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WRITTEN BY BENJAMIN
(MARINE DEPARTMENT)

ENG 222.2

Course Outline

1 AC/DC Machines.
- Principles Of Operations

2 Transformers.

3 3-D Phase Systems
- Balanced 3D Systems
- Delta/Star Connections
- Line and Phase Voltages & Currents.

4 Measurements
- Electric Currents, Voltages, Freq and Power measurements
- Measurements Of Resistance, Capacitance and Inductance

5 Bipolar and Field effect Transistors
- Biasing, DC Characteristic, Diode characteristics and diode rectifiers (Single phase and three phase), Zener diodes and its regulating characteristics.

The resistivity (Ωm) at room temperature of a pure Silicon is 2.5×10^{3} while that Of a pure germanium is 0.6.

* Those Valence electrons which are Very loosely attached to the nucleus Of an atom are Called free electrons.
* The electrons in the Outermost Orbit Of an atom are known as Valence Electrons.
* The directed flow Of free electrons (Or charge) is Called electric Current.
* Doping is the process Of adding a Suitable impurity to a pure Semi-conductor.
* Whenever an electron leaves its Original position, It will Create a hole there which is the positive ~~~~ charge

Basic Electrical Engineering.

Semi-conductor. 7/09/20.

A conductor is any material that allows the easy flow of electric charges or current around the material.

An insulator is any material that opposes the flow of electric charges or current.

A semiconductor is any material that have the resistivity property of an insulator and a conducting property of a conductor.

Types Of Semiconductor.

Silicon and Gallium → Types of material of semiconductor.

The above can be classified / categories into:

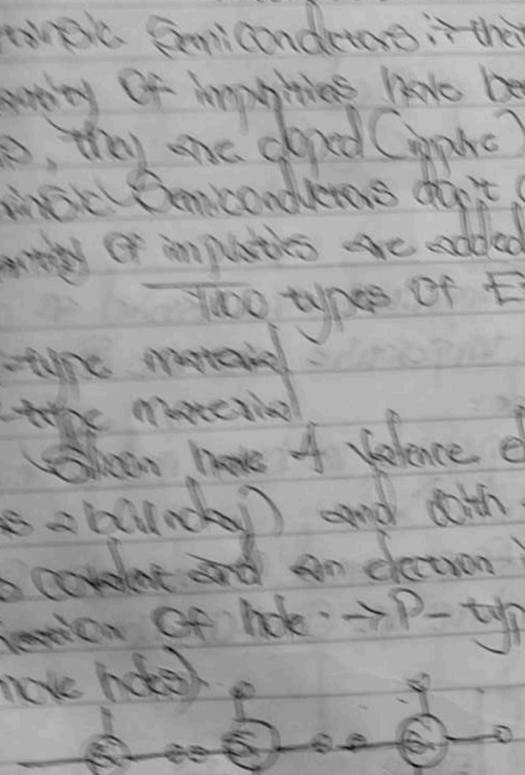
1. Intrinsic Semiconductors: they are pure in nature e.g Si & Ge
2. Extrinsic Semiconductors: they are impure in nature i.e minute quantity of impurities have been added to the pure semiconductors, they are doped (impure). They / don't / con

* Intrinsic semiconductors don't conduct electricity so a minute quantity of impurities are added so as to conduct electricity.

Two types of Extrinsic Semi-conductors.

1. N-type material
2. P-type material

Silicon have 4 valence electrons which bond with itself (as a building) and with aluminium (Al) or ~~barium~~ boron (B), the bond is covalent and an electron is shared leading to excess creation of hole → P-type material (Excess ~~of~~ free to move holes).



P-type material is doped with a trivalent element.

N.B: Hole have the ability to accept electrons i.e P-type is regarded as an acceptor.

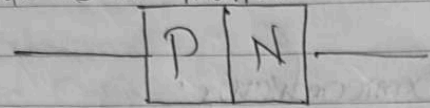
While in N-type material, it is bonded with Arsenic or Phosphorous leading to the excess free to move electrons. i.e. N-type material is doped with a pentavalent element.

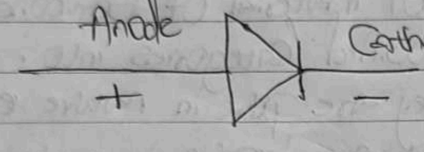
N-type is regarded as a donor

* When there is an equal number of holes or electrons, it can not conduct electricity. Electricity is conducted due to the movement of electrons.

PN JUNCTION DIODE

Diode is the intimate contact of the P and N material.





Diagrammatical representation of a Diode:

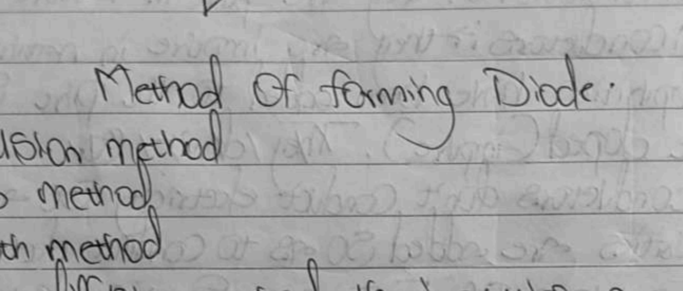
Method of forming Diode:

1 Diffusion method
2 Alloys method
3 Growth method

In diffusion method, the impurities are carried as gases and are diffused at elevated temperature into the Semi-conductor material to form Diode.

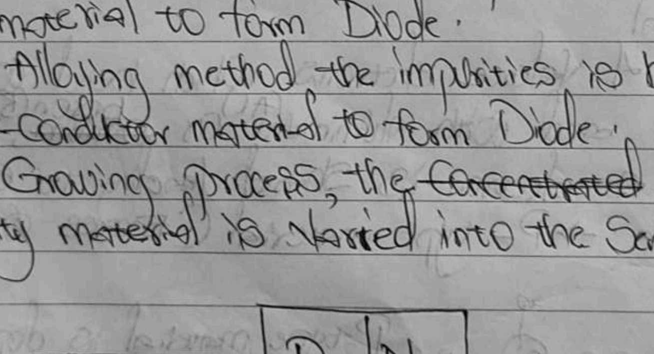
Alloying method, the impurities is been melted into the Semi-conductor material to form Diode.

Growing process, the ~~concentrated~~ concentration of the impurity material is varied into the Semi-conductor.



Forward Biase.

Due to the repulsion at both side, Diode contains/conduct current in a forward Biase



They will be a deflection.

Reverse ~~Revised~~ Biase.

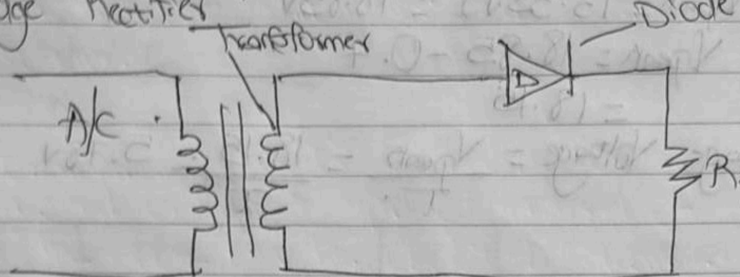
due to the attraction at both side, diode do not conduct current in a ~~ELT~~ Current reverse ~~Revised~~ Biase.

Application Of Diode.

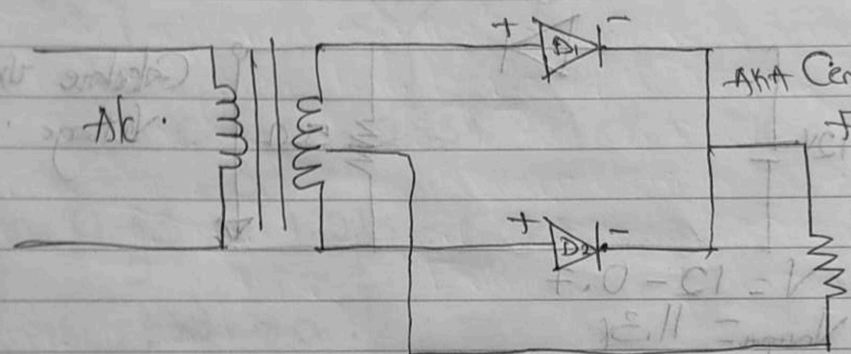
They are mostly used as a rectifier.

* Rectifiers are used to stabilize an A.C current (in a transformer) in one direction (due to use by home appliances, they use D.C current)

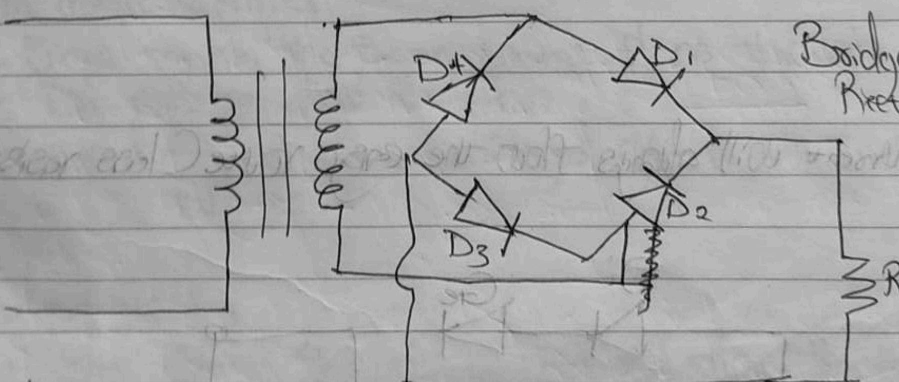
1. Half wave Rectifier
2. Full wave Rectifier
3. Bridge Rectifier



Half wave Rectifier. → Resistive Load

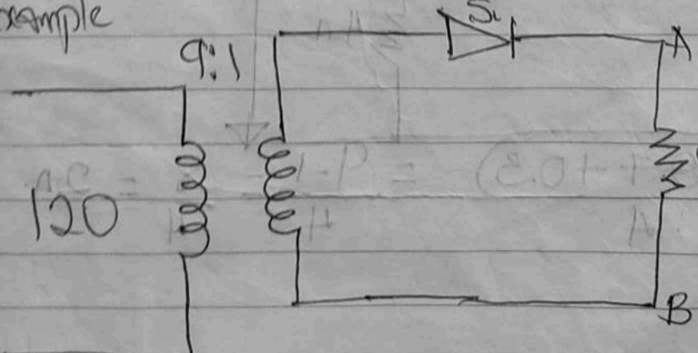


AKA Center tap. Full wave Rectifier.



Bridge Rectifier

Example



$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \Rightarrow \frac{V_s}{120} = \frac{1}{9}$$

* When there is an equal number of holes or electrons, it can not conduct electricity. Electricity is conducted due to the movement of electrons.

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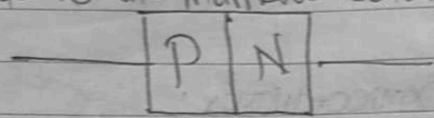

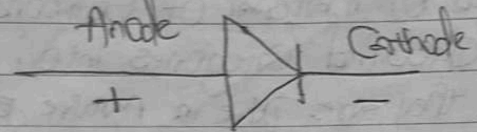

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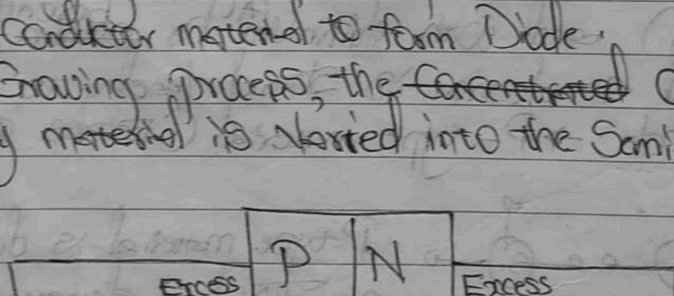
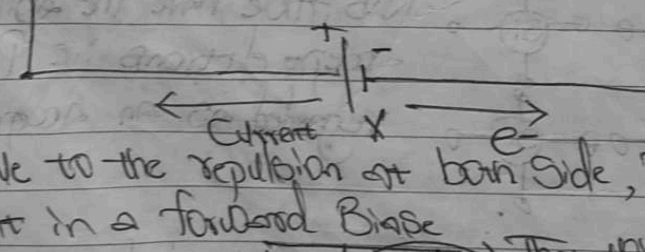


Forward Biase.

Due to the repulsion at both side, Diode contains/conduct current in a forward Biase



They will be a ~~deflection~~.

Reverse ~~Revised~~ Biase.

due to the ~~attraction~~ at both side, diode do not conduct current in a ~~If~~ reverse ~~Reversed~~ Biase.

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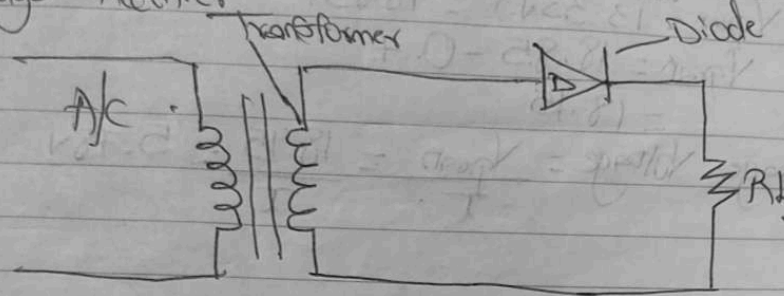
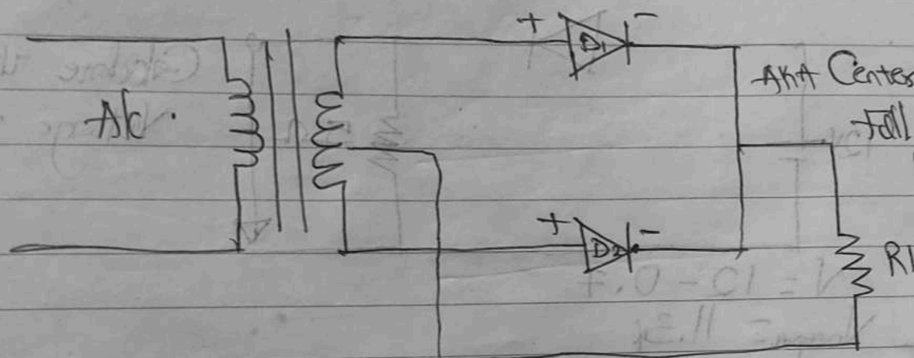


Half Wave Rectifier.

→ Resistive Load



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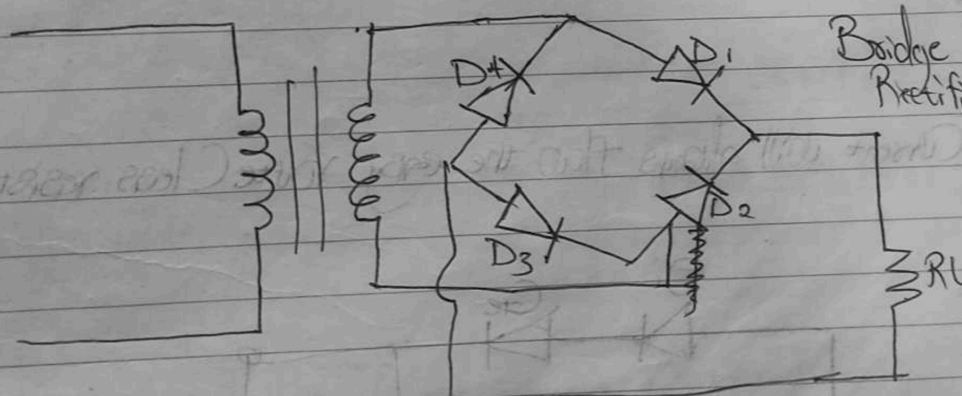
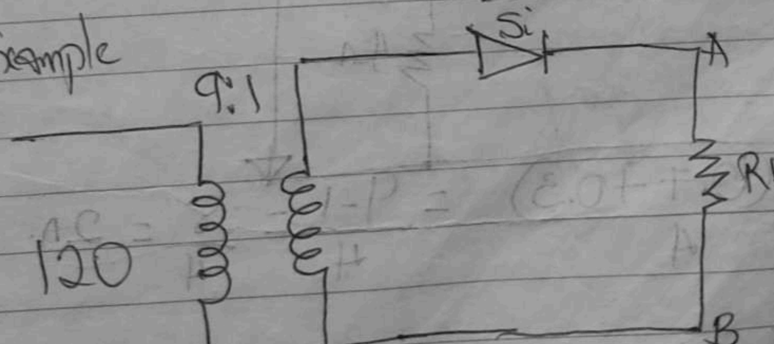


Bridge Rectifier

Example



$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \Rightarrow \frac{V_s}{120} = \frac{1}{9}$$

* Energy gap Voltage Of Si = 0.7
Energy gap Voltage Of Ge = 0.3

$V_S = \frac{120}{9} = 13.33$ Volts

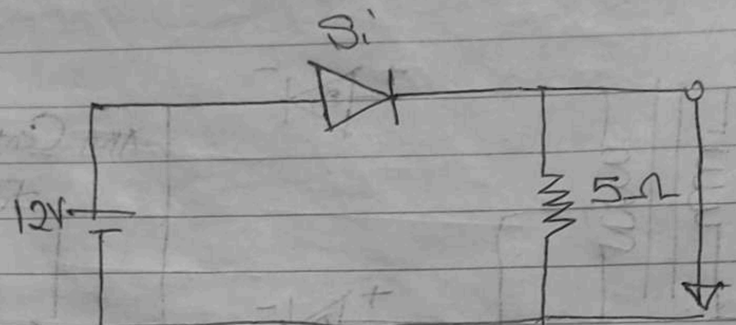
$V_{peak} = V_{r.m.s}\sqrt{2}$

$V_{peak} = 13.33\sqrt{2} = 18.85V$

$V_{peak} = 18.85 - 0.7$

$= 18.15$

Average Voltage $= \frac{V_{peak}}{\pi} = \frac{18.15}{\pi} = 5.78V$

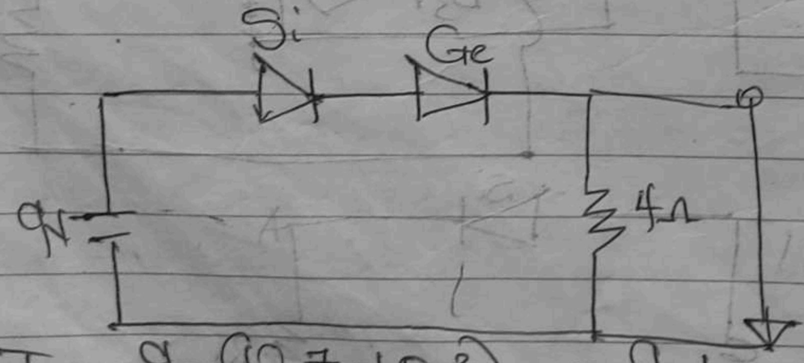


Calculate the Output Voltage.

$V = 12 - 0.7$

$V_{output} = \underline{11.3V}$

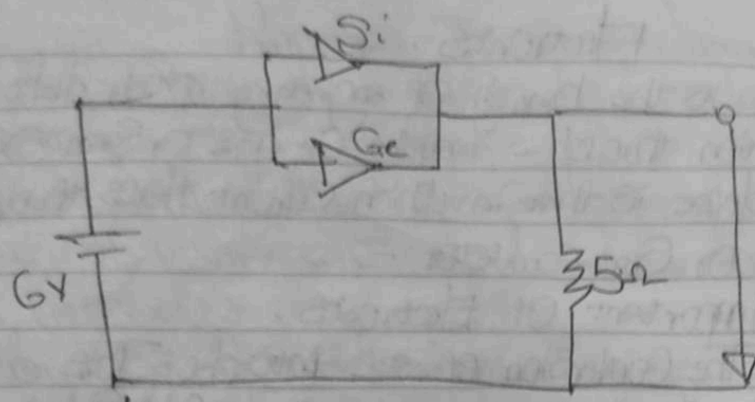
N.B Current will always flow the easy route (less resistance route)



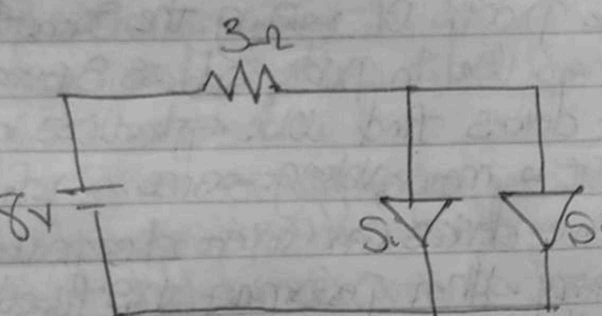
$I = \frac{9-(0.7+0.3)}{4} = \frac{9-1}{4} = \frac{8}{4} = 2A.$

$I = \frac{V}{R}$

$V_{output} = 2 \times 4 = \underline{8V}$



$I = \frac{V}{R} = \frac{6-0.3}{5} = 1.14A$



$I = \frac{8-0.7}{3} = 2.43A$

$I = \frac{2.43}{2} = 1.215 = \underline{1.22A}$

Explanation.

Full wave rectifier:

* If the signs remain the same, current flows through D_1 while D_2 will not allow the flow.
* If the + and − signs are interchanged, current will flow through D_2 but not D_1

Bridge rectifier.

* If the signs remain the same, current will flow through D_1 and D_3 while D_2 and D_4 are not conducting.
* If the signs are changed, current will flow through D_2 and D_4 while D_1 and D_3 will not conduct.

Electronics.

* Electronics is the branch of engineering which deals with Current conduction through a Vacuum or gas or Semi-conductor. An electronic device is that in which Current flows through a Vacuum or gas or Semi-conductor.

Important of Electronics.

i) Rectification :-> The Conversion of a.c into d.c. This d.c. Supply can be used for Charging Storage batteries, field Supply of d.c generators, electroplating etc.

ii) Amplification :-> The Process of raising the Strength of a weak Signal. They are used in public address System, television.

iii) Control :-> Electronic devices find wide applications in automatic Control e.g Speed of a motor, Voltage across a refrigerator etc.

iv) Generation :-> Electronic devices can convert d.c power into a.c power of any frequency. When performing this function, they are known as Oscillators.

v) Photo-electricity :-> Conversion of light into electricity.

vi) Conversion of electricity into light.

* The Valence electrons determine the physical and chemical properties of a material.

* Energy levels :-> electrons moving in a particular Orbit possess the energy of that Orbit. The larger the Orbit, the greater is its energy. Energy band is the range of energies possessed by an electron in a Solid.

* Valence band is the range of energies (band) possessed by Valence electrons. Conduction band is the range of energies (i.e band) possessed by conduction band electrons. Forbidden energy gap is the Separation between conduction band and Valence band on the energy level diagram.

⇒ Insulators :-> In terms of energy band, the Valence band is full while the conduction band is empty; the energy gap is Very large.

⇒ Conductors :-> the Valence and conduction bands overlap each other; a Slight potential difference across a conductor causes the free electrons to constitute electric current.

⇒ Semiconductors :-> the Valence band is almost filled and conduction band is almost empty, the energy gap is Very Small

Properties Of Semiconductors.

i) The resistivity Of a Semiconductor is less than an insulator but more than a conductor.

ii) Semi-conductors have negative temperature co-efficient Of resistance i.e. the resistance Of a Semiconductor decreases with the increase in temperature.

iii) When a Suitable metallic impurity (eg Arsenic, gallium etc) is added to a Semi-conductor, its Current conducting properties change appreciably.

* A Substance in which the atoms or molecules are arranged in an Orderly pattern is known as a Crystal. All Semi-conductors have a Crystalline Structure.

Effect of temperature on Semiconductors.

1. At absolute zero:-> covalent bonds are very strong, all the electrons are tightly held by the Semi-conductor atoms. There are no free electrons, Semiconductor Crystal behaves as a perfect insulator.

11. Above absolute zero:-> Conducting properties.

* Thermal energy creates hole-electron pairs.

* Intrinsic Semi-Conductor has little Current conduction capability at room temperature.

=> In n-type, the majority Carriers are electrons and the minority Carriers are holes while in P-type, the majority Carriers are holes while the minority Carriers are electrons.

Important terms (Often Used with Pn junction).

i) Breakdown Voltage:-> is the minimum reverse Voltage at which Pn junction breaks down with Sudden rise in reverse Current.

ii) Knee voltage:-> is the forward Voltage at which the current through the junction Starts to increase rapidly.

Limitations in the Operating conditions Of Pn junction.

i) Maximum forward Current:-> is the highest instantaneous forward Current that a pn junction can conduct without damage to the junction (F.C. > than this rating, the junction will be destroyed due to Overheating).

ii) Peak inverse Voltage (PIV):-> is the maximum reverse Voltage that can be applied to the Pn junction without damage to the junction. If the reverse Voltage across the junction exceeds its PIV, the junction may be destroyed due to excessive heat.

* iii) Maximum power rating :-> is the maximum power that can be dissipated at the junction without damaging it.
* A Crystal diode has two terminals. When it is connected in a circuit, one thing to decide is whether the diode is forward or reverse bias.

Equivalent Circuit Of Crystal Diode.

i) Approximate Equivalent Circuit :-> When the forward voltage V_F is applied across a diode, it will not conduct till the potential barrier V_0 at the junction is overcome.

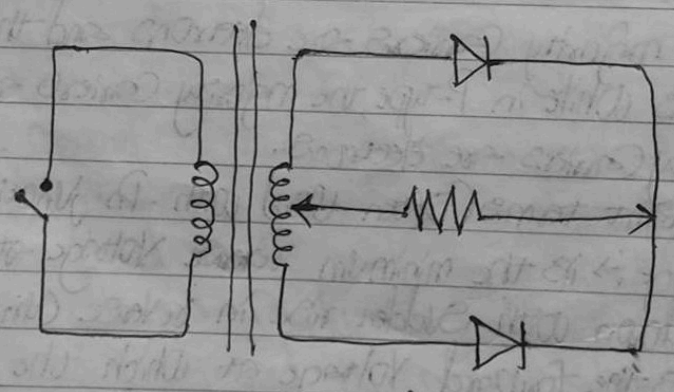
$$V_F = V_0 + I_F r_F$$

For a Silicon diode $V_0 = 0.7V$, Ge diode $V_0 = 0.3V$.

ii) Simplified Equivalent Circuit :-> For most applications, the internal resistance (r_f) of the crystal diode can be ignored in comparison to other elements in the equivalent circuit.

iii) Ideal diode model :-> is one which behaves as a perfect conductor when forward bias and as a perfect insulator when reversed bias.

$$I_{D.C} = \frac{I_{A.C}}{\pi}$$



Center Tap Rectifier.

Crystal Diode Rectifiers.

The main a.c supply is rectified by using crystal diodes. The following two rectifier circuits can be used:

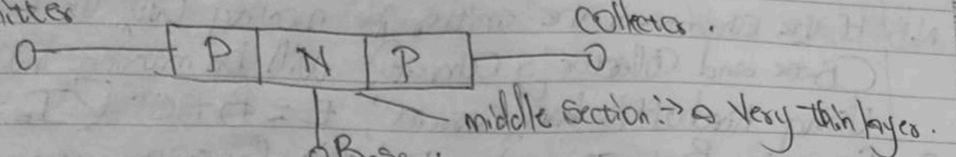
1. Half wave rectifier
2. Full wave rectifier < Centre-tap full wave rectifier / Full wave bridge rectifier

In Half wave rectifier current always flows in one direction (i.e d.c) through the load though after every half-cycle.

In a full wave rectifier, it utilizes both half cycles of input a.c voltage to produce the d.c output.

12/10/22.

Bipolar Junction Transistor.



It is a three terminals and is used for amplification of electrical Signals. In transistor, the majority Carrier will Supply the charges to the base.

Transistor may be regarded as a Combination Of two diodes connected back to back.

The majority carriers are Supplied from the Emitter to the base and the Collector terminal will receive the charges. The emitter is heavily doped to enable charges to Occur while the collector is lightly doped.

Condition Of Bipolar Junction Transistor.

The emitter to base is a forward biase

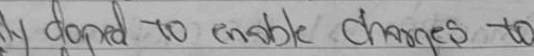
The collector to base is a Reverse biase.

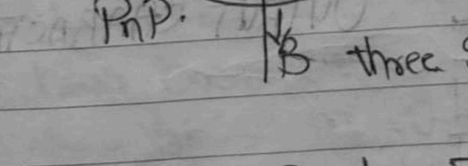
Types Of Bipolar Junction Transistor

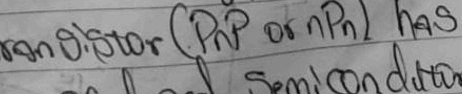
1. PNP Transistor:⇒ N is Sandwich between the two P material.
2. NPN Transistor:⇒ P is Sandwich between the two N material.

Difference between PNP and NPN Transistor.

PNP :⇒ the Current Signal is moving inward at the Emitter terminal while for the NPN, it is moving Outward.







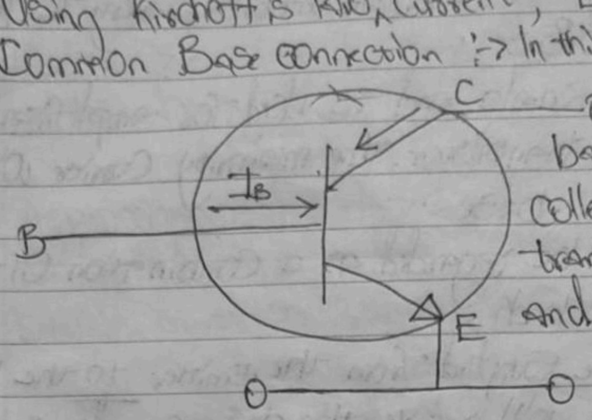
A transistor (PnP or nPn) has three Sections Of doped Semiconductors.

Configuration Of Bipolar Junction Transistor (Transistor Connection)

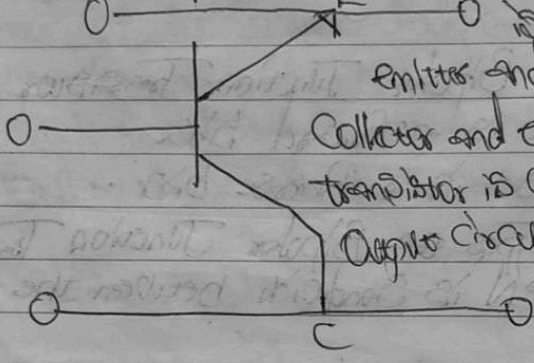
1. Common collector Connection:⇒ input is applied between base & Collector while Output is taken between the emitter and collector. Here, collector of the transistor is common to both input and output circuits.

* NB If the current at the emitter is moving Outward, the Other two (Base and Collector's current) will be moving Inward.
Using Kirchoff's law of current; E = B + C. ($I_E = I_B + I_C$)

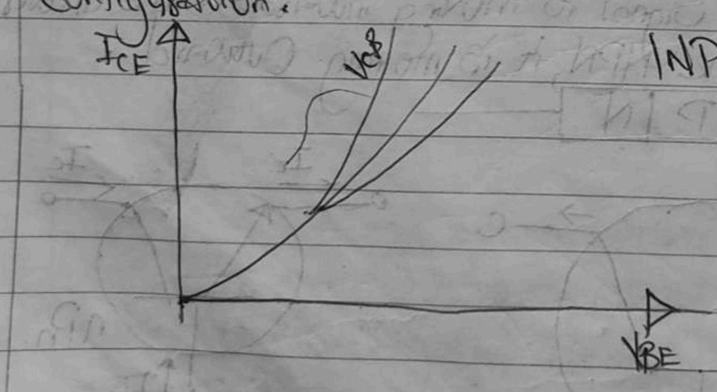
2. Common Base Connection :-> In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base. Here, base of the transistor is common to both input and output circuits.

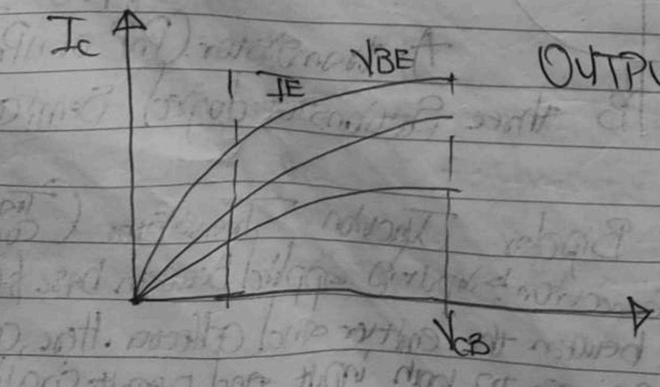


3. Common Emitter Connection :-> In this circuit arrangement, input is applied between base and emitter and output is taken from the Collector and emitter. Here, emitter of the transistor is common to both input and output circuits.



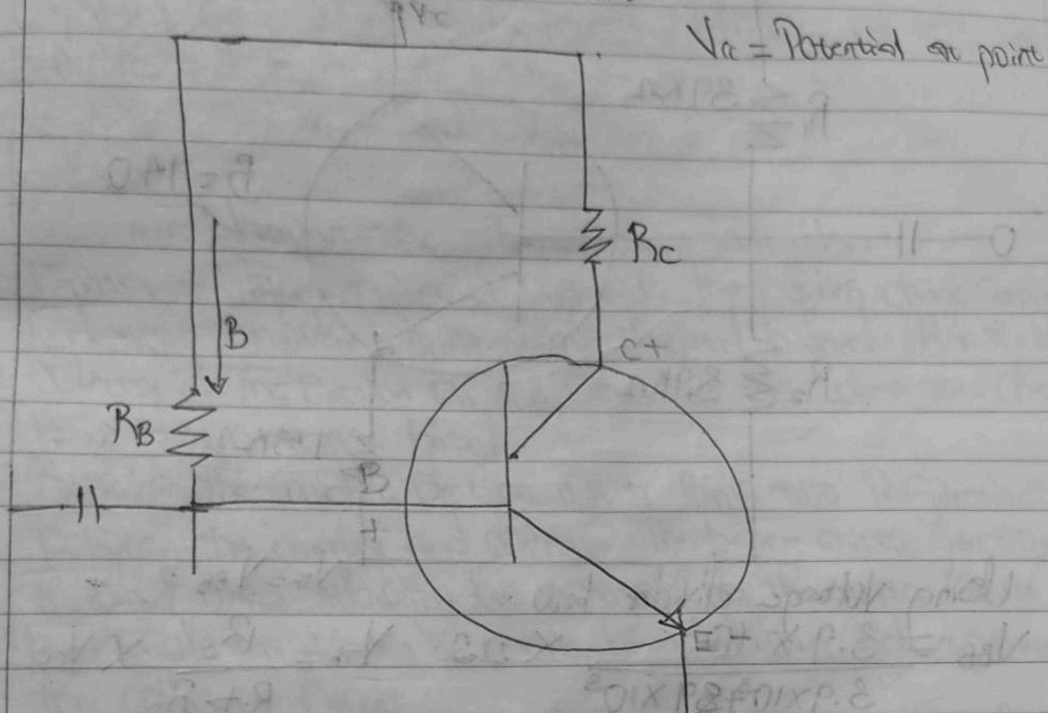
Input and Output characteristics of all the different configuration.





* For the transistor to conduct, it needs to be biase with different type of Circuit.

Fixed Biase Circuit.



$V_{CC} = I_B R_B + V_{BE}$

To calculate base Current I_B

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

After calculating for I_B, We see;

$I_C = \beta I_B$ ⇒ To calculate I_C.

$V_{CC} = I_C R_C + V_{CE}$

$V_{CE} = V_{CC} - I_C R_C$.

Example. $V_{CC} = 12V$, $R_C = 22\Omega$ $I_B = 4708.33\mu A$

$R_B = 2.4K\Omega$

NB: For Silicon Vibrator $(V_{BE}) = 0.7$

$R_B = 2.40k\Omega$ $\beta = 50$.

$I_C = \beta I_B = 50 \times 4708.33\mu = 235416.5\mu$

$I_C R_C = 235416.5\mu \times 22 = 5.18V$

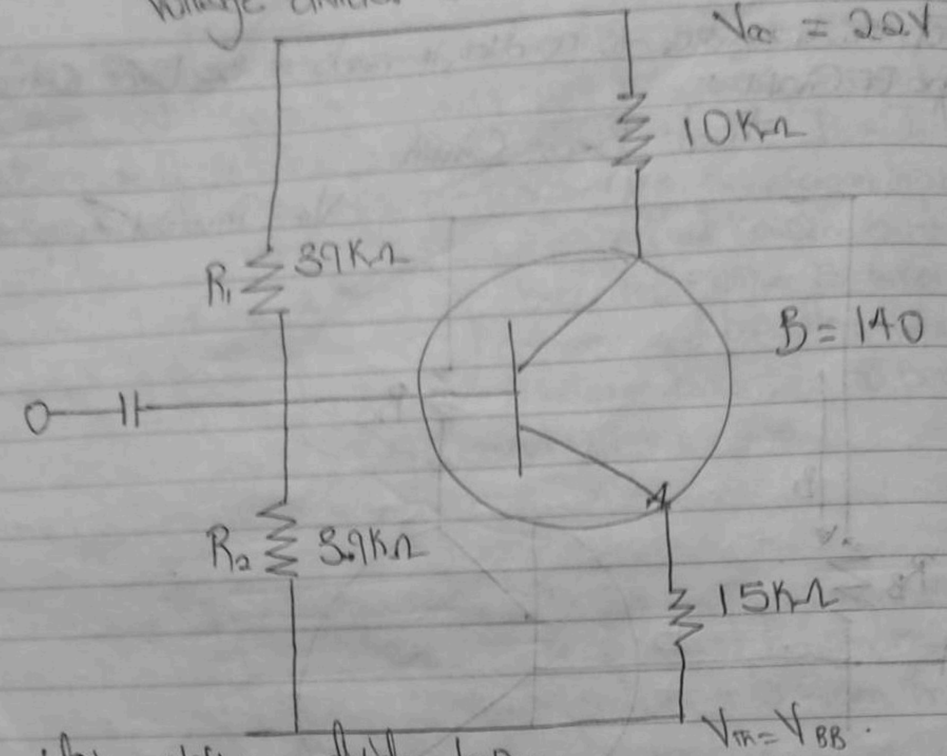
$V_{CE} = V_{CC} - I_C R_C = 12 - 5.18 = 6.82V$

⇒ Collector bias based Circuit.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.7}{2.4 \times 10^3} = 4.70833 \times 10^{-3}$$

$I_B = 4708.33 \times 10^{-6} = 4708.33\mu A$

Voltage divider bias Circuit.



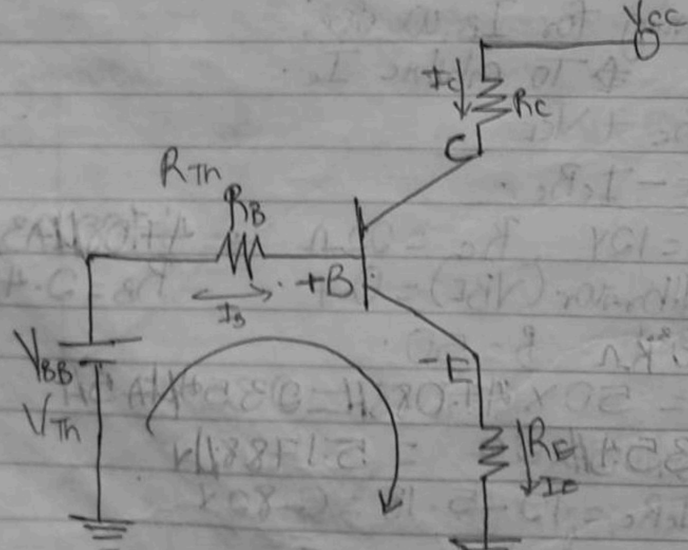
Using voltage divider law.

$$V_{BB} = \frac{3.9\times10^3}{3.9\times10^3 + 39\times10^3} \times 22 \qquad V_{Th} = \frac{R_2}{R_1 + R_2} \times V_{cc}$$

$V_{BB} = 2$ volts.

$$R_B \text{ (equivalent resistance)} = \frac{3.9\times10^3 \times 39\times10^3}{3.9\times10^3 + 39\times10^3} \qquad R_{Th} = R_B \; (R_1 // R_2)$$

$R_B = 3.545 \times 10^3$ KΩ



$V_{BB} = I_B R_B + I_E R_E + V_{BE}$

$I_E = I_C + I_B$

$I_E = \beta I_B + I_B$ but $I_C = \beta I_B$.

$I_E = (\beta + 1) I_B$

$I_B = 6.04 \times 10^{-6} A$.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B + (\beta+1) R_E}$$

$$V_{CE} = 22 - 0.85 \times 10^{-3} \times 10 \times 10^{3} - 140 \times 6.0 \times 10^{-6} \times 15 \times 10^{3}$$

$\Rightarrow V_{CC} = I_C R_C + I_E R_E + V_{CE}$;

$V_{CC} = I_C (R_C + R_E) + V_{CE}$

Naming the Transistor Terminals.

* Emitter :-> The section on one side that supplies charge carriers (electrons or holes). It is always forward biased w.r.t base.
* Collector :-> The section on the other side that collects the charges. It is always reverse biased.
* Base :-> The middle section which forms two PN junctions between the emitter and collector. The base-emitter junction is forward bias allowing low resistance for the emitter circuit. The base-collector junction is reverse bias allowing high resistance to the collector circuit.

The transistor has two Pn junction i.e two diodes. The junction between emitter and base may be called emitter-base diode or simply the emitter diode. The junction between the base and collector may be called collector-base diode or simply collector diode.

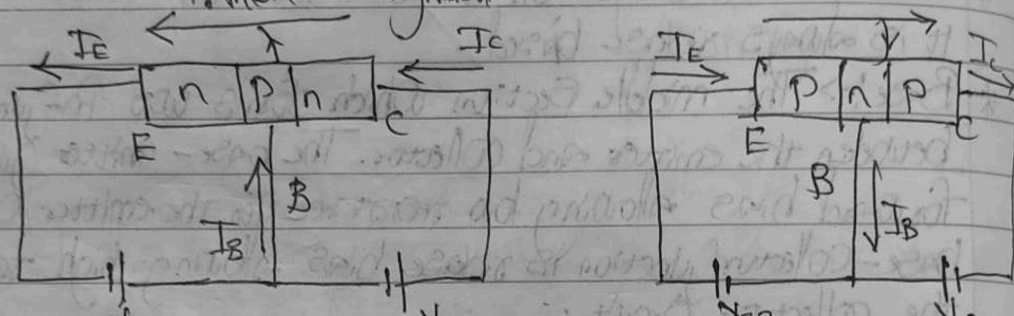
Working of nPn transistor.

The forward bias causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current IE. As these electrons flow through the P-type base, they tend to combine with holes. As the base is lightly doped and very thin, therefore only a few electrons (less than 5%) combine with holes to constitute base current I_B. The remainder (more than 95%) cross over into the collector region to constitute collector current I_C. In this way, almost the entire emitter current flows in the collector circuit. It is clear that emitter current is the sum of collector and base currents i.e $I_E = I_B + I_C$.

Working of PnP transistor.

The forward bias causes the holes in the P-type emitter to flow towards the base. This constitutes the emitter current I_E. As these holes cross into n-type base, they tend to combine with the electrons. As the base is lightly doped and very thin, therefore, only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) cross into the collector region to constitute collector current I_C. In this way, almost the entire emitter current flows in the collector circuit. It may be noted that current conduction within PNP transistor is by holes. However, in the external connecting wires, the current is still by electrons.

Transistor Symbols.



DC Machine

It is divided into two part:→

- DC Generator
- DC Motor

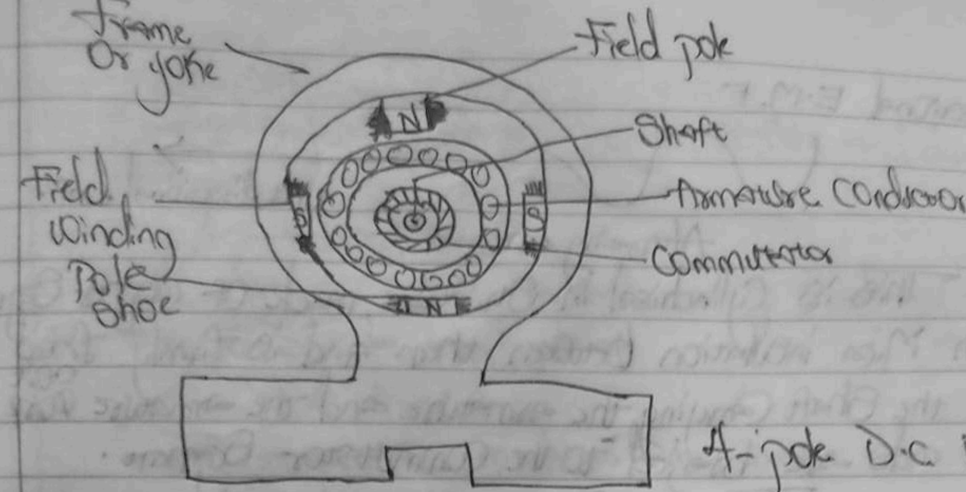
D.C machine have two main part:→

1. Stator
2. Rotor

Stator is the stationary part of the machine while the Rotor is the rotating part.

Method of Winding

* Lap Winding
* Wave Winding



4-pole D.C Machine

The parts Of a D.C machine are

1 Field pole
2 Armature Conductor
3 Commutator
4 Frame Or yoke
5 Pole shoe
6 Field Winding
7 Shaft

Field pole:→ The field pole are located on the Stator (Stationary part Of the machine) and are projected inward from the inside Surface Of the Iron Cylinder that forms the Stator yoke. There are made up Of ~~electromagnetic~~ electrode magnet, Wherein a iron laminated core is wound with well insulated enameled copper wire.

Exam

Frame Or Yoke:→ This is the Outermost part Of the machine made Of cast Steel Which is the mechanical enclosure Of the machine to protect it from dust and moisture. → stator

Pole Shoe:→ A pole shoe, usually laminated, distribute magnetic flux Over the rotor Surface.

Field Winding:→ This is an exciting winding in each Of the iron pole, Which has a narrow part than is placed in the pole core. → stator.

Armature Conductor:→ This is the rotating part Of the machine made up Of laminated iron core, Cylindrical in construction with Slot On its periphery. Insulated copper core are lay in this slot, and this cores are connected for lap or wave connection.

Commutator:→ as the induced E.M.F in the armature is alternating, Commutator Convert alternating E.M.F into Unit directional E.M.F

Alternating emf — Unit directional emf.

This is Cylindrical in Structure, made of copper Segment with Mica insulation between them and is firmly fixed into the Shaft Carrying the armature and the armature coil free ends are brazed to the commutator Segment.

Types Of DC machine

There are two types of DC machine

1. DC generator
2. DC motor

A DC generator is a rotating machine that convert mechanical energy to electrical energy. e.g Alternator in Car

Types Of D.C generator

D.C. generator are classified on the basis of two method of exciting the field coils. These are:

1. Separately Excited
2. Self Excited.

Separately Excited generator:-> In this type, the field coil are excited from an independent DC source.

Self Excited generator:-> In this type, the excitation of the field coil are done by feeding back a part of the output of the generator. Self Excitation can be done in three ways:

1. By connecting the field coils across the armature: This is called Shunt excitation.
2. Series excitation:-> is done by connecting the field coils in Series with the armature.
3. Compound excitation:-> This is a combination of Shunt and Series excitation.

Principle of Operation Of a D.C generator.

Whenever a coil is rotating in a magnetic field, an emf is induced in the coil

$$e = BLVsin\theta$$

where B is flux density. (Wb → Webber)

L is length of coil (m)

V = Velocity (m/s)

θ = Angle between the direction of flux and direction of rotation.

e = induced emf

The direction of the induced emf is fixed by applying the fleming's right hand rule.

DC motors

DC motors are machines that convert electrical energy into mechanical energy eg fan

The method of excitation for DC generator is the same with DC motor

Principle of Operation of a DC motor

Whenever a current coil is displaced under a magnetic field, the coil experiences a mechanical force

$F = BIL\sin\theta$

where F = Force

B = flux density

I = Current

L = length in metre

The direction of force is fixed by applying the fleming's left hand rule.

EMF Equation.

P is number of Pole

Z is number of armature conductors.

A is number of parallel paths

N is speed of rotation

t is time

$$E = \frac{PNZ\phi}{60A}$$

Example

A 4-pole generator with wave armature has 51 slots, each having 24 conductors. The flux per pole is 0.01Wb. At what speed must be armature be rotating, given an induced e.m.f of 220v. What will be the voltage developed if the winding is lap and the armature rotate at same speed.

N.B For wave winding A = 2

For lap Winding A = no of pole.

Solution

$P = 4$

slot = 51

Conductor = 24

$\phi = 0.01 Wb$

Z = Slot × No of Conductors

$= 51 \times 24$

$Z = 1224$

I $E = \frac{PZN\phi}{60A}$

$E = 220V$

$220 = \frac{4 \times 1224 \times N \times 0.01}{60 \times 2}$

$N = \frac{26400}{48.96}$

$N = 539.22 RPM$.

II $E = \frac{\cancel{4} \times 539.2 \times 1224 \times 0.01}{60 \times \cancel{4}}$

$E = 109.99 \simeq 110V$

$A = P$ → For lap winding.

Back EMF

* It helps to regulate armature Current in a motor. Back EMF is the real Cause Of the production Of torque in a motor.

Back EMF $E = V - I_a R_a$.

Where

E = Back EMF

V = applied EMF

I_a = Armature Current

R_a = Armature Resistance.

Torque Equation.

P = Total number of Poles.
Z = Total number of armature conductors.
Φ = flux per pole
N = Speed of rotation (rpm)
T = ~~Thrue~~ Torque (Nm)

Recall

$$E = V - I_a R_a$$

$$EI_a = VI_a - I_a^2 R_a$$

EI_a = Total power output of the armature which is the electrical power converted into mechanical power and is also called electromechanical power.

$I_a^2 R_a$ = Armature copper loss.

VI_a = Power input to the armature.

The equivalent mechanical power $= \frac{2\pi NT}{60}$

$$EI_a = \frac{2\pi NT}{60}$$

Recall

$$E = \frac{PNZ\Phi}{60A}$$

$$\left(\frac{PNZ\Phi}{60A}\right) I_a = \frac{2\pi NT}{60}$$

$$\left(\frac{PZ\Phi}{A}\right) I_a = 2\pi T$$

$$T = \frac{PZ\Phi I_a}{2\pi A} \rightarrow \text{Torque Equation.}$$

Example

A 500V Shunt motor has 4 poles and a wave connected winding with 492 conductors. The flux per pole is 0.05Wb. The full load current is 20A. The armature and Shunt field resistance are 0.1Ω and 250Ω respectively. Calculate the Speed and the developed torque

Solution.

$P = 4$
$V = 500V$
$Z = 492$

$R_{s} = 250$
$R_{a} = 0.1$
$\Phi = 0.05$
$I_{FL} = 20A$.
$I_{sh} = \frac{V}{R_{sh}} = \frac{500}{250}$
$I_{sh} = 2A$
$I_{FL} = I_a + I_{sh}$
$I_a = I_{FL} - I_{sh}$
$= 20 - 2$
$I_a = 18A$
$E = V - I_a R_a$.
$= 500 - (18 \times 0.1)$
$E = 498.2V$
$E = \frac{PNZ\Phi}{60A}$
$N = \frac{E}{PZ\Phi}(60A)$
$N = \frac{60AE}{PZ\Phi}$
In Wave Winding
$A = 2$
$N = \frac{60(2 \times \cancel{8}\ 498.2)}{4 \times 492 \times 0.05} = 607.56RPM$.

Exercise :> Solve for lap Winding; the Same question.

$T = \frac{PZ\Phi I_a}{2\pi A}$
$= \frac{4 \times 492 \times 0.05 \times 18}{2\pi \times 2}$
$T = 140.95Nm$

Synchronous Generator/Machine

A Synchronous machine is an A.C rotating machine whose speed, Under Steady State condition is proportional to the frequency of the current in its armature. By definition, Synchronous generators produce electricity whose frequency is Synchronies with its mechanical speed

The relationship between Synchronous Speed and frequency is $F = \frac{PNs}{120}$

Where f = electric frequency (Hertz)
Ns = Synchronous Speed
P = No of poles.

Synchronous machine are commonly used as generators especially for large power System. Example Turbine, hydro-electric generator in power ~~Grid~~ ~~Grid~~ Grid.

Scheme of Work. 25/10/22

1. Three phase A.C. Circuit.
2. Measuring of power in 3 phase A.C Circuits
3. Television

Polyphase

Polyphase is the combination of Several Single phase Voltages with the Same magnitude frequency but apart in electrical degrees.

$$\text{No of phase} = \frac{360}{\text{Electrical degrees}}$$

For 3.θ

$$\text{Electrical degrees} = \frac{360}{3} = 120°$$

For 2 phase

$$\frac{180}{\theta} = \frac{180}{2} = 90° \text{ (Electrical quadrature)}.$$

Advantages Of 3 Phase System.

1. Three phase System are Self Starting.
2. A three phase alternator Of the Same Size, has a high Output rate compared to a Single phase alternator.
3. A three phase alternator Of the Same output has a Smaller Size compared to a Single phase alternator.
4. A three phase System has lower Vibration Compared to single phase machines.

Examples Of Single phase System :→ Fan, grinding machine.
Examples Of three phase System :→ Generator.

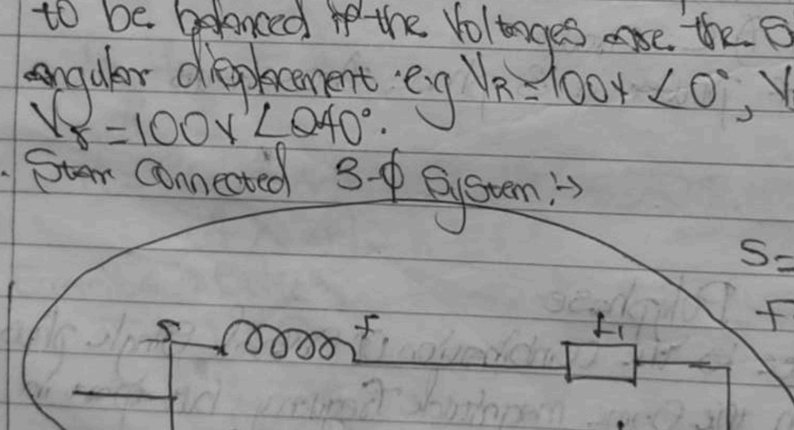
5. Three phase Systems are Cheaper compared to Single phase

Every three phase System Can :→

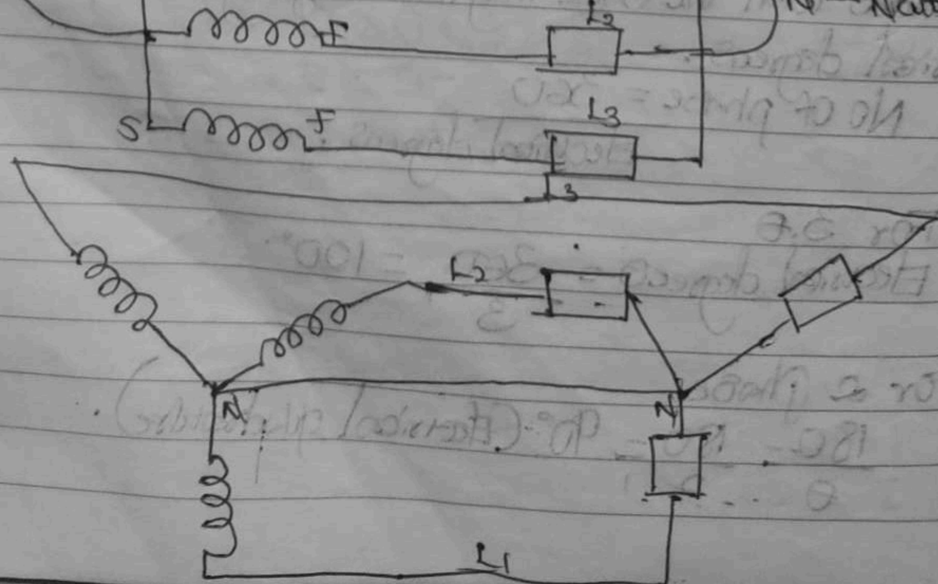
* It can either be balanced Or Unbalanced
* It can Either be ~~Dela~~ Delta Or Star.

Types Of three phase Systems.

1. Unbalanced three phase System (3ϕ) :→ A three phase System is Said to be Unbalanced when the Voltages are different in magnitude Or the angular displacement are different.
2. Balanced 3-ϕ System :→ A three phase System is Said to be balanced if the Voltages are the Same with equal angular displacement e.g $V_R = 100V\angle 0^\circ$, $V_B = 100V\angle 120^\circ$ and $V_Y = 100V\angle 240^\circ$.
3. Star Connected 3-ϕ System :→



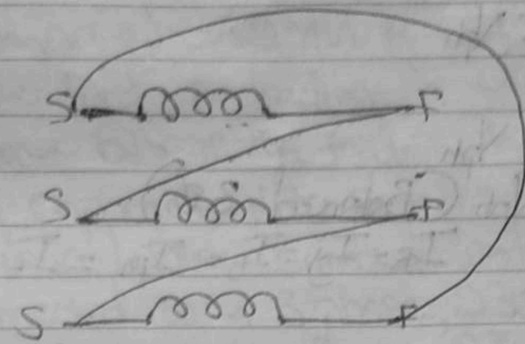
S = Starting point
F = Finishing point
L - Load
N - Neutral

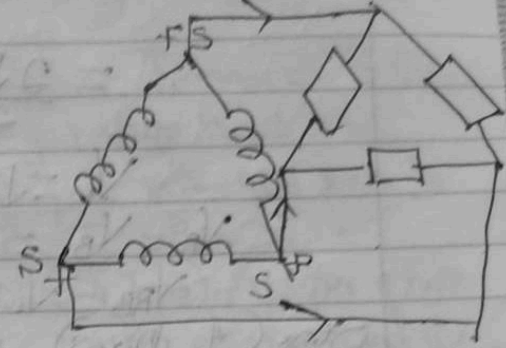


In Star Connection, the start connects to the start and the finish to the finish. There is Neutral point.

4 Delta connected 3 Φ System: In Delta connection, the start connect to the finish and there is no neutral.

N.B In Star, you need neutral to complete the circuit.

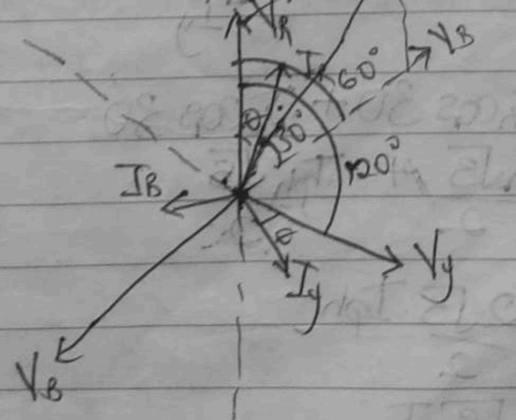




Difference between Star and Delta connections.

	Star	Delta
1.	Neutral point available	No neutral point.
2.	Line Current equals Phase Current	line Current higher than phase Current.
3.	~~Phase~~ Line Voltage higher than phase Voltage	Line Voltage equals phase Voltage.
4.	Power $= \sqrt{3}\, V_m I_m \cos\theta$	Power $= \sqrt{3}\, V_m I_m \cos\theta$. Both Side power is the Same.

Line Voltage in Star Connection



R = Red wire   B = Blue wire

Y = Yellow wire

The travel of one front to another (rotation) is called Electrical degrees while the travel of immediate neighbours is called the Mechanical degree.

$$V_{RB} = V_R \cos 30 + V_B \cos 30^\circ$$
$$= V_{ph}\frac{\sqrt{3}}{2} + V_{ph}\frac{\sqrt{3}}{2}$$
$$= \frac{2\sqrt{3}}{2} V_{ph}$$
$$V_L = \sqrt{3}\, V_{ph}$$
$$V_R = V_B = V_{ph} \text{ (Balanced } 3\phi)$$
$$V_{RB} = V_L \qquad I_R = I_y = I_B = I_{ph} = I_L.$$

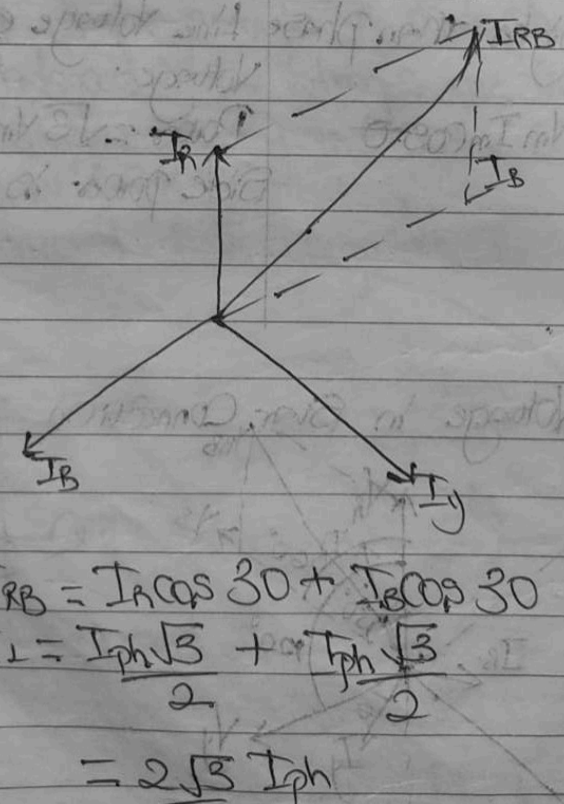
Star (4 wires)

Delta (3 wires)

Types of current flow

* Line current (line to line).
* Phase current (line to neutral connection).

Line Current in Delta Connection



$$I_{RB} = I_R \cos 30 + I_B \cos 30$$
$$I_L = I_{ph}\frac{\sqrt{3}}{2} + I_{ph}\frac{\sqrt{3}}{2}$$
$$= \frac{2\sqrt{3}}{2} I_{ph}$$
$$\underline{I_L = \sqrt{3}\, I_{ph}.}$$

Electri-

1 A balanced 3 phase Star connected load of 18KW taken a leading current of 60A when connected across a 3 phase 440V, 50 Hz supply. Find the values and nature of the load (Hint find the reactance, impedance and resistance)

N.B The nature of the load: is it a leading load or a lagging load

ANS Impedance (Z) = 4.234 Ω, Resistance R = 1.67 Ω, Reactance 3.892 Ω

* If the load is leading, it tells you that it is an Inductor but if the load is lagging, it tells you that it is a Capacitor N.B $Z = R + X_L$, $Z = R - X_C$.

2. A balanced star connected load of $(8 + j6)$ Ω per phase is connected to a 3 phase, 230V, 50Hz supply. Find the line current, power factor, Power, Volt ampere and the Reactive power. Draw the phasor diagram of the above circuit and the circuit diagram.

Ans Line Current = 13.28A, Power factor = 0.8 lagging, Volt ampere = 5.29 KVA, Reactive power = 3.174 KVAR, Power = 4.232 KW

3. A balanced delta connected load of $(12 + j9)$ Ω per phase is connected to a 3-phase 400V supply. Find (a) Line current (b) Power factor (c) Power drawn (d) Reactive Volt ampere (e) Total Volt ampere.

Ans Line Current = 46.2A (b) P.F = 0.8 lagging (c) Power drawn = 25.6KW (d) RVA = 19.2KVAR (e) TVA = 32KVA

4 Each phase of a Delta connected load has a resistance of 25 Ω, and a ~~impedance~~ Inductance of 0.15H and a capacitance of 120μF in series. The load is connected across a 400V, 50Hz 3 phase supply. Determine the line current, Active power & Reactive Volt ampere.

Ans ⇒ L.C = 21.38A, A.P = 11.43 KW, RVA = 9.42 KVAR

Solution

Star

1. $P = 18KW = 18000W$

$I_L = 60A$ leading

$V_L = 440V$, 50Hz

$R = ?$ $X = ?$ $Z = ?$

Power in each phase = $\frac{18,000}{3}$

$= 6000W$

$I_{ph} = 60A$

$\therefore I_{ph} = I_L$

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}} = 254V$

$V = IZ$

$Z = \frac{V}{I} = \frac{254}{60} = 4.23\Omega$

$P = I^2R$

$R = \frac{P}{I^2} = \frac{6000}{(60)^2}$

$= 1.67\Omega$

$Z = \sqrt{R^2 + X^2}$

$Z^2 = R^2 + X^2$

$X = \sqrt{Z^2 - R^2}$

$= \sqrt{(4.233)^2 - (1.67)^2}$

$X = 3.89\Omega$

Nature of load is lagging

N.B Whenever the Current is leading, the load is lagging i.e the load is always the opposite of the Current.

N * You solve using the phase Value not the line Value.

2. Star

$Z = (8 + j6)\Omega$

$V_L = 230V$, $50Hz$

$I_L = ?$ $P.F = ?$ $P = ?$, $VA = ?$ $KVAR = ?$

N.B $Z = R + jX$

Resistance = R, X = Reactance.

$V_{ph} = \frac{230}{\sqrt{3}} = 132.8V$

$V = IZ$

$I = \frac{V}{Z}$

$Z = \sqrt{8^2 + 6^2} = \sqrt{64 + 36} = \sqrt{100} = 10\Omega$

$I_{ph} = \frac{132.8}{10} = 13.28A$

$I_{ph} = I_L$

$I_L = 13.28A$

$P.F = \cos\theta = \frac{R}{Z} = \frac{8}{10} = 0.8$

$P = 3I^2R$ (3 phase)

$= 3 \times (13.28)^2 \times 8 = 4230.6W$

$= 4.23KW$

Or

$P = \sqrt{3} V_m I_m \cos\theta = \sqrt{3} V_L I_L \cos\theta$

$= \sqrt{3}(230)(13.28)(0.8)$

$= 4232.3W$

$= 4.23KW$

$VA = 3I_{ph}V_{ph} = 3 \times 13.28 \times 132.8$

$= 5290.75 VA$

$= 5.29KVA$

Or

$VA = \sqrt{3} V_m I_m = \sqrt{3} V_L I_L$

$= \sqrt{3} \times 230 \times 13.28$

$= 5290.38VA$

$= 5.29KVA$

$KVAR = 3I^2X = 3 \times (13.28)^2 \times 6$

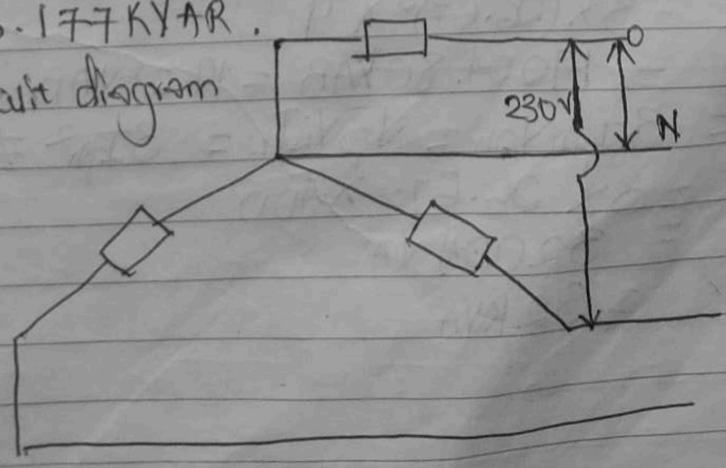
$= 3174.45 = 3.17KVAR$

$= \sqrt{KVA^2 - Power^2}$

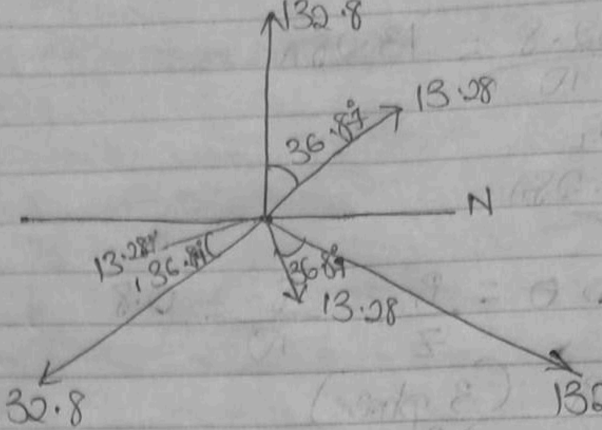
$= \sqrt{(5.29)^2 - (4.23)^2}$

$= 3.177KVAR$

Circuit diagram



Phasor diagram



3 Delta

$Z = (12 + j9)\Omega$

$V_L = 400V$

$I_L = ?$ $P.F = ?$ $P = ?$

$VAR = ?$ $VA = ?$

$V_{ph} = V_L$

$V_{ph} = 400V$

$V_{ph} = I_{ph} Z_{ph}$

$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{400}{\sqrt{12^2+9^2}} = \frac{400}{15} = 26.67A$

$I_L = \sqrt{3} I_{ph}$

$= \sqrt{3} \times 26.67$

$= 46.19A$

$P.F = \cos\theta = \frac{R}{Z} = \frac{12}{15} = 0.8$

$P = 3I_{ph}^2 R = \sqrt{3} V_L I_L \cos\theta$

$= 3 \times (26.67)^2 \times 12$

$= 25606.4W = 25.606KW$

$VAR = 3I_{ph}^2 X = \sqrt{3} V_L I_L \sin\theta$

$= 3 \times (26.67)^2 \times 9$

$= 19204.80VAR = 19.2KVAR$

$VA = 3I_{ph}V_{ph} = \sqrt{3} V_L I_L = 3I_{ph}^2 Z_{ph}$

$= 3 \times 26.67 \times 400$

$= 32004 VA$

$= 32KVA$

Diagram.

Delta

4 $R_{ph} = 25\Omega$

$L = 0.15H$

$C = 120\mu F = 120\times10^{-6}F$

$V_L = 400V,\ 50Hz$

$I_L = ?$ $P = ?$ $VAR = ?$

$X_L = 2\pi f L$

$= 2\pi\times50\times0.15 = 47.12\Omega$

$X_C = \dfrac{1}{2\pi f c} = \dfrac{1}{2\pi\times50\times120\times10^{-6}} = 26.53\Omega$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

$Z = \sqrt{25^2 + (47.12 - 26.53)^2}$

$= 32.39\Omega$

$V_{ph} = V_L = 400V$

$I_{ph} = \dfrac{V_{ph}}{Z_{ph}} = \dfrac{400}{32.39} = 12.35A$

$I_L = \sqrt{3} I_{ph}$

$= \sqrt{3}\times12.35 = \underline{21.39A}$

$P = 3I_{ph}^2 R_{ph}$

$= 3\times(12.35)^2\times25$

$= 11439.19W$

$= 11.44KW$

$VAR = 3I_{ph}^2 X$

$X = X_L - X_C = 47.12 - 26.53$

$X = 20.59$

$VAR = 3(12.35)^2\times20.59$

$= 9421.31 VAR$

$= 9.42 KVAR$

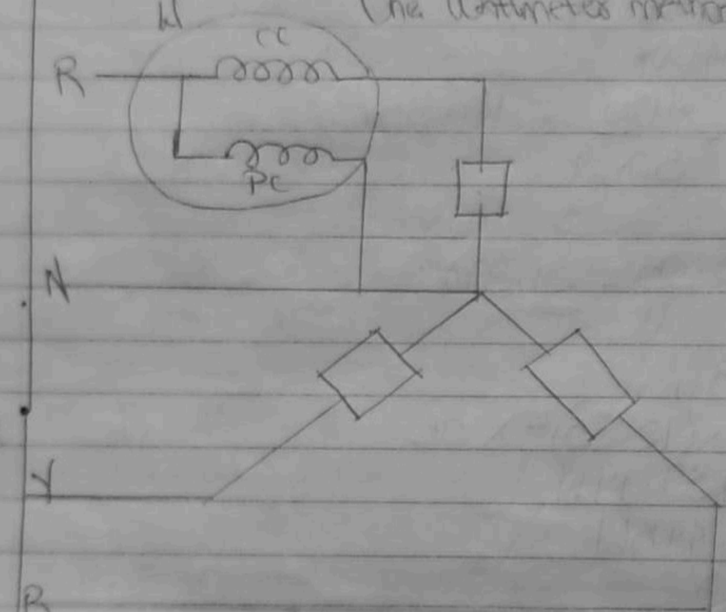
Measuring power in A.C circuit

Wattmeter is a device for measuring power in electrical circuits. It consists of two coils: The current coil (CC) and the pressure coil (PC). While the current coil is a low resistance coil connected in series with the phase, the pressure coil is a high resistance is connected in series with the two terminals between the phase and neutral for star connection.

Methods of measuring power in three phase circuits.

1. One wattmeter method.
2. Two wattmeter method
3. Three wattmeter method.

One wattmeter method

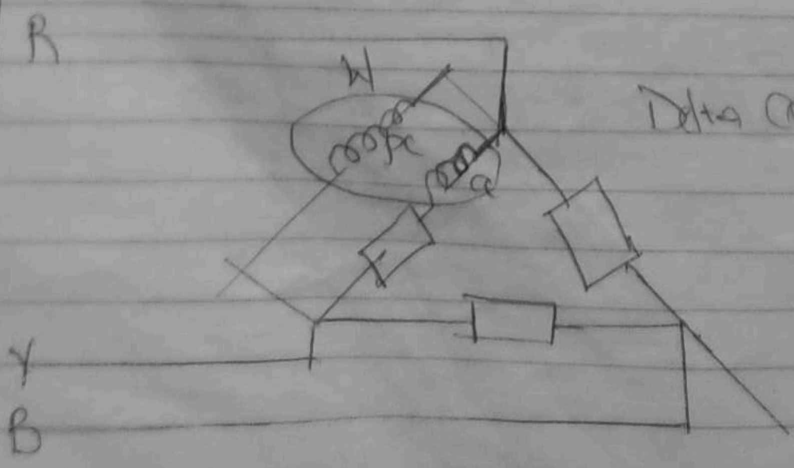


Star Connection

The One wattmeter method is used only in balanced 3-ϕ system

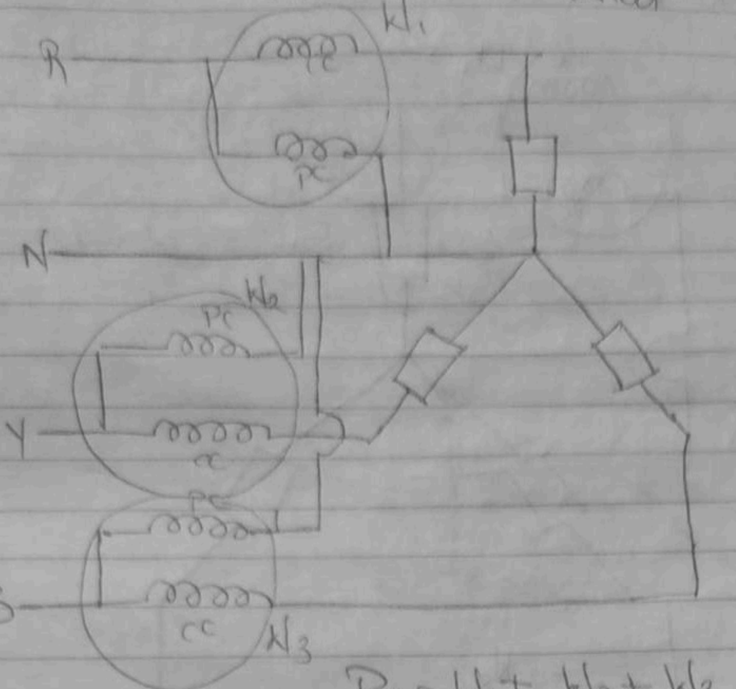
$P_T = 3W$

* One wattmeter method depends on the voltage, current and phase angle



Delta Connection

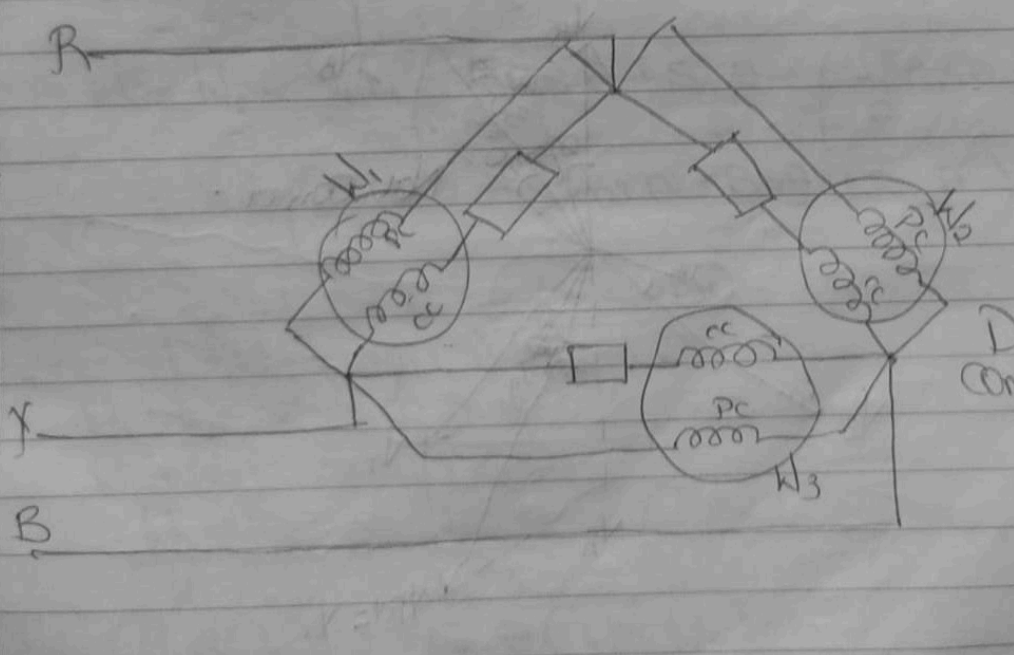
Three Wattmeter method.



Star Connection.

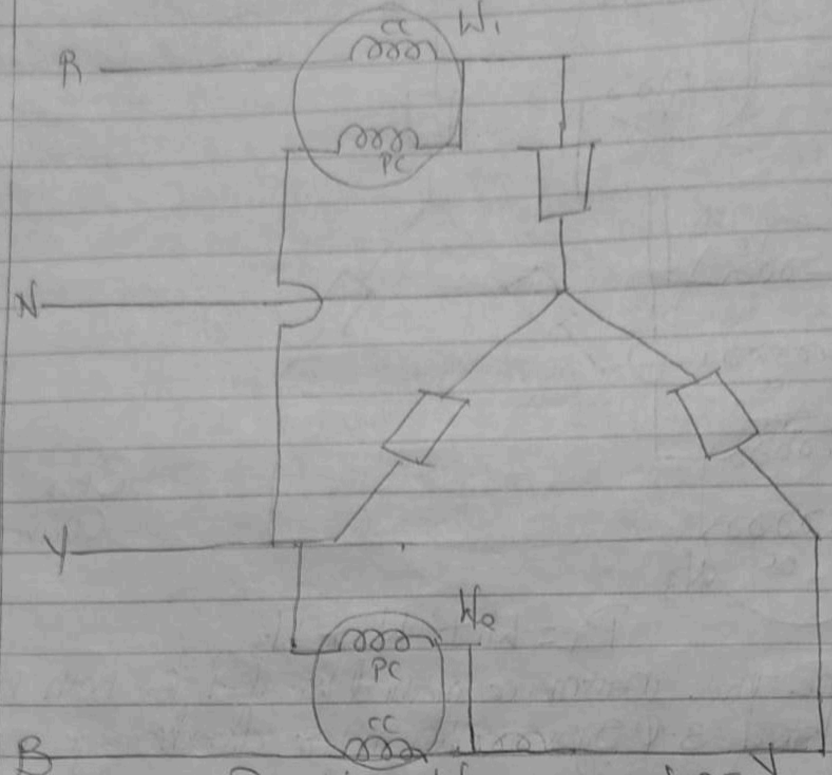
$P_T = W_1 + W_2 + W_3$

The three wattmeter method is used for both balanced and unbalanced 3-Φ systems. Its major disadvantage is that it is the most expensive.

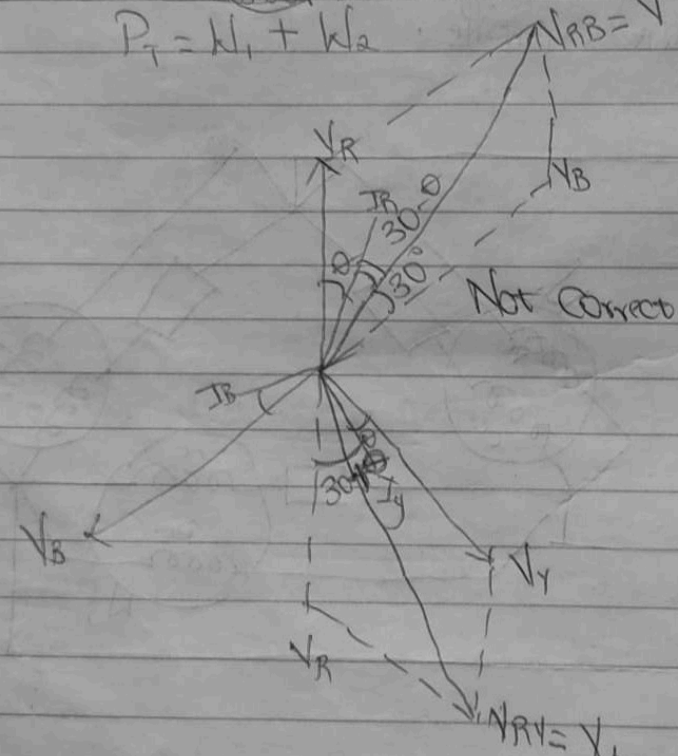


Delta Connection.

Two Wattmeter method



$P_T = W_1 + W_2$



$W_1 = V_L I_L \cos(30-\theta)$

$W_2 = V_L I_L \cos(30+\theta)$

But $\cos(A+B) = \cos A \cos B - \sin A \sin B$

and $\cos(A-B) = \cos A \cos B + \sin A \sin B$

$W_1 = V_L I_L [\cos 30° \cos\theta + \sin 30 \sin\theta]$

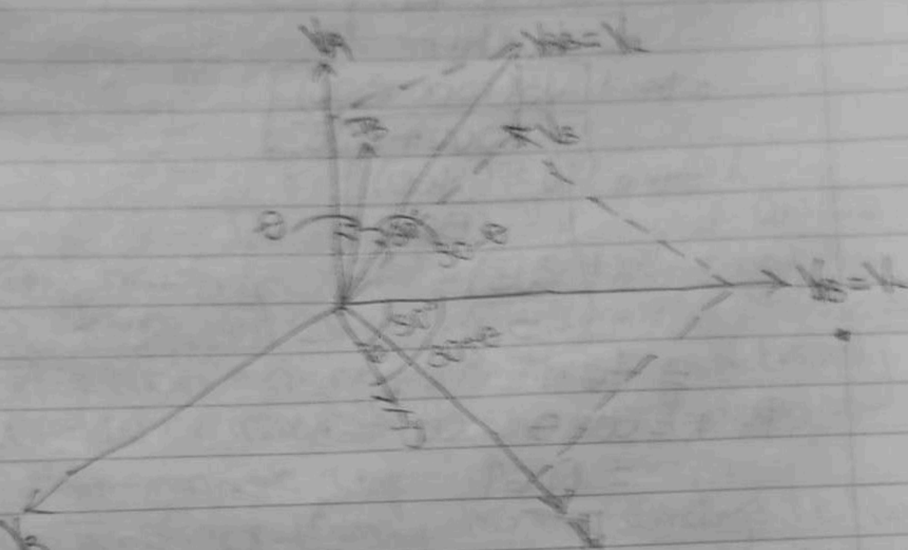
$W_2 = V_L I_L [\cos 30° \cos\theta - \sin 30 \sin\theta]$

$$W_1 = V_L I_L\left[\frac{\sqrt{3}}{2}\cos\theta + \frac{\sin\theta}{2}\right] \quad \text{—— (1)}$$

$$W_2 = V_L I_L\left[\frac{\sqrt{3}}{2}\cos\theta - \frac{\sin\theta}{2}\right]$$

$$W_1 + W_2 = V_L I_L(\sqrt{3}\cos\theta)$$

$$W_1 + W_2 = \sqrt{3}\, V_L I_L \cos\theta \quad \text{—— (2)}$$



$$W_1 - W_2 = V_L I_L\left(\frac{\sqrt{3}}{2}\cos\theta + \frac{\sin\theta}{2} - \left(\frac{\sqrt{3}}{2}\cos\theta - \frac{\sin\theta}{2}\right)\right)$$

$$= V_L I_L\left(\frac{\sqrt{3}}{2}\cos\theta - \frac{\sqrt{3}}{2}\cos\theta + \frac{\sin\theta}{2} + \frac{\sin\theta}{2}\right)$$

$$= V_L I_L \sin\theta \quad \text{—— (3)}$$

Dividing eqn (3) by eqn 2

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\theta}{\sqrt{3} V_L I_L \cos\theta}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\tan\theta}{\sqrt{3}}$$

$$(W_1 - W_2)\sqrt{3} = \tan\theta(W_1 + W_2)$$

$$\tan\theta = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$\theta = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right]$$

Example :-

1. In a two wattmeter method, readings of the two wattmeters were 1200W and 300W. Find the power factor of the load.

2. In a two wattmeter method, Total power measured was 30kW at 0.7PF lagging. Find the readings of each wattmeter.

Solution.

1. $\theta = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right]$

$= \tan^{-1}\left[\frac{\sqrt{3}(1200-300)}{1200+300}\right]$

$= \tan^{-1}\left[\frac{\sqrt{3}(900)}{1500}\right]$

$= \tan^{-1}\left(\frac{3\sqrt{3}}{5}\right)$

$= 46.1°$

$P.F = \cos\theta = \cos 46.1°$

$= \underline{\underline{0.69}}$

2. $W_1 + W_2 = 30kW$

$P.F = 0.7$

$\cos\theta = 0.7$

$\theta = \cos^{-1}(0.7)$

$= 45.57$

$\tan\theta = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$

$\tan 45.57 = \frac{\sqrt{3}(W_1 - W_2)}{30}$

$\sqrt{3}(W_1 - W_2) = 30(\tan 45.57°)$

$\sqrt{3}(W_1 - W_2) = 30.60$

$+ \quad W_1 - W_2 = 17.67kW \quad — (1)$

$W_1 + W_2 = 30kW \quad — (2)$

$2W_1 = 47.67$

$W_1 = 23.84kW$

$W_2 = 30 - W_1$

$W_2 = 30 - 23.84$

$W_2 = 6.16kW.$

Tele -> distance
Vision -> to see.

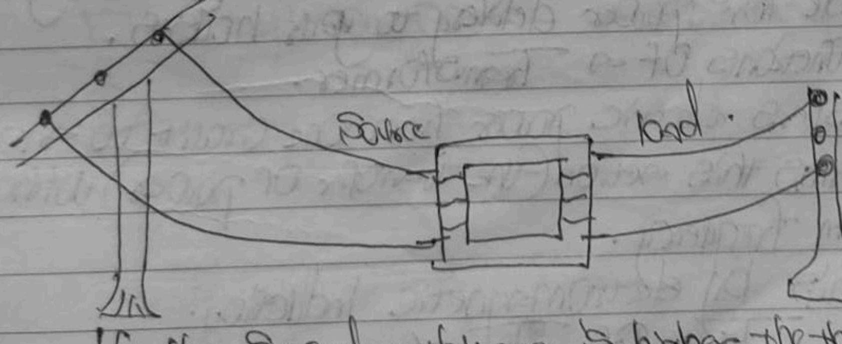
Exam
(a) Define
(b) List
(c) derive
(d) Calculate

Transformer. 2/11/22.

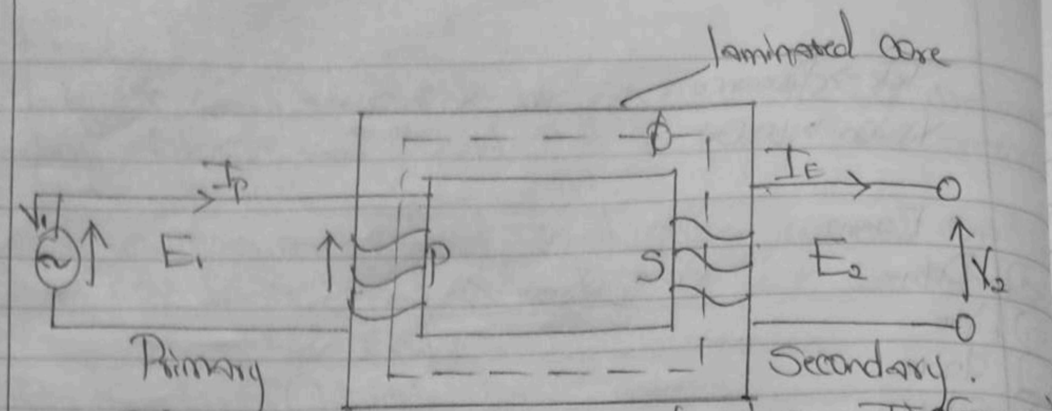
A Transformer transforms electrical energy from a Certain Voltage and Current level to another Voltage and Current level without a change in its frequency. It basically comprises Of two or more Coils Of wire, wound around a common Ferro-magnetic Core.

A Transformer normally has two Windings i.e Primary and Secondary Windings.

The Primary Winding is where the Source is Connected and the Secondary Winding is where the load is connected across.



If the Secondary Voltage is higher the the primary Voltage, it is called Step-up Transformer and if the Secondary Voltage is lesser than the Primary Voltage, it is called Step-down Transformer.



Schematic diagram of a Single phase ~~Trf~~ (Transformer)

Principle of Operation of a Transformer.

When an alternating voltage V_1 is applied to the primary winding of a Transformer, a current flows through it and that current is called Exciting current. The Exciting current produces an alternating flux in the core which links ~~to~~ with both winding (Primary and Secondary winding).

According to Faraday's law of Electromagnetic induction, the flux will cause self-induced emf E_1 in the primary and mutually induced emf E_2 in the secondary winding. When a load is connected to the secondary side, current will start flowing in the secondary winding and the voltage induced in the ~~to that~~ secondary winding is responsible for power delivery to your houses.

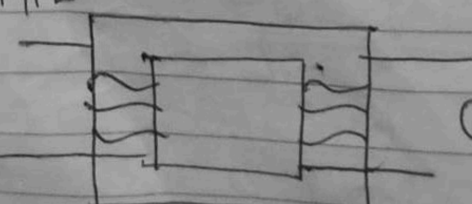
Functions of a Transformer.

1. It transfers electric power from one circuit to another.
2. It performs this action (the transfer of power) without a change in frequency.
3. It does this by electromagnetic induction.

Types of Transformer

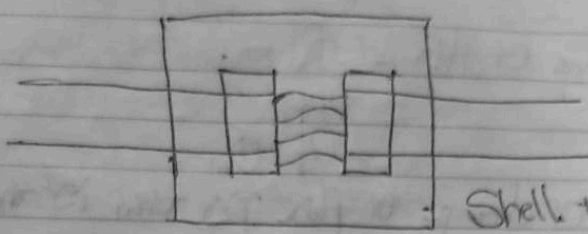
There are generally two types of Transformer:

1. CORE-TYPE
2. SHELL-TYPE



Core-type.

The Core type :-> The winding surrounds a considerable part of the Steel Core. The core consist of two vertical ~~feeds~~ limbs or legs and the horizontal part is called the Yoke.



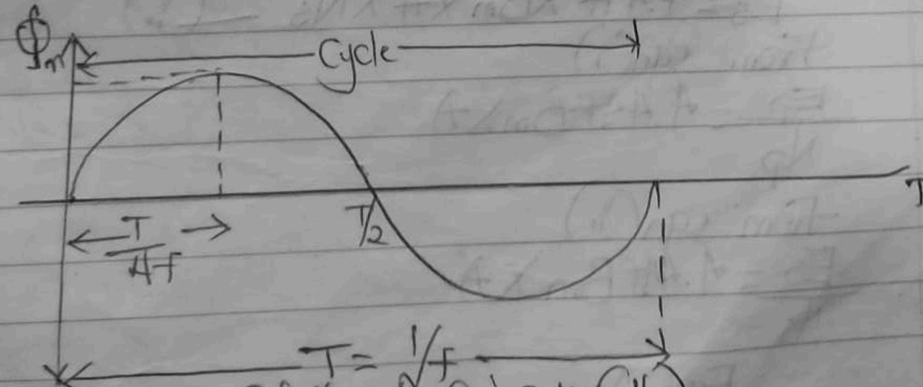
Shell type.

The Shell type :-> The Steel core encircle or surrounds the major part of the winding. The low voltage and high voltage winding are wound over the Center limb.

The ~~difference~~ difference between the core type and Shell-type transformer.

Core type	Shell type.
1. In the core type transformer, the flux has a single path around the leg.	The flux in the Center limb divides equally and returns through the Outer two legs.
2. Concentric core are used for core type transformer	Sandwich core are used for Shell-type transformer.

EMF Equation Of a Transformer.



f = Frequency Of the A.C inputs (Hz)
E_p = R.m.s Value Of primary induced emf.
N_p = No Of turns in the Primary
N_s = " " " " " Secondary
Φ_m = Maximum flux in the core

E_s = Rms Value of the Secondary induced emf.

$\Phi_m = B_m \times A$

The maximum flux will occur at the quarter of the frequency.

Average change of flux $= \dfrac{\Phi_m}{1/4f}$

$= 4f\Phi_m$

The rate of change of flux per turn is the same as the induced emf voltage.

Average emf per turn $= 4f\Phi_m$.

If the flux varies sinusoidally, then the rms value of the induced emf is multiplied by the average value in form factor and the form factor is 1.11

Rms value of induced emf/turn × form factor

Average emf/turn

$= 4f\Phi_m \times 1.11$

$= 4.44f\Phi_m$.

The Rms value of the induced emf in a complete primary winding is equal to induced emf per turn multiplied by the number of primary turns.

Rms = Induced emf/turn × NO of primary turn.

$E_p = 4.44f\Phi_m \times N_p$

$E_p = 4.44f \times B_m \times A \times N_p$ — (i)

Similarly

$E_s = 4.44f \times B_m \times A \times N_s$ — (ii)

From eqn (i)

$\dfrac{E_p}{N_p} = 4.44fB_m \times A$

From eqn (ii)

$\dfrac{E_s}{N_s} = 4.44fB_m \times A$

Equating

$\dfrac{E_p}{N_p} = \dfrac{E_s}{N_s}$.

For an ideal transformer, it means that the induced

Ideal transformer — transformer without losses.
emf per turn is the Same for both primary and Secondary,

Example 1

A Single phase transformer 250/3000V 50Hz has a peak flux density of 1.2 Wb/m². Taking an emf per turn to be 8V. Calculate

i) Primary and Secondary turns.

ii) The core area of the transformer.

Solution.

i) $\frac{E_p}{E_s} = \frac{250V}{3000}$

$E_p = 250V$

$E_s = 3000V$

$F = 50Hz$

emf per turn $= \frac{E_p}{N_p}$,

$\frac{E_p}{N_p} = 8V$

$N_p = \frac{E_p}{8} = \frac{250}{8}$

$N_p = 31.25$ turns

$\simeq 32$ turns (above 31, for turns no approximation).

$\frac{E_p}{N_p} = \frac{E_s}{N_s}$

$\frac{250}{32} = \frac{3000}{N_s}$

$N_s = \frac{3000 \times 32}{250} = 384$ turns.

ii) $\Phi_m = B_m \times A$.

$B_m = 1.2 Wb/m^2$ (T) (Tesla).

$\frac{E_p}{N_p} = 4.44 f \times B_m \times A$

$A = \frac{E_p}{N_p \times 4.44 f \times B_m} = \frac{250}{32 \times 4.44 \times 50 \times 1.2}$

$A = 0.029 m^2 \simeq 0.03 m^2$

Φ_m = Peak flux (maximum flux).
B_m = Peak flux density.

Example 2:

The primary winding of a 50Hz Transformer is supplied from a 440V 50Hz source and has 200 turns.

i) Find the peak value of the flux

ii) Find the induced voltage in the secondary winding if the secondary turns is 50.

Solution.

$E_p = 440V$

$f = 50Hz$

$\Phi_m = ?$

$N_p = 200 turns$

$E_s = ?$

$N_s = 50 turns$

i) $E_p = 4.44f \times \Phi_m \times N_p$.

$$\Phi_m = \frac{E_p}{4.44f \times N_p}$$

$$\Phi_m = \frac{440}{4.44(50) \times 200}$$

$\Phi_m = 0.00991Wb$

ii) $E_s = 4.44f \times \Phi_m \times N_s$

$E_s = 4.44(50) \times 0.00991 \times 50$

$= 110.001$

$= 110V$

Voltage Transformation ratio(K) 3/11/20.

This is defined as the ratio of the Secondary induced emf to the primary induced emf i.e

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} = K$$

For an ideal transformer, the input power is equal to the Output power i.e

$$E_p I_p = E_s I_s$$

$$\frac{E_s}{E_p} = \frac{I_p}{I_s} = K.$$

Also the induced emf per turn is the Same for both primary and Secondary turn. If the Value of the transformer ratio, K is greater than 1, it is a Step up case and if K is less than 1, it is a Step down case and if K is equal to 1, it is called a ONE: ONE transformer i.e

$K > 1 \rightarrow$ Step up

$K < 1 \rightarrow$ Step down

$K = 1 \rightarrow$ One to One.

Example

A Single phase transformer has 400 primary and 1000 Secondary turns, the net Cross Sectional area of the core is $60cm^2$. If the primary winding is connected to a 50Hz supply at 520V. Calculate

I the Peak Value of the flux density of the core.

II The Voltage induced in the Secondary.

Solution.

$N_p = 400$ turns

$N_s = 1000$ "

$A = 60cm^2$

$f = 50Hz$

$E_p = 520V$

$E_s = ?$

i) $E_p = 4.44f \times N_p \times \Phi_m$

$\Phi_m = B_m \times A$

$520 = 4.44 \times 50 \times 400 \times \Phi_m$

$\Phi_m = 5.856 \times 10^{-3} Wb$

$\Phi_m = B_m \times A$

$$B_m = \frac{\Phi_m}{A} = \frac{5.856 \times 10^{-3}}{60 \times 10^{-4}} \text{ (actual value).}$$

$$B_m = \underline{0.976 \, Wb/m^2}$$

ii) $E_s = ?$

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} = K$$

$$\frac{E_s}{520} = \frac{1000}{400}$$

$$E_s = \frac{10 \times 520}{4}$$

$$E_s = 1300V.$$

Example 2

A 250KVA, 11000/415 V 50Hz single phase transformer has 80 turns in the secondary. Calculate

I The rated primary and secondary current.

II The numbers of primary turns

III The maximum value of the flux.

IV Voltage induced per turn.

Solution

Power = 250KVA

$E_p = 11{,}000V$

$E_s = 415V$

$f = 50Hz$

$N_s = 80$ turns

I $P_{output} = P_{input} \Rightarrow E_pI_p = E_sI_s$

$$250{,}000 = 11000 \times I_p$$

$$I_p = \frac{250}{11}$$

$$= 22.727A$$

$$I_s = \frac{KVA}{E_s} = \frac{250\,000}{415}$$

$$I_s = \underline{602.41A}.$$

II $$\frac{E_s}{E_p} = \frac{N_s}{N_p}$$

$$\frac{415}{11,000} = \frac{80}{N_p}$$

$$N_p = \frac{11000 \times 80}{415}$$

$$N_p = 2120.48 \text{ turns}$$

$$\simeq 2121 \text{ turns}$$

III $\Phi_m = B_m \times A$

$E_s = 4.44 f \times \cancel{B_m} \times \Phi_m \times N_s$

$$\Phi_m = \frac{E_s}{4.44 f \times N_s}$$

$$\Phi_m = \frac{415}{4.44 \times 50 \times 80}$$

$\Phi_m = 0.0234 \, Wb.$

IV Voltage Induced per turn $= 4.44 f \Phi_m$

$= 4.44 \times 50 \times 0.0234$

$= 5.19 v/turn.$

Or

$$\frac{E_p}{N_p} = 5.19 v/turn$$

Losses and Efficiency of a Transformer.

There are two types of losses in a transformer:

1 Copper loss
2 Iron loss

Copper loss :-> This is the power loss that Occur in the primary and Secondary Winding when the transformer is On load. This power is wasted in the form of heat due to the resistance of the Winding. This loss is proportional to the non-Uniformity of the Current density in the Conductors.

Iron loss :-> This is the power loss that Occur in the iron part of the transformer. This loss is due to the alternating frequency of the e.m.f. This is further divided into:

I Eddies Current loss.
II Hysteresis Current loss

Efficiency Of a Transformer

Efficiency Of a Transformer is defined as the ratio of the output power to the input power.

$$Eff\ (\eta) = \frac{\text{Power Output}}{\text{Power Input}}$$

$$= \frac{\text{Power Output}}{\text{Power Output} + \text{power losses}}$$

$$\eta = \frac{\text{Power Output}}{\text{Power Output} + \text{Cu loss} + \text{Iron loss}}$$

Or

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{\cancel{x} + \cancel{\text{losses}}}{} \quad 1 - \frac{\text{losses}}{\text{Input}}$$

Example

In a 25KVA 2000/200V transformer, the Fe and Full load Cu losses are 350W and 400W respectively. Find the efficiency at Unity power factor at

a) Full load
b) Half load
c) Determine the load for maximum efficiency.

Solution

$P_{output} = 25\,KVA = 25\,000VA$

$E_p = 2000V$

$E_s = 200V$

Iron loss (Fe) = 350W

Copper loss (Cu) = 400W

$$\eta = \frac{P_{output}}{P_{output} + \text{Iron loss} + \text{Copper loss}}$$

At full load

a) $$\eta = \frac{25\,000}{25000 + 350 + 400}$$

$= 0.97$ or 97%

b) At half load

$$P_{output} = \frac{P_{out}}{2} = \frac{25\,000}{2} = 12{,}500VA$$

$$\eta = \cancel{\frac{12,500}{12,500+350+400}}$$
$$\cancel{= 0.94 \text{ or } 94\%}$$

Iron loss $=$ 350kW (constant).

Copper loss $= I^2R = \left(\frac{1}{2}\right)^2 \times 400 = 100\text{kW}$

$$\eta = \frac{12500}{12500+350+100}$$

$$\eta = 0.965 = 96.5\%$$

Condition for maximum efficiency:

In general, for the efficiency to be maximum for any device, the losses must be minimum. The iron and copper losses, the iron loss, fixed loss and the copper loss is the variable,

When these two losses are equal and minimum, efficiency will be maximum.

Therefore, the condition for maximum efficiency of a transformer is

Iron loss = Copper loss (which ever is minimum)

$$\text{Maximum efficiency} = \text{Full load} \times \sqrt{\left(\frac{\text{Iron loss}}{\text{F.L Cu loss}}\right)}$$

$$\eta_{max} = \text{Full load (KVA)} \times \sqrt{\left(\frac{\text{Iron loss}}{\text{Full load copper loss}}\right)}$$