.f. per turn =2×(e.m.f. per conductor)

=2×(2 fΦ)=4fΦ volts

Let$T_{ph}$bethetotalnumberofturnperphaseconnectedinseries.Assumingconcentrated winding,wecansay thatallareplacedinsingleslotperpoleperphase.Soinducede.m.f.sinallturnswillbeinphaseasplacedinsingleslot.Hencenete.m.f.perphasewillbealgebraicsumofthee.m.f.s per turn.

Average$E_{ph}$=$T_{ph}$×(Averagee.m.f. per turn)

Average$E_{ph}$= $T_{ph}$×4 f Φ

But in AC. circuits R.M.S. value of an alternatingquantityisused forthe analysis. Theform factor is 1.11 of sinusoidal e.m.f.

$$K_f = \frac{\text{R.M.S.}}{\text{Average}} = 1.11 \quad \text{for sinusoidal}$$

∴ R.M.S. value of$E_{ph}$=K ×Averagevalue

$E_{ph}$=1.11 ×4 f Φ $T_{ph}$volts

$E_{ph}$=4.44 f Φ$T_{ph}$volts ........... (2)

Thisisthebasice.m.f.equationforaninducede.m.f.perphaseforfullpitch,concentratedtype of winding.

Where$T_{ph}$=Number ofturns per phase

$T_{ph}$=$Z_{ph}$/2 ....... as 2 conductorsconstitute 1 turn

Butasmentionedearlier,thewindingusedforthealternatorsisdistributedandshortpitchhence e.m.f. induced slightlygets affected.

*<u>GeneralizedExpression forE.M.F. Equation of an Alternator</u>*

Consideringfull pitch, concentratedwinding.

$E_{ph}$=4.44 fΦ $T_{ph}$Volts.

But due to short pitch, distributed windingused inpractice, this willreducebyfactors and sogeneralisedexpression fore.m.f. equation can bewritten as

$$\mathbf{E_{ph}} = \mathbf{4.44 K_c K_d} f \mathbf{\Phi T_{ph}} \text{volts}$$

Where,

$$K_c = \cos\left(\frac{\alpha}{2}\right)$$

$$K_d = \frac{Sin\left(\frac{m\beta}{2}\right)}{mSin\left(\frac{\beta}{2}\right)}$$

For fullpitch coil, $K_c$=1

For concentrated winding, $K_d$=1

*PitchFactororCoil SpanFactor(Kc)*

Thefactor bywhich, induced e.m.f.gets reduceddueto short pitchingiscalled**pitchfactororcoilspanfactor**denoted by$K_c$.It is defined as the ratio of resultant e.m.f. when coilis short pitch to theresultant e.m.f. when coil is fullpitched.It is always less than one.

$$K_c = \cos\left(\frac{\alpha}{2}\right)$$

Where, α=Angle of short pitch

*Distribution Factor(Kd)*

Thefactor bywhich thereis a reduction in thee.m.f. dueto distribution of coils iscalled**distributionfactor** denoted as $K_d$.

The distribution factor is defined as the ratio of the resultant e.m.f. when coils are distributed to the resultant e.m.f. when coils are concentrated. It is always less than one.

$$K_d = \frac{Sin\left(\frac{m\beta}{2}\right)}{mSin\left(\frac{\beta}{2}\right)}$$

Where, m = slots per pole per phase

β = slot angle

n = slot per pole

*Effect ofChording*

Thee.m.f.generated in thewindingis proportional to cos (x/2) whereis angle ofchordingand xis order ofharmonic.Ifproper valueof angle ofchordingis selected thenharmonic e.m.f.scan be reduced significantly.

**4. Explain in detail about armature reaction in alternator and also state voltage regulation?**

*ARMATURE REACTION ANDVOLATGE REGULATION*

Thevoltageregulationofanalternatorisdefinedasthechangeinitsterminalvoltagewhen fullloadis removed,keepingfieldexcitation andspeedconstant,dividedbytherated terminal voltage.

So if, $V_{ph}$=Rated terminal voltage

$E_{ph}$=No load induced e.m.f.

Thevoltageregulation is defined as,

$$Regulation\,\% = \frac{Eph - Vph}{Vph} X\,100$$

Aslong asthealternatorterminalsareopen(i.e),noloadisconnectedtoanalternator,the inducede.m.fissameasthevoltageavailableattheterminals.ThusterminalvoltageperphaseV$_{ph}$and induced e.m.f per phaseE$_{ph}$aresame as long as alternator is on no load. Butwhenthealternatorisloaded,thearmatureofanalternatorcarriescurrent.Weknowthat,any currentcarryingconductorproducesitsownflux.Henceonload,armatureofanalternatorproduces itsownfluxcalledarmatureflux.Thisfluxhassignificanteffectontheperformanceofanalternator on load. Theterminal voltage V$_{ph}$no longerremains same as inducede.m.f E$_{ph}$on load conditions.The performanceofanalternatoronloadismathematically expressedby aparametercalledvoltage regulation.

*Parameters ofArmatureWinding*

There arethreeimportant parameters ofan armaturewindingof analternator. Theseare,

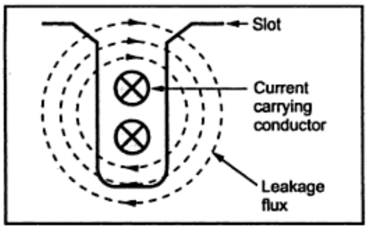
1. ArmatureresistanceR$_a$
2. ArmatureleakagereactanceX$_L$
3. Reactance correspondingto armaturereaction

*1. ArmatureResistance*

Everyarmaturewindinghasitsownresistance.Theeffectiveresistanceofanarmaturewinding per phaseis denoted asR$_a$Ω/ph. GenerallythearmatureresistanceismeasuredbyapplyingtheknownDCvoltageandmeasuring theD.C.Current throughit. The ratio of applied voltage and measured current is the armature resistance.Generally theeffectivearmatureresistanceunderA.C.conditionsistaken1.25to1.75times the D.C. resistance.

*2. ArmatureLeakageReactance*

Whenarmature carriesa current,itproducesitsownflux. Somepartofthis fluxcompletesitspath throughtheairaround the conductorsitself. Sucha fluxiscalledleakageflux.Thisis shown in the Fig.




*Note:* Thisleakagefluxmakesthearmaturewindinginductive innature.Sowindingpossessesaleakagereactance,inaddition to theresistance.

Soif'L'istheleakageinductanceofthearmaturewinding perphase,thenleakagereactanceper phaseisgiven byX$_L$ =2πfLΩ/ph.Thevalue of leakagereactanceis much higherthanthearmature resistance. Similar to theDC machines, thevalueof armatureresistanceisveryverysmall.

*3. ArmatureReaction*

Whentheloadisconnectedtothealternator,thearmaturewinding ofthealternatorcarriesa current.Every currentcarryingconductor producesitsownfluxsoarmatureofthealternatoralso producesitsownflux,whencarryingacurrent.Sotherearetwofluxespresentintheairgap,onedue toarmaturecurrentwhilesecondisproducedby thefiledwindingcalledmainflux.Thefluxproduced bythearmatureis calledarmatureflux. Soeffectofthearmaturefluxonthemainfluxaffectingitsvalueandthedistributioniscalled **armature reaction.**

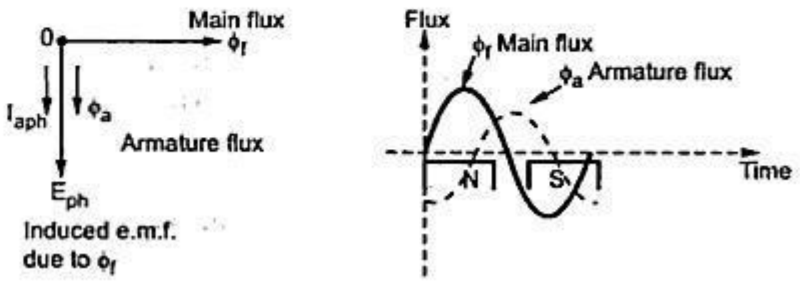
Theeffectofthearmaturefluxnotonly dependsonthemagnitude ofthecurrentflowingthrough thearmaturewinding butalsodependsonthe natureofthepowerfactor oftheloadconnectedto the alternator.

*Effectof nature of the load power factor on thearmature reaction*

*1.UnityPowerFactor Load*

Consider a purelyresistiveload connected tothe alternator, having unitypowerfactor. Asinduced e.m.f.$E_{ph}$drivesacurrentof$I_{aph}$andloadpowerfactorisunity,$E_{ph}$and$I_{ph}$areinphasewitheach other.

If$\Phi_f$ isthemainfluxproducedbythefieldwindingresponsibleforproducing$E_{ph}$then$E_{ph}$lags $\Phi_f$ by$90^0$. Nowcurrentthrougharmature$I_a$,producesthearmaturefluxsay$\Phi_a$.Soflux$\Phi_a$and$I_a$arealways in thesame direction. This relation between$\Phi_f$ , $\Phi_a$, $E_{ph}$and$I_{aph}$can beshown in thephasordiagram.(SeeFig.)



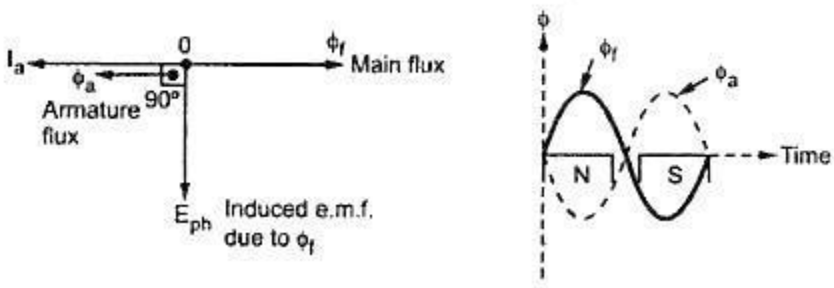

***Armature reaction forunity powerfactor***

Itcanbeseenfromthephasordiagramthatthereexistsaphasedifferenceof $90^0$betweenthe armaturefluxandthemainflux.Thewaveformsforthetwofluxesare alsoshownintheFig.1.From thewaveformsitcanbeseenthatthetwofluxesopposeeachother onthelefthalfofeachpolewhile assisteachother ontherighthalfof eachpole.Henceaveragefluxinthe airgap remainsconstantbut its distribution gets distorted.Hencesuchdistortingeffectofarmaturereactionunderunity p.f.conditionoftheloadiscalled cross**magnetising effect**of armaturereaction. Dueto such distortion of theflux, thereis small dropin theterminal voltageof the alternator.

*2. Zero LaggingPowerFactorLoad*

Considerapurelyinductiveloadconnectedtothealternatorhavingzerolaggingpowerfactors. This indicates that$I_{aph}$driven by$E_{ph}$lags $E_{ph}$by$90^0$which is thepower factor angle Φ. Inducede.m.f.$E_{ph}$lagsmainflux$\Phi_f$by$90^0$while$\Phi_a$isinthesamedirectionasthatof $I_a$.Sothe phasor diagramand thewaveforms areshown in the Fig. Itcan beseenfromthephasordiagramthatthearmature fluxandthemainfluxareexactly in opposite direction to each other. Soarmaturefluxtriestocancelthemainflux.Suchaneffectofarmaturereactioniscalled **demagnetising effect**of the armaturereaction.

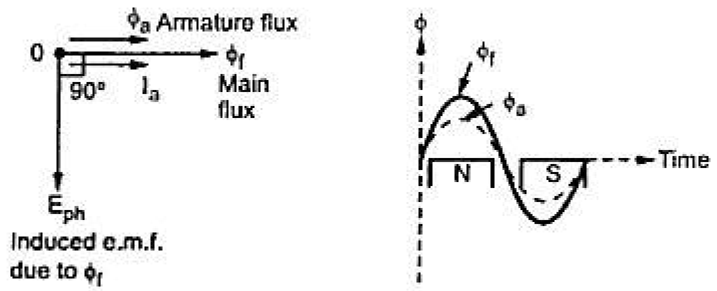
Asthiseffectcausesreductioninthemain flux, theterminalvoltagedrops.Thisdropinthe terminal voltageis more than thedrop correspondingto theunityp.f. load.




***Armature reaction for zero lagging p.f. load***

*3. Zero Leading PowerFactorLoad*

Considerapurely capacitiveloadconnectedtothealternatorhavingzeroleading powerfactor. Thismeansthatarmaturecurrent$I_{aph}$drivenby$E_{ph}$,leads$E_{ph}$by$90^0$,whichisthepowerfactorangle Φ. Inducede.m.f.$E_{ph}$lags$\Phi_f$by$90^0$while$I_{aph}$and$\Phi_a$arealwaysinthesamedirection.Thephasor diagram and thewaveforms areshown in theFig.




***Armature reaction for zero leading p.f.load***

Itcanbe seenfromthe phasordiagramandwaveformsshowninthe Fig,the armature fluxand themainfieldfluxareinthesamedirectioni.e.they arehelpingeachother.Thisresultsintothe addition in main flux. Suchaneffectofarmaturereactionduetowhicharmaturefluxassistsfieldfluxiscalled **magnetising effect** of the armaturereaction.

Asthiseffectaddsthe fluxtothemainflux,greatere.m.f.getsinducedinthearmature.Hence thereis increasein theterminal voltageforleadingpower factor loads.

5. Draw and explain the phasor diagram of a loaded alternator. (APRIL/2014)(or) Explain in detail with phasor diagram of an alternator on load. (APRIL/2012)

*PhasorDiagramofaLoaded Alternator*

Thephasordiagramsforvariousloadpowerfactorconditionsareasfollows.Fordrawingthephasor diagram considerallperphasevaluesand remember followingsteps.

***Steps to drawthe phasordiagram:***

1. Choose currentas areferencephasor.

2.NowifloadpowerfactoriscosΦitindicatesthatanglebetween $V_{ph}$and$I_a$isΦas$V_{ph}$isthevoltage available to the load. Soshow thephasor$V_{ph}$insuchawaythatanglebetween $V_{ph}$and$I_a$isΦ.Forlagging'Φ',$I_a$should lag$V_{ph}$andforleading'Φ',$I_a$shouldlead$V_{ph}$.ForunitypowerfactorloadΦiszero,so$V_{ph}$and$I_a$are in phase.

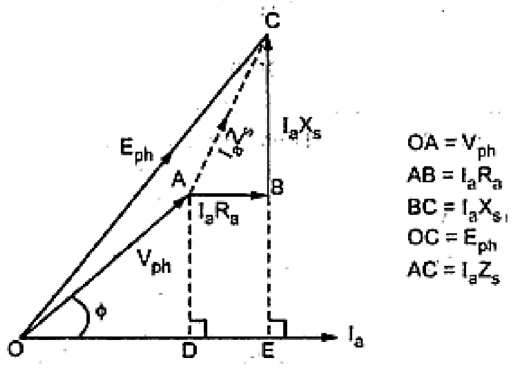
3.Nowthedrop$I_aR_a$ isaresistivedropandhencewillalwaysbeinphasewith$I_a$.Sophasor$I_aR_a$ directionwillbealwayssameas$I_a$,i.e.parallelto$I_a$.Butasitistobeaddedto$V_{ph}$,$I_aR_a$phasormust bedrawnfrom thetip ofthe $V_{ph}$phasor drawn.

4.Thedrop$I_aX_s$isdropacrosspurelyinductivereactance.Inpureinductance,currentlagsvoltageby $90^0$.So'$I_aX_s$'phasordirectionwillbealwayssuchthat$I_a$willlag$I_aX_s$phasorby$90^0$.Butthisphasor is to bedrawn from the tip of the $I_aR_a$phasor to complete phasoradditionof $V_{ph}$,$I_aR_a$and$I_aX_s$.

5. Joiningthe startingpointto theterminatingpoint, weget thephasor$E_{ph}$. Whatever maybetheload power factor,$I_aR_a$is a resistivedrop, willbein phasewith$I_a$while$I_aX_s$ is purelyinductive drop and hencewillbeperpendicular to$I_a$in suchawaythat$I_a$willlag $I_aX_s$by$90^0$. By usingtheabovesteps,thephasordiagramsforvariousloadpowerfactorconditionscanbe drawn.

***Lagging PowerFactorLoad***

Thepowerfactor ofthe load is cos Φ lagging so$I_a$lags $V_{ph}$byangle Φ.Byusingsteps discussed above, phasor diagram canbedrawnas shown in the Figure.




***Phasordiagramforlaggingp.f. load***

TodeterivetherelationshipbetweenEphandVph,theperpendiculars aredrawnonthecurrentphasor from points A and B. Theseintersect current phasorat points D and E respectively.

Now, $OD = V_{ph}\cos\Phi$

$AD = BE = V_{ph}\sin\Phi$

$DE = I_aR_a$

Consider ΔOCE, forwhich wecan write,

$$(OC)^2 = (OE)^2 + (EC)^2$$

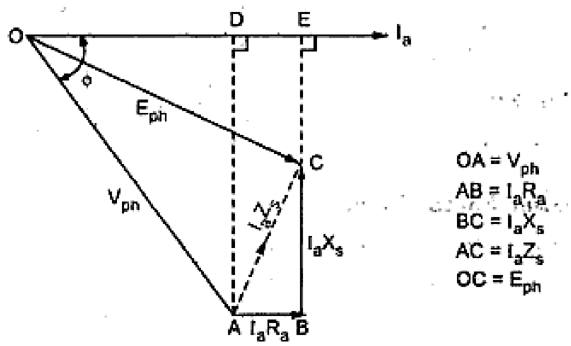
$$(E_{ph})^2 = (OD + DE)^2 + (EB + BC)^2$$

$$(E_{ph})^2 = (V_{ph}\cos\Phi + I_aR_a)^2 + (V_{ph}\sin\Phi + I_aX_s)^2$$

$$E_{ph} = \sqrt{\left(V_{ph}cos\Phi + I_aR_a\right)^2 + \left(V_{ph}sin\Phi + I_aX_s\right)^2}$$

***<u>LeadingPowerFactorLoad</u>***

ThepowerfactoroftheloadiscosΦleading.SoIaleadsVphbyanangleΦ.Byusingsteps discussed, the phasor diagram can bedrawn as shown in the Figure.




TodeterivetherelationshipbetweenEphandVph,theperpendicularateredrawnonthecurrent phasorfrom points A andB. Theseintersectcurrent phasorat points D andE respectively.

From ΔOCE, $OD = V_{ph}\cos\Phi$

$AD = BE = V_{ph}\sin\Phi$

$DE = I_aR_a$

Consider ΔOCE, forwhich wecan write,

$$(OC)^2 = (OE)^2 + (EC)^2$$

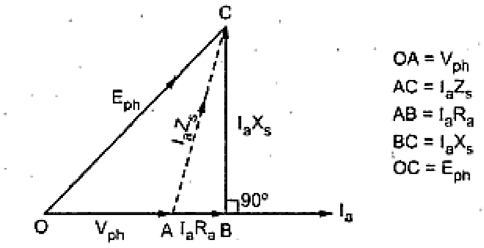
$$(E_{ph})^2 = (OD + DE)^2 + (BE - BC)^2$$

$$(E_{ph})^2 = (V_{ph}\cos\Phi + I_aR_a)^2 + (V_{ph}\sin\Phi - I_aX_s)^2$$

$$E_{ph} = \sqrt{\left(V_{ph}cos\Phi + I_aR_a\right)^2 + \left(V_{ph}sin\Phi - I_aX_s\right)^2}$$

***Unity PowerFactor Load***

Thepowerfactor ofthe load is unityi.e. cosΦ=1. So Φ =0, which means $V_{ph}$isin phasewith$I_a$. So phasor diagram can bedrawnas shown in the




Consider ΔOBC, forwhich wecan write,

$$(OC)^2=(OB)^2+(BC)^2$$

$$(E_{ph})^2=(OA+AB)^2+(BC)^2$$

$$(E_{ph})^2=(V_{ph}+I_aR_a)^2+(I_aX_s)^2$$

$$E_{ph} = \sqrt{(V_{ph} + I_aR_a)^2 + (I_aX_s)^2}$$

Itisclearfromthephasordiagramthat$V_{ph}$islessthan$E_{ph}$forlaggingandunityp.f.conditions duetodemagnetisingandcrossmagnetizingeffectsofarmaturereaction.While$V_{ph}$ismorethan$E_{ph}$forleadingp.f.condition due to the magnetizing effect ofarmaturereaction.

Thus in general for anypower factor condition,

$$(E_{ph})^2= (V_{ph}\cos\Phi+ I_aR_a)^2+ (V_{ph}\sin\Phi\pm I_aX_s)^2$$

*+ sign forlagging p.f. loads*
*-sign forleadingp.f. loads*
$V_{ph}$=per phaserated terminal voltage
$I_a$=per phasefull load armature current

6. Describe any two methods of determining the voltage regulation of three phase alternator (11) (NOV/2014)

## VOLTAGE REGULATION OFANALTERNATOR

Undertheloadcondition,theterminalvoltageofalternatorislessthantheinducede.m.f.$E_{ph}$.So if load isdisconnected,$V_{ph}$willchangefrom $V_{ph}$to$E_{ph}$, if fluxand speed ismaintained constant.This isbecausewhenloadisdisconnected,$I_a$iszerohencetherearenovoltagedropsandnoarmatureflux tocausearmature reaction.Thischangeintheterminalvoltageissignificantindefining thevoltage regulation.

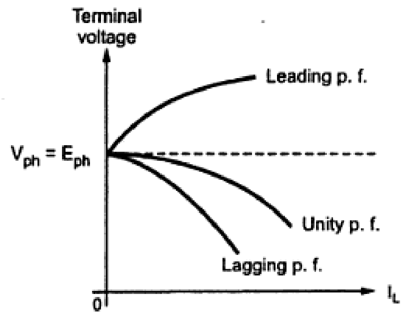
***"Thevoltage regulationofanalternatorisdefinedasthechangeinitsterminalvoltagewhenfull load is removed, keeping field excitation and speed constant, divided bytherated terminal voltage."***

So if $V_{ph}$=Rated terminal voltage

$E_{ph}$=No load induced e.m.f. Thevoltageregulationis defined as,

$$\boldsymbol{Regulation}\ \% = \frac{\boldsymbol{Eph - Vph}}{\boldsymbol{Vph}} \boldsymbol{X\ 100}$$

Thevalue of theregulation not onlydepends on theload current butalso on the power factor of theload.Forlaggingandunity p.f.conditionsthereisalwaysdropintheterminalvoltagehence regulationvalues arealwayspositive.Whileforleadingcapacitiveloadconditions,theterminal voltage increases as load current increases. Hence regulation is negative in such cases. The relationship between load current and the terminal voltage is called load characteristics of an alternator. Such loadcharacteristics forvarious load powerfactorconditions areshown inthe below figure.




***Loadcharacteristics ofanalternator***

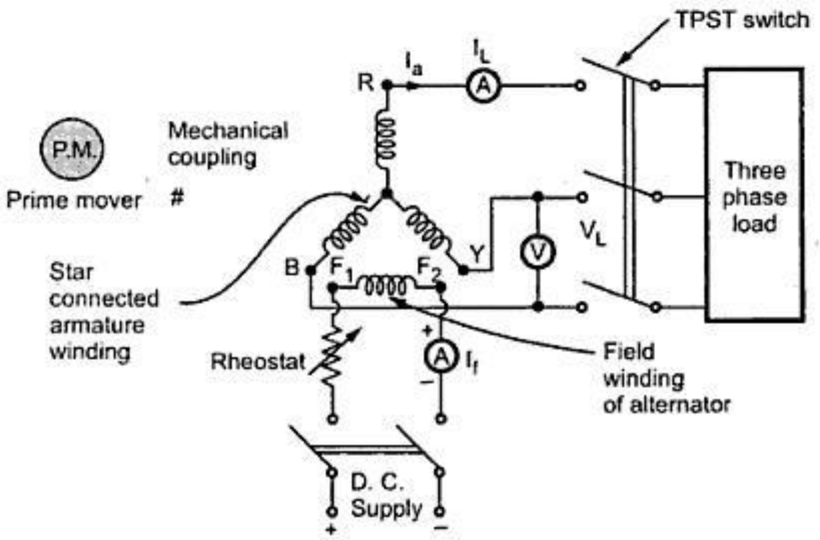
## METHODS OFDETERMININGTHEREGULATION

Theregulationofanalternatorcanbedeterminedby variousmethods.Incaseofsmallcapacity alternatorsitcanbedeterminedby directloading testwhileforlargecapacity alternatorsitcanbe determined bysynchronous impedancemethod. Thus there followingmethods available to determinethe voltageregulation ofan alternator,

- ***Direct loadingmethod***
- ***Synchronous impedancemethod orE.M.F. method***
- ***Ampere-turns method or M.M.F. method***
- ***Zero power factor method orpotier triangle method***
- ***ASA modified formofM.M.F. method***
- ***Two reaction theory***

## VOLTAGEREGULATION BY DIRECT LOADING

Thebelow figure showsthecircuitdiagramforconductingthedirectloading testonthethreephase alternator.The starconnected armatureistobe connectedtoa three phase loadwiththehelp oftriple polesinglethrow(TPST)switch.Thefieldwindingisexcitedby separateDCsupply.Tocontrolthe fluxi.e. the currentthroughfieldwinding,arheostatisinserted inserieswiththe fieldwinding.The primemoveris shown which is drivingthe alternator at its synchronous speed.




***Circuit diagramfordirect loading test on alternator***

The alternator is first driven at itssynchronous speed $N_S$bymeans of aprimemover. Now

$E_{ph} \alpha\ \Phi$ ..... (From e.m.f. equation)

BygivingDC supplytothefieldwinding,thefieldcurrentisadjustedtoadjustthefluxsothat rated voltage isavailableacross the terminals.Thiscanbe observedonthevoltmeter connectedacross thelines.Theloadisthenconnected by meansofaTPSTswitch.Theloadisthenincreasedsothat ammeterreadsratedvalueofcurrent.Thisisfullloadconditionofthe alternator.Againadjustthe voltagetoitsratedvalueby meansoffieldexcitationusingarheostatconnected.Thethrowoffthe entireloadby openingtheTPSTswitch,withoutchangingthespeedandthefieldexcitation.Observe thevoltmeterreading. Asloadisthrownoff,thereisnoarmaturecurrentandassociateddrops.So the voltmeterreadinginthissituationindicatesthevalueofinternally inducede.m.f.callednoload terminalvoltage.Convertboththereadingtophasevalues.TheratedvoltageonfullloadisVphwhile readingwhen load is thrown offis $E_{ph}$. So byusingthe formula,

$$\textbf{Regulation}\ \% = \frac{E\,ph - Vph}{Vph} X\ 100$$

Thefullloadregulationofthealternatorcanbedetermined.Thevalueoftheregulationobtainedby this method is accurateas aparticularload at required p.f.is actuallyconnected to thealternator. Butforhighcapacityalternators,thatmuchfullloadcannotbesimulatedordirectlyconnected to the alternator. Hencemethod is restricted onlyforsmall capacityalternators.

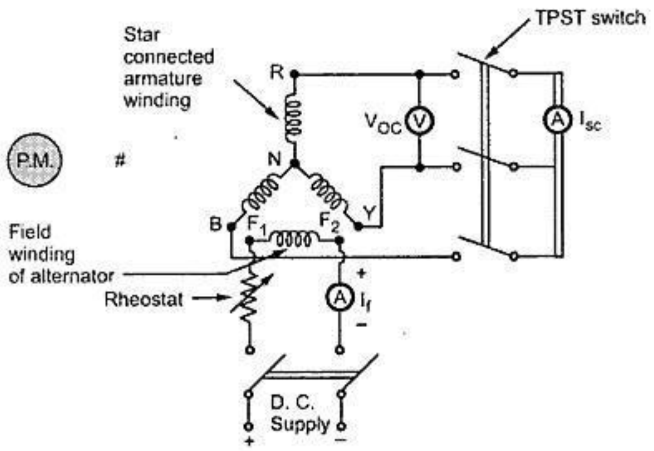
7. Explain the EMF method to determine the voltage regulation of an alternator. (APRIL/2013)

**SYNCHRONOUS IMPEDANCE METHOD (OR)E.M.F. METHOD**

ThemethodisalsocalledE.M.F.methodofdeterminingtheregulation.Themethodrequires followingdata tocalculatethe regulation.

- The armatureresistanceper phase($R_a$).
- Opencircuitcharacteristicwhich isthegraphofopencircuitvoltageagainstthefieldcurrent.This is possiblebyconducting open circuittest on thealternator.
- Shortcircuitcharacteristicswhichisthegraphofshortcircuitcurrentagainstfieldcurrent. Thisis possible byconductingshort circuittest on the alternator.

The circuitdiagram is shown in the below figure.




*OpenCircuit Test*

Proceduretoconduct this test is as follows:

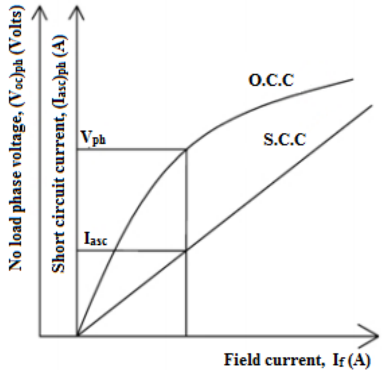
- Theswitch S across the load is kept open.
- Starttheprimemoverandadjustthespeedtothe synchronous speed of thealternator.
- Keeping rheostat inthe fieldcircuit (Alternator) maximum,switch on theDC supply.
- TheT.P.S.Tswitchinthearmaturecircuitiskept open.
- With the help of rheostat,field current isvariedfrom itsminimumvaluetotheratedvalue.Due tothis, fluxincreasing theinducede.m.f.Hencevoltmeter reading, which ismeasuring line value of open circuitvoltage,increases.Forvariousvaluesoffield current, voltmeterreadings areobserved.

*Short Circuit Test*

Proceduretoconduct this test is as follows:

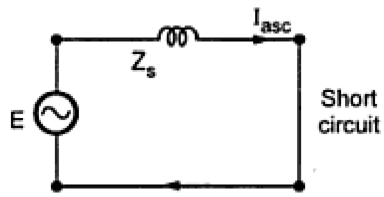
- TheT.P.S.Tswitchisclosedsothearmaturegetsshortcircuited.

- Thenthe fieldexcitationisgradually increasedtillfullloadcurrentisobtainedthrougharmaturewinding.
- This canbe observedonthe ammeter connected inthe armature circuit.
- The graphof shortcircuitarmature currentagainstfieldcurrentisplotted fromthe observationtable of shortcircuittest.
- Thisgraphis called short circuitcharacteristics (S.C.C). This is also shown in the below figure.
- AsS.C.C.isstraightlinegraph,onlyonereadingcorrespondingtofullloadarmaturecurrent alongwith theorigin is sufficient to draw thestraight line.




*<u>Determination of $Z_S$ from O.C.C and S.C.C</u>*

Thesynchronousimpedanceofthealternatorchangesasloadconditionchanges.O.C.C.and S.C.C. can beused to determine$Z_S$for anyload and load p.f. conditions. Consider afieldcurrent$I_f$.TheO.C.voltagecorresponding to thisfieldcurrentisE.Whenwinding isshort-circuited,the terminalvoltageiszero.Hence,itmay beassumedthatthewhole ofthisvoltageEisbeing usedtocirculatethearmature short- circuitcurrent$I_{asc}$againstthe synchronous impedance$Z_S$. This can beshown in theequivalent circuitdrawnin the below figure.



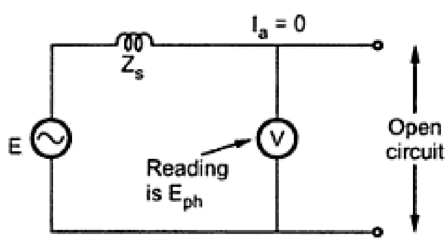

From the equivalent circuitwe can write, $Z_S=E/I_{asc}$

Nowvalueof$I_{asc}$isknown,whichcanobserveonthealternator.Todetermine$Z_S$itisnecessary to determinevalue of Ewhich is driving $I_{asc}$against $Z_S$.

Nowinternallyinducede.m.f. isproportional to the fluxi.e. field current$I_f$.

$E \; \alpha \Phi \; \alpha I_f$ ...... from e.m.f. equation

Soiftheterminalsofthealternatorare openedwithout disturbing $I_f$whichwaspresentatthe time of shortcircuited condition,internally inducede.m.f.willremainsameasE. But nowcurrent will be zero. Under this condition equivalent circuitwillbecome as shown in thebelow figure.




Itisclearnowfromtheequivalentcircuitthatas$I_a$=0thevoltmeterreading$(V_{oc})_{ph}$willbeequal to internally**induced**e.m.f. (E).

Thisiswhatweareinterestedinobtainingtocalculatevalueof$Z_S$.Soexpressionfor$Z_S$canbe modified as,

Thus in general,

$$Z_s = \left.\frac{\text{Phase e.m.f. on open circuit}}{\text{Phase current on short circuit}}\right|_{\text{For same excitation}}$$

So O.C.C. and S.C.C. can beeffectivelyto calculate $Z_S$.

Thevalue of$Z_S$is different for different values of$I_f$as thegraph ofO.C.C. is non linear in nature. General steps to determine $Z_S$at anyloadcondition are:

- Determinethevalueof$(I_{asc})_{ph}$forcorrespondingloadcondition.Thiscanbedeterminedfrom known fullload current of the alternator. For half load, itis half ofthe fullload value and so on.
- S.C.C.givesrelationbetween$(I_{asc})_{ph}$and $I_f$.Sofor$(I_{asc})_{ph}$required,determinethecorresponding value of$I_f$from S.C.C.
- Nowforthissamevalueof$I_f$,extendthelineonO.C.C.togetthevalueof$(V_{oc})_{ph}$.Thisis $(V_{oc})_{ph}$forsame$I_f$, required to drivethe selected$(I_{asc})_{ph}$.
- The ratio of $(V_{oc})_{ph}$and $(I_{asc})_{ph}$, forthe same excitation gives the value of $Z_S$ at any load conditions.

*RegulationCalculations*

From O.C.C. and S.C.C., $Z_S$can bedetermined for anyloadcondition. Thearmatureresistanceperphase($R_a$)canbemeasuredbydifferentmethods.Oneofthemethods isapplyingDC knownvoltageacrossthetwoterminalsandmeasuringcurrent.SovalueofR$_a$per phaseis known.

Now,

$$Z_s = \sqrt{(R_a)^2 + (X_s)^2}$$

$$X_s = \sqrt{(Z_s)^2 - (R_a)^2}\ \Omega/ph$$

So synchronous reactanceper phasecan bedetermined.

Noloadinducede.m.f.perphase,$E_{ph}$canbedetermined by themathematicalexpressionderived earlier. $E_{ph} = \sqrt{(V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi \pm I_a X_s)^2}$

Where, $V_{ph}$=Phasevalue ofrated voltage

$$Z_s = \left.\frac{(V_{oc})_{ph}}{(I_{asc})_{ph}}\right|_{\text{for same } I_f}$$

$I_a$=Phasevalue of current dependingon the loadcondition

Cos Φ =p.f.of load

Positivesignforlaggingpowerfactorwhilenegativesignforleadingpowerfactor,$R_a$and$X_S$ values areknown from thevarious tests performed.

Theregulation thencan bedetermined byusingformula,

$$\boldsymbol{Regulation}\ \% = \frac{\boldsymbol{E\ ph - Vph}}{\boldsymbol{Vph}} \boldsymbol{X\ 100}$$

*Advantages:*

Themainadvantagesofthismethodarethevalueofsynchronousimpedance$Z_S$ foranyload conditioncanbecalculated.Henceregulationofthealternatoratany loadconditionandloadpower factorcanbedetermined.Actualloadneednotbe connectedtothealternatorandhencemethodcanbe used forveryhighcapacityalternators.

*Disadvantages:*

Themain limitation ofthis method is thatthemethod gives largevalues of synchronous reactance.
Thisleadstohighvaluesofpercentageregulationthantheactualresults.Hencethismethodiscalled ***pessimisticmethod.***

8. Explain the parallel operation of alternators (APRIL/2014)(or) With neat sketch, explain the parallel operation of an alternator.(NOV/2013)(APRIL/2012)

**<u>PARALLELOPERATIONANDSYNCHRONIZATIONOF ALTERNATORS</u>**

**INTRODUCTION**

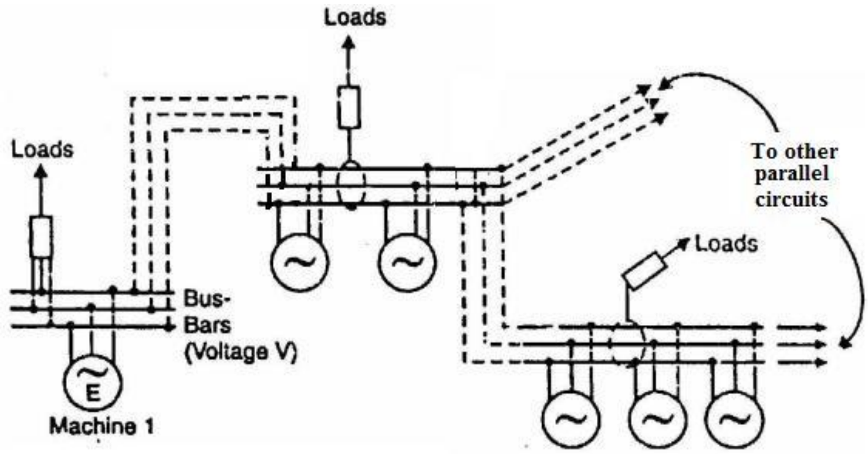
Theprocessofswitching ofanalternatortoanotheralternatororwithacommonbusbar withoutanyinterruptioniscalled**synchronization.**Alternately itcanalsobedefinedastheprocessof connecting thetwoalternatorsinparallelwithoutany interruption.Thesynchronousmachinewhichis tobesynchronizedisnormallycalledanincomingmachine.Ifanyalternatorsisconnectedtoabus barwhichhasmany otheralternatorsalreadyconnected,nomatterwhatpoweritissupplyingthen alternatorissaidtobeconnectedtoinfinitebusbar.Aninfinitebusbarisoneofwhosefrequency and phase e.m.f.remains unaffected bychanges incondition of anyonemachine connected to it. Thus they arenothingbut constant frequencyand constant voltagebus bars.

***ParallelOperationof Alternators***

Itisraretofinda3-phasealternatorsupplying itsownloadindependently exceptundertest conditions.Inpractice,avery largenumberof3-phasealternatorsoperateinparallelbecausethe variouspowerstationsareinterconnectedthroughthenationalgrid.Therefore,theoutputofanysingle alternator is small compared with thetotal interconnected capacity.

Forexample,thetotalcapacityoftheinterconnectedsystemmaybeover40,000MWwhile thecapacity ofthebiggestsinglealternatormaybe500MW.Forthisreason,theperformanceofa singlealternatorisunlikelytoaffectappreciablythevoltage andfrequencyofthewholesystem.An alternatorconnectedtosuchasystemissaidtobeconnectedtoinfinitebusbars.The outstanding electrical characteristics of such busbarsare that they are constant-voltage, constant frequency busbars.

The below figure showsatypicalinfinitebussystem.Loadsare tappedfromtheinfinitebusat variousloadcentres. Thealternatorsmay beconnectedtoordisconnectedfromtheinfinite bus, depending onthepowerdemandonthe system.Ifanalternatorisconnectedtoinfinitebusbars,no matterwhatpowerisdeliveredby theincomingalternator,thevoltageandfrequency ofthesystem remain thesame.The operation ofconnecting an alternator to theinfinite busbarsis knownas parallelingwiththeinfinitebusbars.Itmaybenotedthatbeforeanalternatorisconnectedtoan infinite busbars, certain conditions mustbesatisfied.




*Advantages*

Thefollowing arethe advantages of operatingalternators in parallel:

- **Continuityofservice.**Thecontinuity ofserviceisoneoftheimportantrequirementsofany electricalapparatus.Ifonealternatorfails,thecontinuityofsupplycanbemaintainedthroughthe otherhealthyunits.This will ensureuninterruptedsupplyto the consumers.
- **Efficiency**.Theloadonthepowersystemvariesduring thewholeday;beingminimumduringdie latenighthours.Sincealternatorsoperatemostefficientlywhendeliveringfull-load,unitscanbe addedorputoffdependingupontheloadrequirement.Thispermitstheefficientoperationofthe power system.
- **Maintenanceandrepair**.Itisoftendesirabletocarryoutroutinemaintenanceandrepairofone ormoreunits.Forthispurpose,the desiredunit/unitscanbeshutdownandthecontinuity ofsupply is maintained through theotherunits.
- **Loadgrowth.**Theloaddemandisincreasing duetotheincreasing useofelectricalenergy.The load growth can bemet byaddingmoreunits withoutdisturbingthe original installation.

## CONDITIONSFORPARALLELING ALTERNATORWITH INFINITEBUSBARS

Theproper methodofconnectinganalternatortotheinfinitebusbarsiscalledsynchronizing. Astationaryalternatormustnot beconnectedtolivebusbars.Itisbecausetheinducede.m.f.iszeroat standstillandashort- circuitwillresult.Inordertoconnectanalternatorsafely totheinfinitebusbars, the followingconditionsaremet:

- Theterminal voltage(r.m.s value)of theincomingalternator mustbethesame as busbars voltage.
- Thefrequencyofthegeneratedvoltageoftheincomingalternatormustbeequaltothebusbars frequency.
- Thephaseoftheincomingalternatorvoltagemustbeidenticalwiththephaseofthebusbars voltage.In otherwords, thetwo voltages must be inphasewith each other.
- Thephasesequenceofthevoltageoftheincomingalternatorshouldbethesameasthatofthe busbars.

The magnitude of thevoltageof the incomingalternator canbeadjustedbychangingits field excitation.Thefrequencyoftheincomingalternatorcanbechangedbyadjustingthespeedofthe primemoverdrivingthealternator.

Condition(i)isindicatedbyavoltmeter,conditions(ii)and(iii)areindicatedby synchronizinglamps or asynchroscope. Thecondition (iv) is indicated bya phasesequenceindicator.

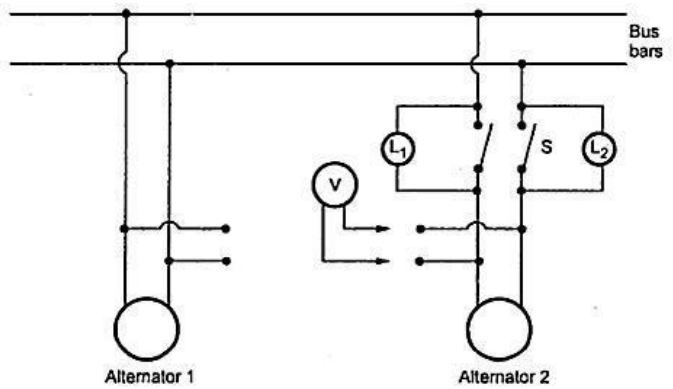
## SYNCHRONIZATIONOFSINGLE PHASE ALTERNATORS

Incaseofsinglephasealternators,synchronizationisdonegenerallybylampmethods.Itcan bedonebytwo ways:

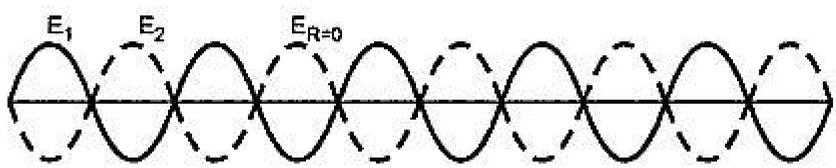
- Lamp dark method
- Lamps bright Method

### 1. Lamps Dark Method

Inthismethodthelampsarearrangedasshown in the below figure.Thealternatortobesynchronized (whichisalsocalledincoming alternator)consistsoftwolampsconnectedacrosstheswitchterminals of thesame phase.

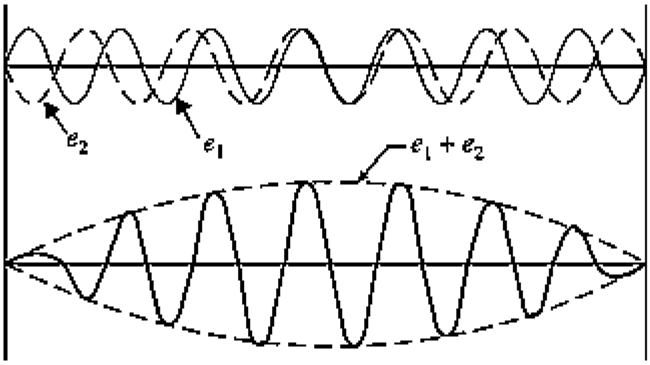



Thevoltageforthetwoalternatorsismeasuredwiththehelpofa voltmeter.Thelampsare connectedinsuchawaythatthepolarityandthefrequency forthetwomachinescanbechecked.No resultantvoltagewillappearacrosstheswitchterminalsifthefrequency ofthetwoalternatorsis exactly sameastheirvoltageisinexactphaseopposition.Thusunderthiscaselampswillnotglow. This is represented in thebelow figure.




Itcanbeseenthatwithunequalfrequenciesof thetwoalternators,thetwolampswillbecome alternately brightanddark.Thelightbeatwillbeproducedwhosenumberisequaltothedifferencein frequencies for thetwomachines.

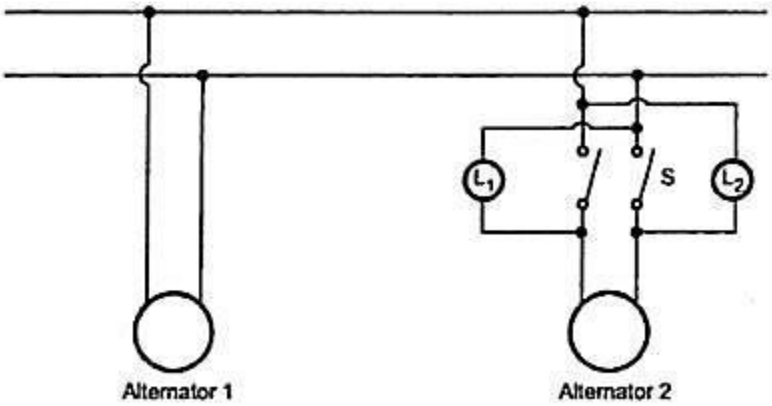
Theresultantvoltageappearing acrossthelampwillbedifferenceofthetwovoltagesatany instant resultingin awaveform shown in the below figure. Sincenumberofcyclecompleted bytwo machines in anygiven time arenot samethe lightbeat is producedwhich is shown in the Figure




Sometimestheresultantvoltageismaximumandsomeothertimesminimum.Hence,thecurrent isalternatingmaximumandminimum.Duetothischangingcurrentthroughthelamps,aflicker will be produced, the frequency of the flicker being ($f_2$-$f_1$). Lamps will dark out and glow up alternatively. DarknessindicatesthatthetwovoltagesE$_1$andE$_2$areinexactphaseoppositionrelativetothelocal circuitandhencethereisnoresultantcurrentthroughthelamps.Synchronizingisdoneatthemiddle of the dark period.Thewordmiddle isusedasthe lampwillnotgloweventhoughthereissufficient voltageacrossit. Soitbecomesdifficulttoknow the correctinstantofzero voltage.Thatiswhy, sometimes, it is known as 'lamps dark'synchronizing

2. **Lamps Bright Method**

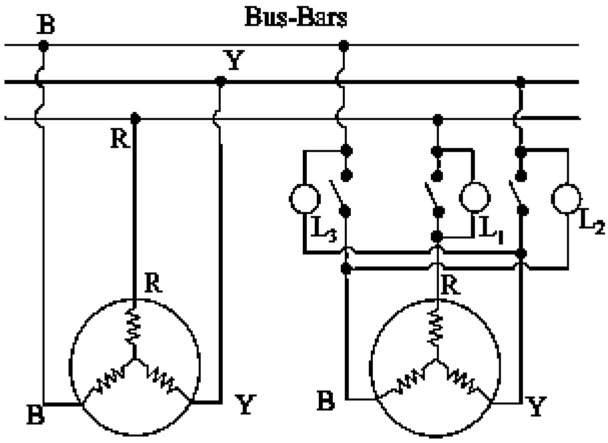
SinceitisverydifficulttojudgethecorrectinstantofzerovoltageinLampsdarkmethod,this method is introduced which is shown in the below figure.




The lamps remain maximum bright when there is no difference in voltages for the two machines.Thisismoresharpandaccuratemethodofsynchronizationbecausethelampsaremuch moresensitive to changes in voltage at their maximumbrightness than when theyaredark.

**<u>SYNCHRONIZATIONOFTHREE PHASE ALTERNATORS</u>**

The conditions to besatisfied forsynchronization ofthreephasealternators are sameasthat for singlephasealternators.Butinsteadofsaying thatvoltagesmustactinphaseopposition,thephase sequencemustbesamei.e. phasemustbeconnected inproper order ofR,Y,B.Typicalsetupfor synchronization of alternators is shown in the below figure.




***Setup forSynchronizationofAlternators***

Insynchronizingthreephasealternators,threelampsareconnectedasshownintheFig.2,sothat itcanbeusedtoindicatewhethertheincomingmachineisrunning sloworfast.Withsymmetrical connectionoflamps,they woulddarkoutorglowupsimultaneously providedthatphasesequenceis same for incomingmachine and bus bar.

ConsiderthetwoalternatorsAandBtobesynchronized.ThealternatorAisalready runningat synchronousspeedanditsexcitationissoadjustedthatitbuildsuptheratedvoltage.ThealternatorB istobe connected tobusbar i.e. itistobe synchronizedwithalternatorA. The processor synchronization can beexplained as below:

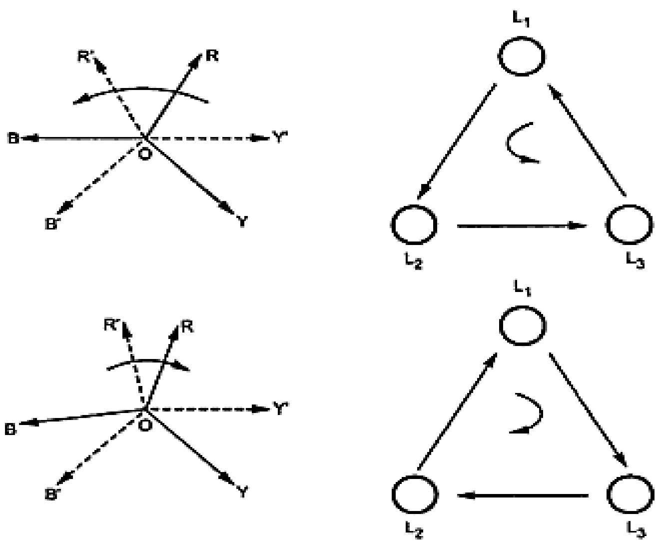
**Step1:**Start theprimemoverof machine B and adjustits speed to a synchronous speed.

**Step2:**By adjustingtherheostat,theexcitationtothefieldisadjustedso thatinducede.m.f.ofBis equal to the inducede.m.f. ofA. This can beverified byvoltmeter.

**Step3:**Tosatisfyremainingconditions,thethreelampspairsareusedwhichare $L_1$,$L_2$ and$L_3$as shownin the above figure.TheseareconnectedinsuchawaythatpairL$_1$ isstraightconnectedwhilethe pairs$L_2$and$L_3$are crossconnected. Thephasor$E_{RR'}$, joiningthetipsRandR'isvoltageacrosslamppair$L_1$.Similarly$E_{YB}$, and $E_{BY}$, arevoltages acrosslamps$L_2$and$L_3$respectively.

Ifthere isdifferencebetweenthetwofrequenciesduetodifferenceinspeedsofthetwpalternators, the lamps will become dark and bright in a sequence. This sequencetells whether incomingalternator frequencyis less orgreaterthan machine A.

ThesequenceL$_1$,L$_2$,L$_3$tellsthatmachineBisfasterasthevoltagestarR'Y'B'willappearto rotateanticlockwisewithrespecttobusbarvoltageRYB ataspeedcorresponding todifference betweentheirfrequenciesshown in the below figure. ThesequenceL$_3$,L$_2$,L$_1$tellsthatthemachineBis slowerbecausevoltagestarR'Y'B'willappeartorotateclockwisewithrespecttobusbarvoltage RYB. Theprimemover speed can be adjustedaccordinglyto match thefrequencies.




ThesynchronizationisdoneatthemomentwhenlampL$_1$ isinthemiddleofdarkperiod.Ifthe lampspairbecomingdarkandbrightsimultaneously,itindicatesincorrectphasesequencewhichcan be correct byinterchanginganytwo leads either of theincomingmachine or ofbus bars. InthismethodwhenlampL1isdarktheothertwolamppairsL2andL3andequallybright.So this method of synchronization is called**''Lamps bright and dark''method.**

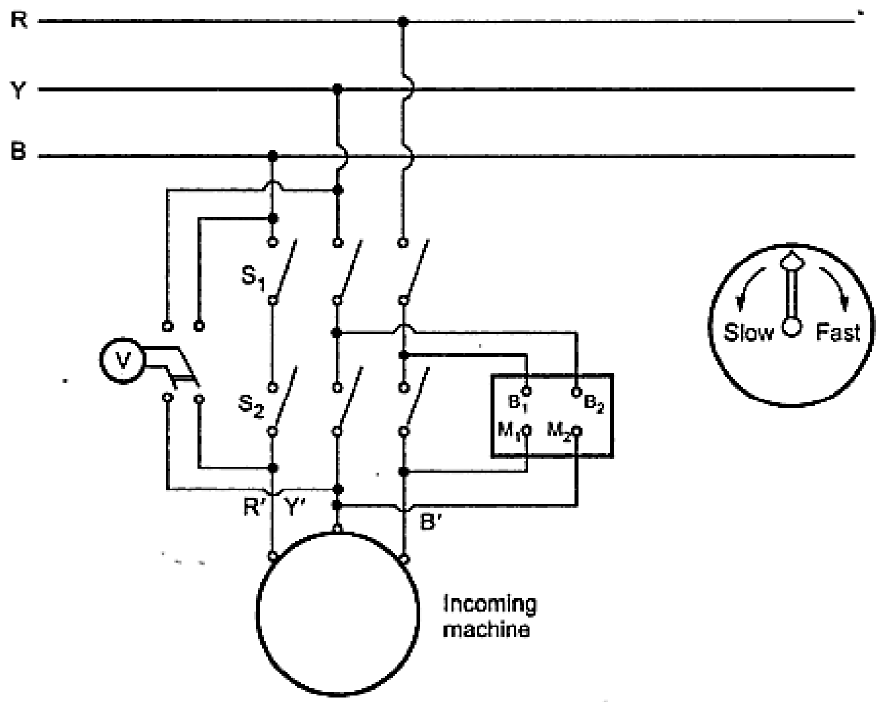
**Synchronization bySynchroscope**

Itcanbeseenthatthepreviousmethodisnotaccuratesinceitrequirescorrect senseof judgementof the operator. Hence toavoidthe personaljudgement,the machinesare synchronizedby accurate deviceknownas synchroscope.

Itconsistsofarotating pointerwhichindicatestheexactmomentofclosing thesynchronizing switch.Ifthepointerrotatesinanticlockwisedirection,itindicatesthatincoming machineisrunning slowwhereasclockwiserotationofpointerindicatesthatincoming machineisrunning faster. The rotationofpointerisproportionaltothedifferenceinthetwofrequencies.Thepointershouldrotateat averylow speed in thedirection of arrowmarkedfast as shown in the below figure.

Whentherotating pointerreachestheverticalpositionatslowspeed,theswitchmustbeclosed. Thepointerwilloscillateaboutsomemeanpositioninsteadofrotating ifdifferenceinfrequenciesis large.In suchcases the speed of incomingmachineis adjusted properly.

Theconnectionsforsynchroscope are showninFigure anytwobusbarslinesareconnectedto itsterminalswhileitsotherterminalsareconnectedtocorresponding linesofincomingmachine. The phase sequence canbe checkedwiththehelpofphase sequence indicator.The voltmeter isusedto checktheequalityofvoltageofbusbarsandincomingmachine.Thesynchronizationprocedure is alreadyexplained before.




Theuseof lamps and synchroscopetogetheris a best method of synchronization.

**Reference:**

- *B.L.Theraja&A.K.Theraja, A Textbook of Electrical Technology: AC and DCMachines, Volume - II, 23rd Edition, S. Chand & Company, New Delhi, 2012*
- *U. A. Bakshi, M. V. Bakshi, Electrical Machines-II, Second Edition, Technical Publications*