LECTURE NOTES
ON

BASIC ELECTRICAL

For
1st & 2nd sem, Electrical Engg. (Diploma)

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AC Theory

- Alternating current (or voltage), i.e AC is a physical electrical parameters which varies continuously in magnitude and periodically reverses direction.

- AC is produced in various types of generating stations such as hydro, thermal and nuclear etc.

- Generation of alternating emf :-

Faraday's law of electromagnetic induction :-

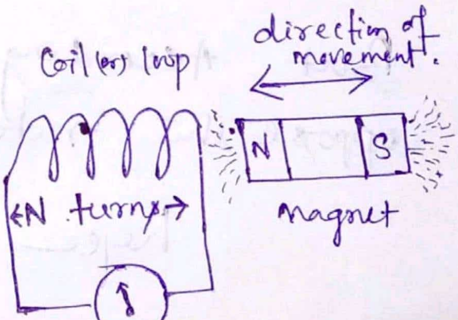
This law is a basic law of electromagnetism. predicting how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction.

Faraday's law states that a current will be induced in a conductor which is exposed to a changing magnetic field.

Lenz's law states that the direction of this induced current will be such that the magnetic field created by the induced current opposes the initial changing magnetic field which produced it.

example :-

Consider, a magnet is approaching towards a coil. Here we consider two instants at time T_1 and time T_2.



Flux linkage with the coil at time,

$$T_1 = N\phi_1 \text{ wb.}$$

Flux linkage with the coil at time,

$$T_2 = N\phi_2 \text{ wb.}$$

Change in flux linkage,

$$N(\phi_2 - \phi_1)$$

Let the $(\phi_2 - \phi_1) = \phi$.

So, the change in flux linkage $= N\phi$.

Now the rate of change of flux linkage $= \frac{N\phi}{t}$

As we are analysing for a small piece of conductor and small piece of magnet,

the rate of change of flux linkage $= N\frac{d\phi}{dt}$

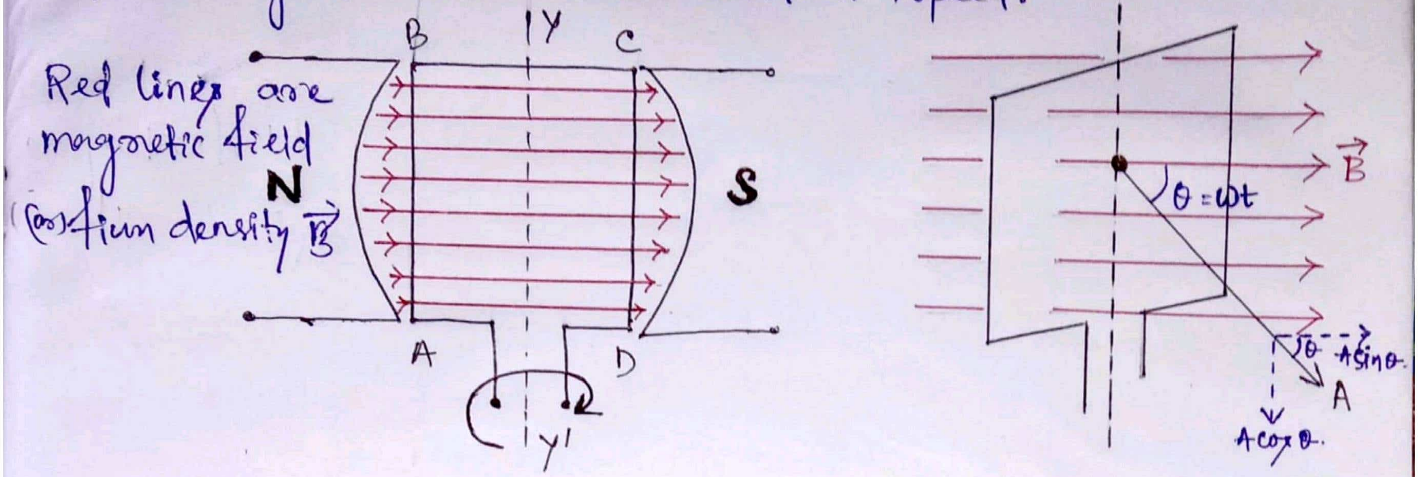
According to Faraday, the rate of change of flux linkage is nothing but the induced emf.

hence $E = N\frac{d\phi}{dt}$.

But According to Lenz's Law Emf should oppose the rate of change of flux.

hence $\boxed{E = -N\frac{d\phi}{dt}}$

The generation of alternating emf and hence alternating current can be possible when a coil or conductor rotates in a magnetic field at a constant speed.



Consider a rectangular coil ABCD which is free to rotate about an axis YY' in a magnetic field with an angular speed of ω. The axis YY' lies perpendicular to the magnetic field (or) flux density ϕ_m. During rotation of coil when the coil makes an angle θ with the direction of the field,

$$\phi = BA\cos\theta \quad (\text{or}) \quad BA\cos\omega t$$

$$= \phi_m \cos\omega t$$

According to Faraday and Lenz's law $E = -\dfrac{d\phi}{dt}$.

hence $$E = -\frac{d}{dt}(\phi_m \cos\omega t)$$

$$= -\phi_m(-\sin\omega t)\,\omega$$

$$= \omega\phi_m \sin\omega t$$

for N no. of turns $E = N\omega\phi_m \sin\omega t$.

$$\boxed{E = E_m \sin\omega t} \qquad \because E_m = N\omega\phi_m.$$

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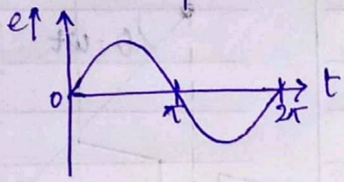
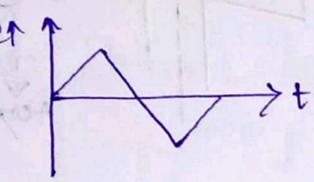
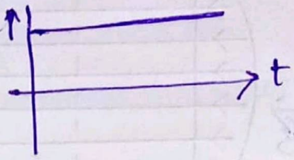
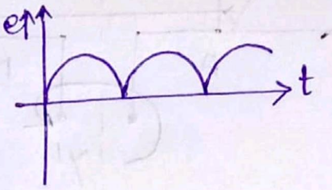
• Difference between AC and DC.

AC	DC
1. It is alternating current.	1. It is direct current.
2. Voltage or current in AC varies with time and changes direction periodically.	2. Voltage and current in DC acts in one direction.
3. AC generator and alternator are used for small uses. Bulk power is generated in various generating plants such as Hydro, thermal and nuclear power plants.	3. DC power is available from cells and batteries. It can be generated from dc generators. The common practice is now to get DC from AC by rectification and use of filters.
4. AC can be converted into DC by rectifier.	4. DC can be converted in to AC by inverter.
5. In India frequency of AC in the power system is 50 HZ while in USA it is 60 HZ.	5. As there is no variation in the magnitude of DC, for analytical purpose, the frequency is zero.
6. The magnitude of AC voltage or current can be either stepped up or down by using transformer.	6. Voltage or current transformation is not possible by using a transformer.



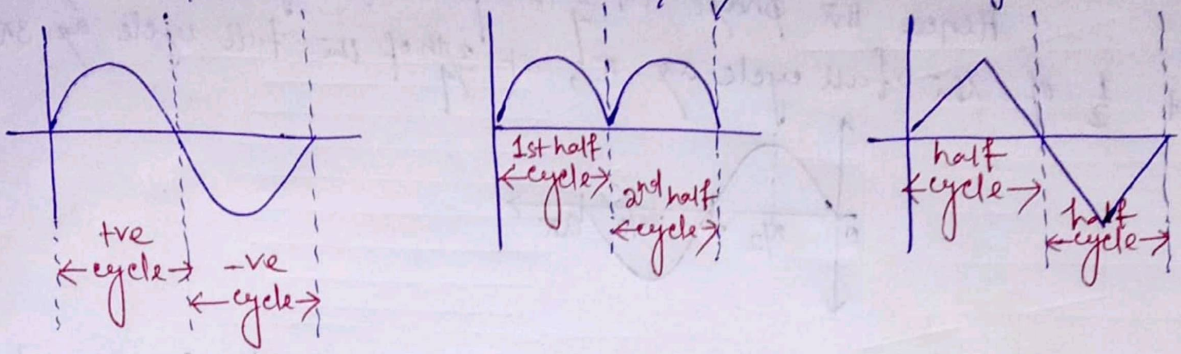




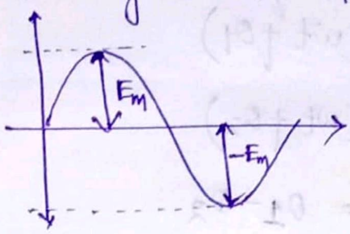


- Definations of Some terms used in AC Circuit

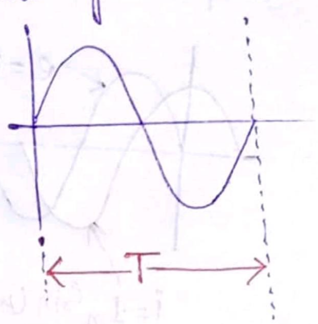
1. cycle:— A complete set of variations of the alternating quantity occuring during the time before the next set of variation starts is called a cycle.



2. Amplitude:— It is the maximum value of alternating quantity during one cycle. It is E_m as shown in figure.



3. Time Period (T) :— It is the time required to complete one full cycle. It is denoted by T.



4. Frequency (f) :— It is the no. of full cycles per second of the alternating quantity. It is denoted by f.

The relation between Time period & frequency

$$\boxed{f = \frac{1}{T}}$$

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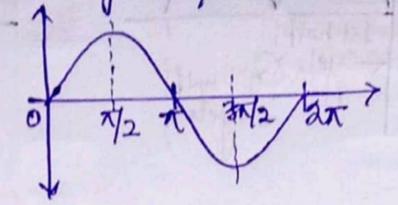
5. Phase Angle :— Phase angle indicates the condition of the alternating quantity during one cycle. It is normally expressed in terms of an angle while a complete cycle is taken equivalent to a phase change of 2π.

Hence the phase at $\frac{1}{4}$th of a fullcycle is taken as $\pi/2$, at $\frac{1}{2}$ of the full cycle as π, at $3/4$th of the full cycle as $3\pi/2$.



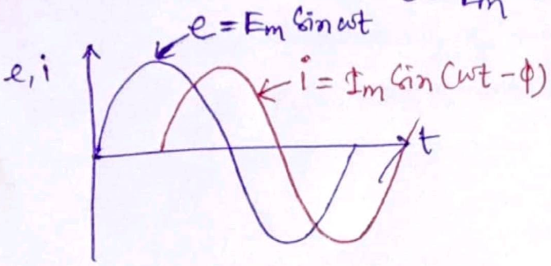
6. Phase difference :— The voltage and current in general are represented by equations.

$$e = E_m \sin(\omega t + \theta_1)$$
$$i = I_m \sin(\omega t + \theta_2)$$

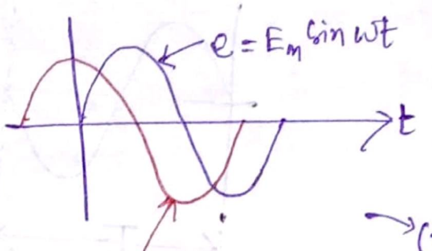
The phase difference $\phi = \theta_1 - \theta_2$

Note, when $\theta_1 = \theta_2 = 0$ these equations reduce to

$e = E_m \sin \omega t$ and $i = I_m \sin \omega t$.

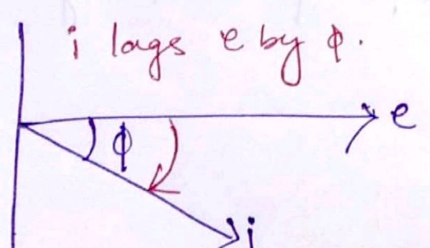


(fig-a)

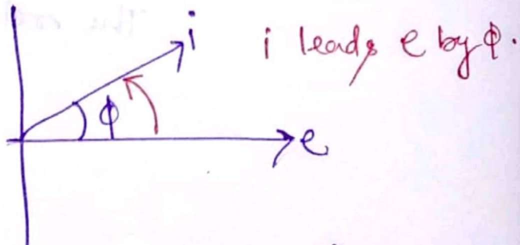


(fig-b)

7. Phasor diagram :— The above waveforms can be represented in phasor form.



phasor diagram for (fig-a)



Phasor diagram for (fig-b)

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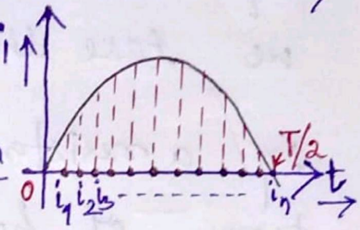
8. Instantaneous Value – The magnitude of the alternating quantity at the given instant or time is called its instantaneous value. This value changes time to time from zero to peak value again from peak value to zero.

9. Average Value – Average value of current (or voltage) is the average of instantaneous values taken over small intervals during one cycle.



Here average value $I_{av} = \dfrac{i_1 + i_2 + i_3 + \dots + i_n}{n}$

It's value can be obtained by integrating the instantaneous values.

For integration we need current waveform's datas i.e. magnitude and time.

the waveform exists between 0 to $T/2$ time.

the magnitude is of the form $I_m \sin \omega t$.

where I_m is the peak value of current

and $\omega = 2\pi f$.

$$I_{av} = \frac{\int_0^{T/2} I_m \sin \omega t \, dt}{\int_0^{T/2} dt} = \frac{\int_0^{\pi/\omega} I_m \sin \omega t \, dt}{\int_0^{\pi/\omega} dt}$$

$$I_{av} = \frac{I_m \left(\frac{-\cos \omega t}{\omega} \right)_0^{\pi/\omega}}{(t)_0^{\pi/\omega}} = \frac{\frac{I_m}{\omega}\left(-\cos \pi + \cos 0\right)}{\frac{\pi}{\omega}} = \frac{I_m}{\pi}[1+1] = \frac{2I_m}{\pi}$$

hence $\boxed{I_{av} = \frac{2I_m}{\pi} = 0.637\, I_m}$.

likewise $\boxed{V_{av} = \frac{2V_m}{\pi} = 0.637\, V_m}$

10. RMS Value (Root mean square) or effective value of AC:–

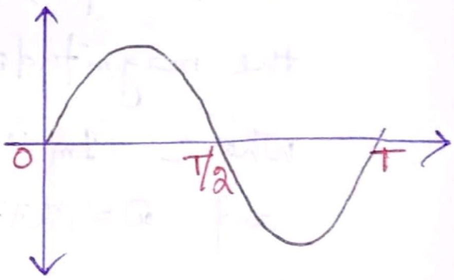
In order to measure the strength of ac current we take the heating effect due to that current

In a resistor the heating is nothing but power in terms of heat. Here P is proportional to square of current. Hence the square of an ac current (or voltage) is taken as a measure of ac.

Mathematically the rms value of current is defined as

$$I_{rms} = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \cdots + i_n^2}{n}}$$

This rms value can be found from integration over a period of T.



$$I_{rms} = \sqrt{\frac{\int_0^T I_m^2 \sin^2 \omega t \; dt}{\int_0^T dt}}$$

$$I_{rms}^2 = \frac{\int_0^{2\pi/\omega} I_m^2 \sin^2 \omega t \; dt}{\int_0^{2\pi/\omega} dt}$$

$$= \frac{I_m^2 \int_0^{2\pi/\omega} \left(\frac{1-\cos 2\omega t}{2}\right) dt}{2\pi/\omega}$$

$\because 2\sin^2\omega t = 1 - \cos 2\omega t$

$$= \frac{\frac{I_m^2}{2}}{2\pi/\omega}\left\{\int_0^{2\pi/\omega} 1\,(dt) - \cancel{\int_0^{2\pi/\omega} \cos 2\omega t\, dt}\right\}$$

$$= \frac{\frac{I_m^2}{2} \times \cancel{(2\pi/\omega)}}{\cancel{(2\pi/\omega)}}$$

$$\Rightarrow I_{rms}^2 = \frac{I_m^2}{2}$$

$$\Rightarrow I_{rms} = \sqrt{\frac{I_m^2}{2}}$$

$$\Rightarrow \boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

11. Form factor :- It is the ratio of rms to average value of the alternating quantity.

for a sinusoidal wave form

$$K_f = \frac{\text{RMS value}}{\text{Average value}} = \frac{I_m/\sqrt{2}}{2I_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11.$$

12. Crest factor (or) Peak factor (K_p) : It is defined as the ratio of peak or maximum value to the RMS value of the alternating quantity in ac. for a sinusoidal ac,

$$K_p = \frac{\text{Maximum Value}}{\text{RMS Value}} = \frac{I_m}{I_m/\sqrt{2}} = \sqrt{2} = 1.414$$

Problems :—

Q.1. An alternating current has peak value of 10 A at a frequency of 50 HZ. Find

i) RMS value
ii) Average Value
iii) Angular frequency
iv) Expression for instantaneous current.

Ans:— Given $I_m = 10\,A$

i) $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{10}{\sqrt{2}} = 7.07\,A$

ii) $I_{avg} = \frac{2I_m}{\pi} = 0.637 \times 10 = 6.37\,A$.

iii) Angular frequency = $\omega = 2\pi f = 2 \times 3.14 \times 50 = 314$ rad/s

iv) Expression for instantaneous current $= I_m \sin \omega t$

$\Rightarrow I_{inst} = 10 \sin (314) t$.

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Voltage & current relation in AC Circuit

Generally three common circuit elements are used in ac circuit. They are resistor, inductor and Capacitor.

a) Relation for a resistor (R)

$V = IR$ (or) $I = V/R$

b) Relation for an Inductor (L)

$$V = L\frac{di}{dt}$$

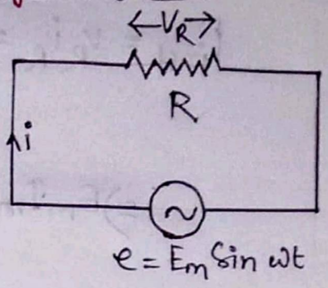
$$i = \frac{1}{L}\int v\,dt \, .$$

c) Relation for a Capacitor (C)

$q = CV$ where q = charge

So $\frac{dq}{dt} = C\frac{dv}{dt}$ or $i = C\frac{dv}{dt}$ (or) $v = \frac{1}{C}\int i\,dt$

Single phase Series AC circuit Containing Resistor



Consider a pure resistor R connected across a single phase AC Source of emf $e = E_m \sin \omega t$

Let i be the resulting current in the circuit.
V_R be the voltage drop across the resistor.

In the closed mesh, we have

$$e = E_m \sin \omega t = V_R .$$

So current through the resistor is

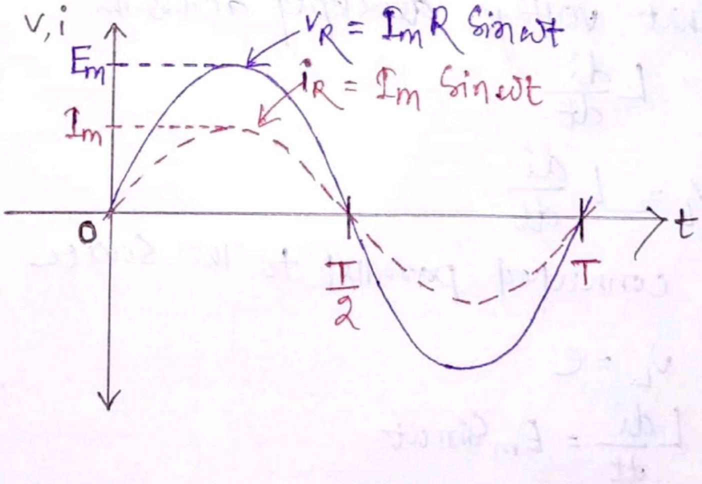
$$i_R = \frac{V_R}{R} = \frac{E_m \sin \omega t}{R} \quad \text{or} \quad i_R = I_m \sin \omega t$$

Where $I_m = \frac{E_m}{R}$ is the maximum current in the circuit.

Salient features of ac through a resistor.

i) Since V_R and i_R both vary as $\sin \omega t$ and thus reach their maximum values at the Same time, they are Said to be 'in phase'.

ii) The graphical presentation of V_R and i_R wrt time is called the timing diagram. The timing diagram shows both voltage and current reach their maximum and then zero values at the same time.



Instantaneous power Consumed,

$$P_{inst} = v_R i_R = (E_m \sin\omega t)(I_m \sin\omega t) = E_m I_m \sin^2\omega t$$

$\because \sin^2\omega t = \frac{1-\cos 2\omega t}{2}$

$$\Rightarrow E_m I_m \sin^2\omega t = E_m I_m \frac{(1-\cos 2\omega t)}{2}$$

$$= E_m I_m \frac{(1-\cos 2\omega t)}{\sqrt{2}\times\sqrt{2}}$$

$$= \frac{E_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \times (1-\cos 2\omega t)$$

$$= V_{rms} \times I_{rms} \times (1-\cos 2\omega t)$$

$\because V_{rms} = \frac{E_m}{\sqrt{2}}$

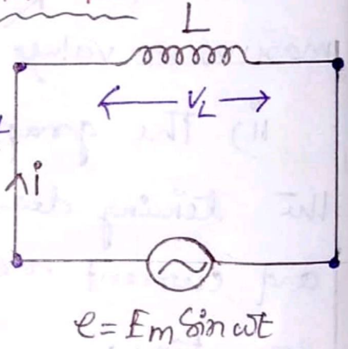
$\because I_{rms} = \frac{I_m}{\sqrt{2}}$

Average Power consumed,

$$P_{avg} = V_{rms} \times I_{rms} = (I_{rms} \times R) I_{rms} = I_{rms}^2 R$$

$$= V_{rms} \times \frac{V_{rms}}{R} = \frac{V_{rms}^2}{R}$$

Single Phase AC Circuit Containing Inductor



Consider an inductor of inductance L connected in series to an ac source of emf $e = E_m \sin\omega t$

Let current i is flowing in the circuit causes a voltage drop v_L across the inductor

we know that voltage developed across the inductor is $L\frac{di}{dt}$.

So $\quad v_L = L\frac{di}{dt}$

As inductor is connected parallel to the source

hence $\quad v_L = e$

so $\quad L\frac{di}{dt} = E_m \sin\omega t$

integrating $i = \frac{E_m}{L}\int \sin\omega t \, dt = \frac{E_m}{L}\left(-\frac{\cos\omega t}{\omega}\right)$ $\because \sin(-\theta) = -\sin\theta$.

$$= -\frac{E_m}{\omega L}(\cos\omega t) = \frac{E_m}{\omega L}\sin(\omega t - \pi/2) = \frac{E_m}{X_L}\sin(\omega t - \pi/2)$$

So $i = I_m \sin(\omega t - \pi/2)$ (lagging Current)

where $X_L = \omega L = 2\pi f L$ is called inductive reactance of the circuit.

'Reactance' – It has the unit same as resistance, Ohm (Ω) in SI unit system. It resists the flow of ac through an inductor and plays the same role as that of resistance in dc circuit.

The instantaneous voltage drop across the inductor,

$$V_L = E_m \sin\omega t = (I_m \sin\omega t) X_L$$

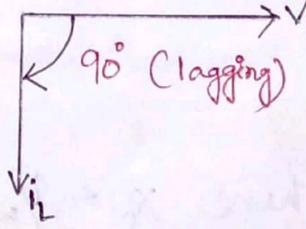
$$X_L = \frac{E_m \sin\omega t}{I_m \sin\omega t} = \frac{E_m}{I_m} = \frac{E_m}{I_m} \times \frac{\sqrt{2}}{\sqrt{2}} = \frac{E_m/\sqrt{2}}{I_m/\sqrt{2}} = \frac{V_{rms}}{I_{rms}}$$

Hence the instantaneous values of voltage across and current in the inductor are

$$V_L = I_m X_L \sin\omega t$$

$$i_L = I_m \sin(\omega t - \pi/2)$$

From i_L expression we can observe current is out of phase with voltage by 90° (or) $\pi/2$. We can say current lags behind voltage by 90°.



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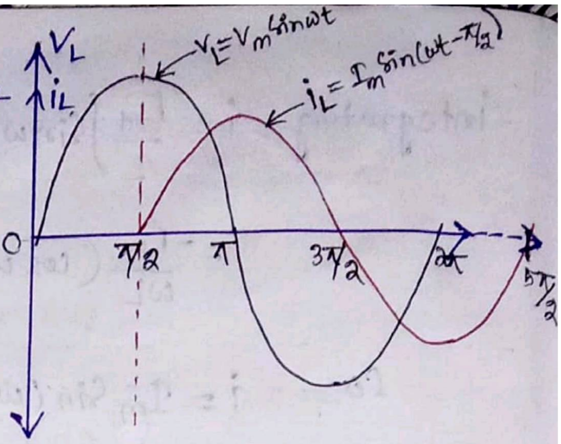
The timing diagram of this circuit is drawn here.



As reactance $= X_L = 2\pi f L$,

the reactance of an inductor increases with increasing frequency.

Hence current through inductor reduces with increasing frequency.

Single phase AC Circuit Containing a Capacitor

Consider a capacitor having capacitance 'C' connected in series with an ac source of emf $e = E_m \sin\omega t$. Let V_c be the instantaneous voltage drop across the capacitor.

if we apply KVL in the circuit

$$e - V_c = 0 \Rightarrow V_c = e = E_m \sin\omega t$$

we know $i = C\frac{d}{dt}(V_c) = C\frac{d}{dt}(E_m \sin\omega t)$

$$= C E_m \frac{d}{dt}(\sin\omega t)$$

$$= (C E_m \omega)\cos\omega t$$

$$= \frac{E_m}{1/\omega C}\cos\omega t$$

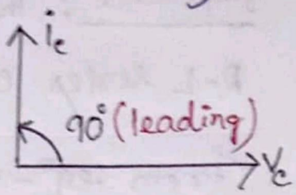
$$= \frac{E_m}{X_c}(\sin(\omega t + 90^\circ))$$

Where $X_c = 1/\omega C$ is called capacitive reactance. SI unit is ohm(Ω)

$i = i_c = I_m \sin(\omega t + 90^\circ)$ where $I_m = \frac{E_m}{X_c}$ (maximum current in the circuit)

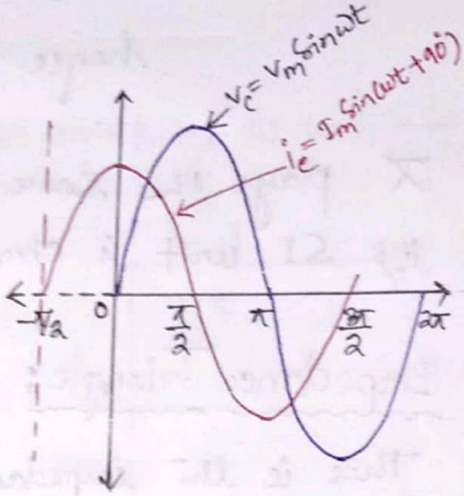
$\underbrace{\qquad\qquad}$ (Leading current)

$V_c = E_m \sin\omega t = I_m X_c \sin\omega t$.



$$X_c = \frac{E_m}{I_m} = \frac{E_m}{I_m} \times \frac{\sqrt{2}}{\sqrt{2}} = \frac{E_m/\sqrt{2}}{I_m/\sqrt{2}} = \frac{V_{rms}}{I_{rms}}$$

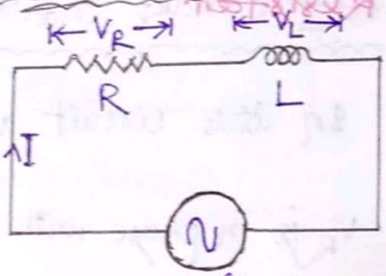
The timing diagram of this circuit is drawn here.



As reactance $X_c = \frac{1}{2\pi f C}$, the reactance of capacitor decreases with increasing frequency.

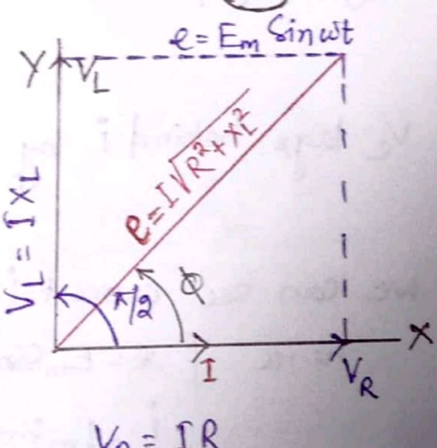
Hence current increases with increase in frequency.

AC circuit containing a resistor and inductor in series



In this circuit $V_R = IR$ and $V_L = IX_L$

we know V_R is in phase with current I while V_L is ahead of I by $\pi/2$. Hence V_L leads V_R by $\pi/2$.



Here $e = \sqrt{V_R^2 + V_L^2} = \sqrt{(IR)^2 + (IX_L)^2}$

$\Rightarrow e = I\sqrt{R^2 + X_L^2}$

$\Rightarrow I = \frac{e}{\sqrt{R^2 + X_L^2}}$ ---- eq^n ①

We can say $I = I_m \sin(\omega t - \phi)$

Impedance : The term $\sqrt{R^2 + X_L^2} = Z$ is called the impedance of R-L series circuit.

from eqn-1 $e = I\sqrt{R^2+X_L^2}$

$$e = I \cdot Z$$

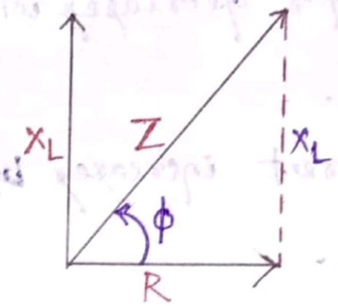
hence $Z = \dfrac{e}{I}$.

Z plays the same role as resistor in a dc circuit. Its SI unit is Ohm (Ω).

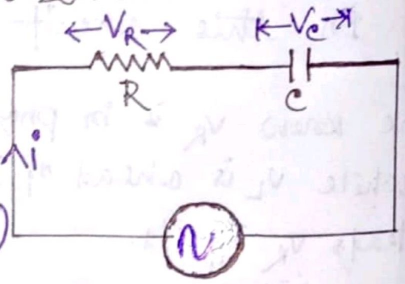
Impedance Triangle:

This is the impedance triangle of the RL circuit where

Power factor $\cos\phi = \dfrac{R}{Z}$



AC circuit containing Resistance and Capacitance in Series

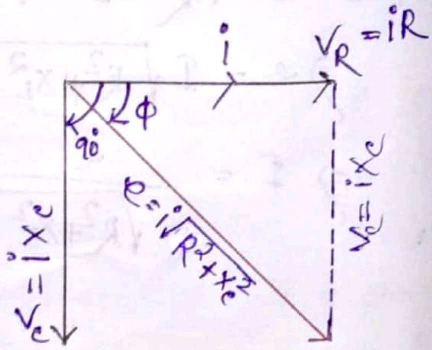


$e = E_m \sin\omega t$

In this circuit $V_R = iR$ and $V_C = iX_C$.

V_R is in phase with i (as in resistance both parameter are in phase)

V_C lags behind i by 90° (as in capacitance i_c leads V_c by 90°)



We can see current i makes angle ϕ with e.

hence if $e = E_m \sin\omega t$

$$i = I_m \sin(\omega t + \phi)$$

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from the phasor diagram $e = \sqrt{V_R^2 + V_c^2}$

$$= \sqrt{(iR)^2 + (iX_c)^2}$$

$$e = i\sqrt{R^2 + X_c^2}$$

<u>Impedance</u>: The term $\sqrt{R^2 + X_c^2} = Z$ is called the impedance of R-C series ckt.

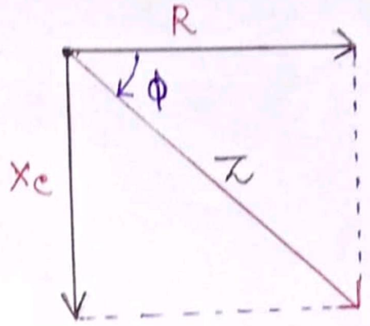
where $e = iZ$ and $Z = e/i$.

Z plays the same role as resistor in a dc circuit. It's SI unit is Ohm (Ω)

Impedance Triangle:

This is the impedance triangle of the RC circuit where

power factor $\cos\phi = \frac{R}{Z}$



Electrical power in single phase AC circuit

Power in AC circuits are of three types.

i) Apparent Power ii) Active Power iii) Reactive Power.

- **Apparent Power (S)** :- It is defined as the product of RMS value of voltage and RMS value of current in an ac circuit.

$$\boxed{S = V_{rms} \times I_{rms}}$$

It's SI unit is VA i.e. Volt-Ampere. Multiples of this unit, KVA and MVA are also used.

$$1\,KVA = 10^3\,VA, \quad 1\,MVA = 10^6\,VA.$$

- **Active Power (P)** :-

$$P = V_{rms} \times I_{rms} \cos\phi.$$

where ϕ is the phase difference between voltage and current.

* $\cos\phi$ is also known as power factor (PF) of the circuit.

SI unit of active power is watt (W). Multiples like kilowatt (KW) and megawatt (MW) are often used.

$$1\,KW = 10^3\,W, \quad 1\,MW = 10^6\,W.$$

- **Reactive Power (Q)** :-

$$Q = V_{rms} I_{rms} \sin\phi.$$

where ϕ is the phase difference between voltage and current.

SI unit of reactive power is VAR i.e. Volt-ampere reactive. Multiples like $1\,KVAR = 10^3\,VAR$; $1\,MVAR = 10^6\,VAR$, are also used.

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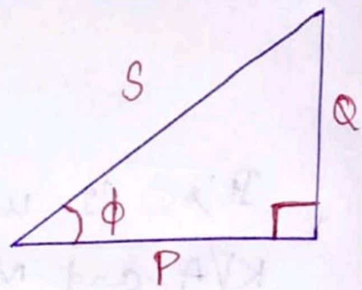
Power triangle and Power factor :-

The equations for S, P, and Q Can be represented by a Power triangle diagram. P and Q are represented by the two sides of a right-angled triangle. S is represented by the hypotenuse that makes an angle ϕ with P.

The power triangle is used used to get the Power factor.

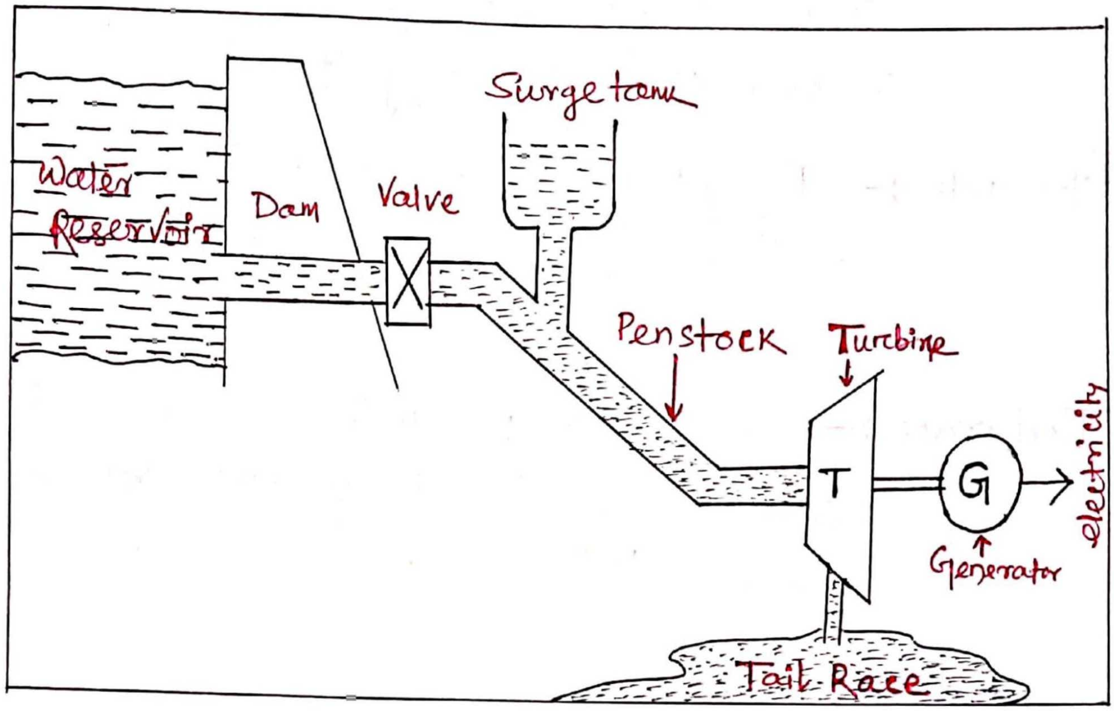
$$PF = \cos\phi = P/S.$$

$$= \frac{\text{Active Power Component}}{\text{Apparent power Component}}$$



Generation of electrical Power

Hydro Power Plant



Elements of hydroelectric power plant:-

Reservoir :- It is an important part of a power plant, where water is stored and supplied to water turbine continuously.

Dam :- A dam is a barrier which stores water and creates water head.

Spill way :- Due to heavy rain fall the water level may exceed the storage capacity of the reservoir. To remove this excess water, a storage is formed around the reservoir. Spill way is a structure used to provide the controlled release of flows of water from a dam in to those storage area or down stream area.

Surge Tank :- It acts like a pressure controller for the flow of water

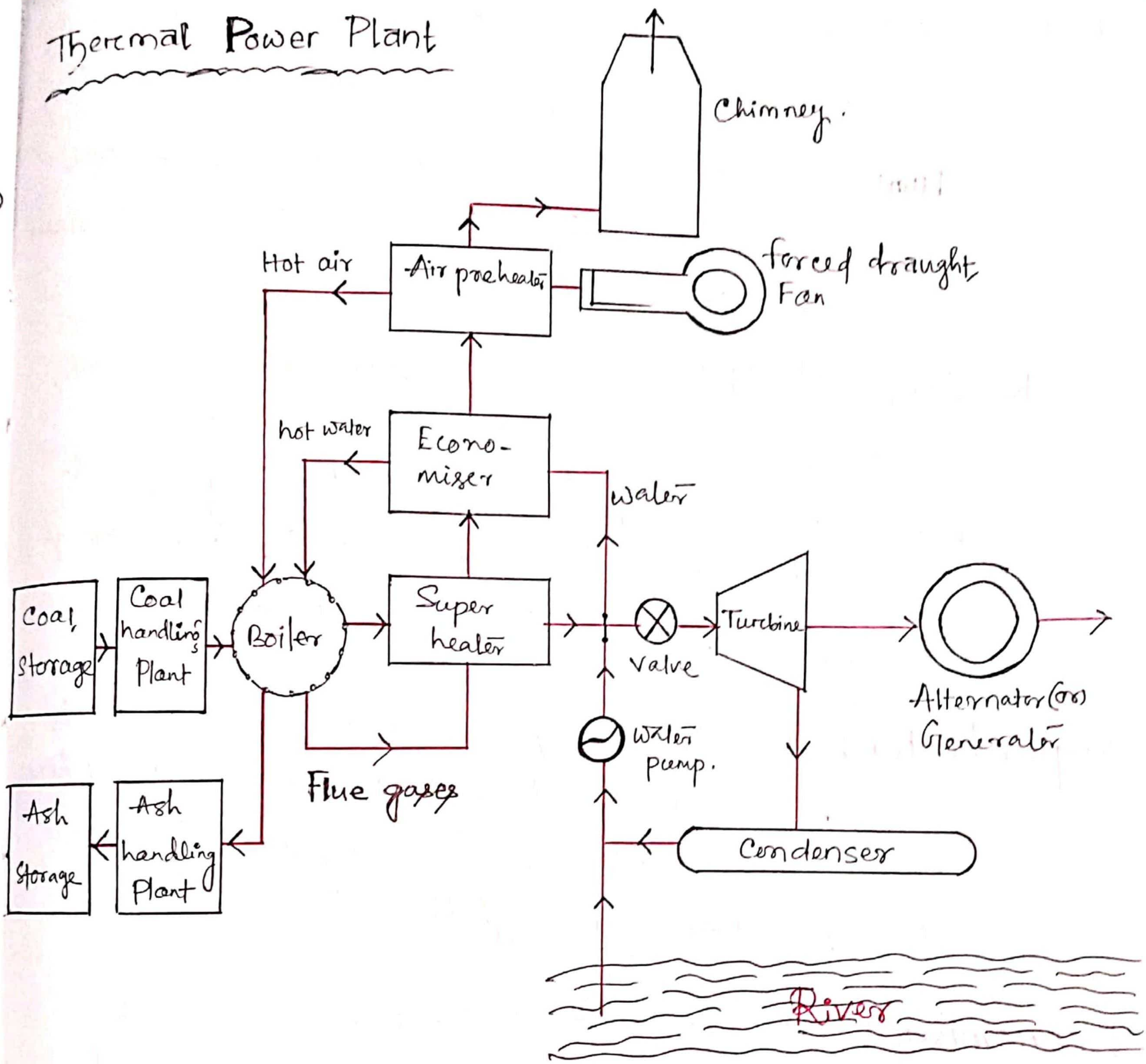
Penstock :- It is a closed tube like structures which carry water to the turbines. They are generally made of steel.

Turbine :- It works as an energy conversion device. It is a device through which potential energy of water is converted in to mechanical energy of shaft.

Generator :- By getting the mechanical energy from turbine, generator generates electricity.

Tail race :- After hitting with the turbine, the waters are collected in a storage like structure, which is called tail race.

Thermal Power Plant



Coal Storage: The coal is transported to the power station by road or rail and is stored in the coal storage plant.

Coal handling plant: From the coal storage plant, coal is delivered to the coal handling plant. Here the coal is crushed in to small pieces, in order to increase its surface exposure, thus promoting rapid combustion.

Boiler : It is used to boil water. The crushed coal is fed to the boiler by conveyor belt. The coal is burnt in the boiler. The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure.

Ash handling & Storage: After the complete combustion of coal, ash is produced. The removal of ash from the boiler is necessary for proper burning of coal. The ash is passed to the Ash handing plant through Conveyer belt and finally it is sent to ash storage.

Super heater : The steam produced in the boiler is wet and is passed through a super heater where it is dried and super heated by the heat of flue gas passed through it.

Economiser : Basically it is a water heater which exchanges heat from flue gas and transfer it to the water before it reaches to the boiler. This results in increasing boiler efficiency. saving fuels.

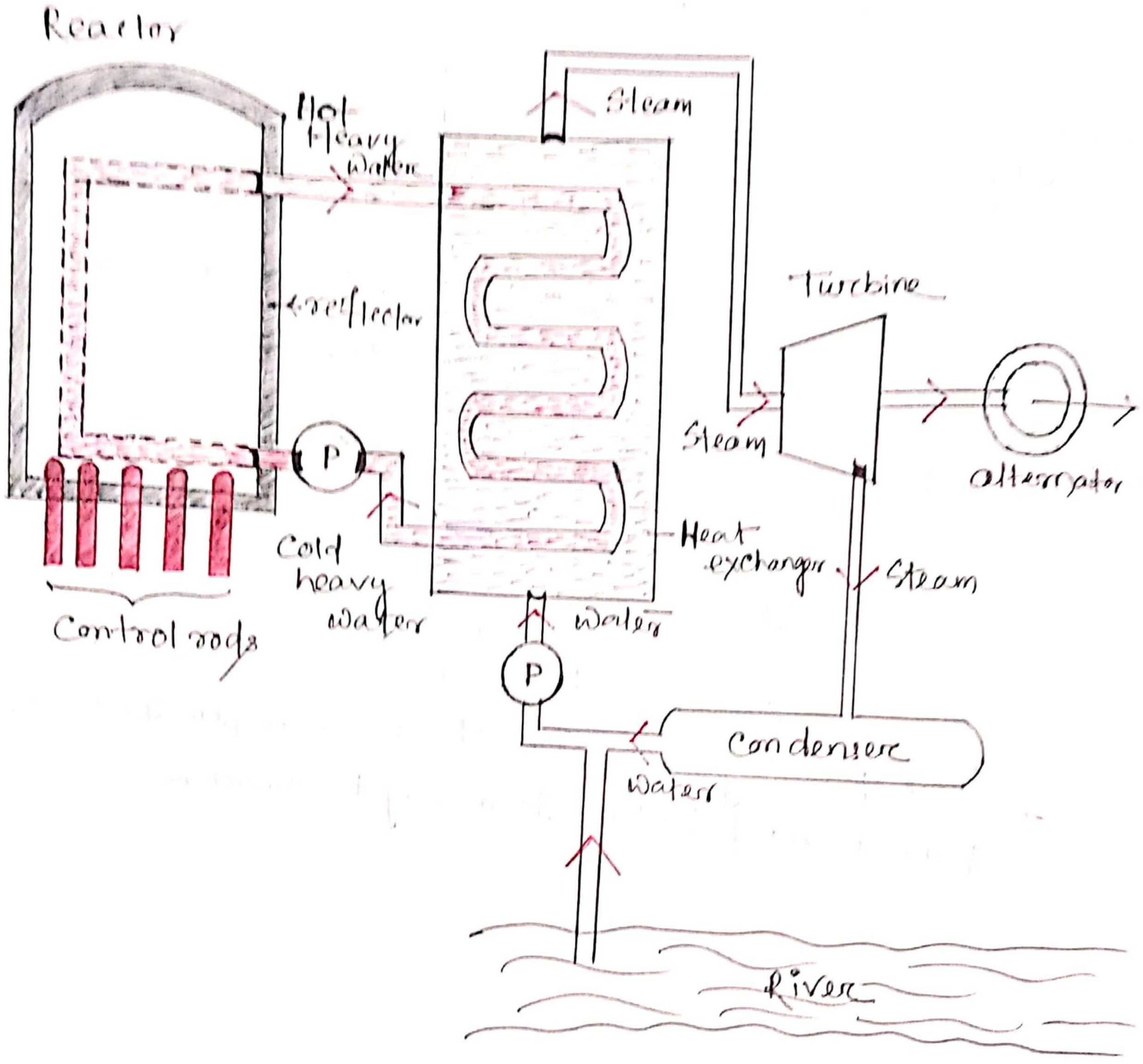
Air pre-heater : It increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air pre-heater before supplying to the boiler furnace.

It extracts heat from flue gases and increase the temp of air used for coal combustion. It increases the thermal efficiency and increased steam capacity.

Turbine & generator: When high pressure steam hits the blade of turbine, it starts to rotate. The generator's shaft is coupled with turbine. Hence generator starts to generate electricity.

Condenser: A condenser is a device which condenses the steam at the exhaust of the turbine. It serves two important functions. Firstly, it creats a very low pressure at the exhaust of the steam turbine. secondly the condensed steam can be used as feed water to the boiler.

Nuclear power plant :



Reactor : It is a closed vessel in side which nuclear reaction takes place and no radiation comes out.

Nuclear fuel : In nuclear power plants the fuels used are $^{235}_{92}U$, $^{239}_{94}Pu$, $^{232}_{92}Th$. The fuel is required in nuclear power plant to produce a huge amount of heat energy.

Control Rods: In nuclear power plant the main function of control rods is to control the chain reaction. if the control rod is inserted then it absorbs the freely moving neutrons & stop the chain reaction. these control rods are made up of Cadmium, Boron (alloyed with steel or aluminum).

Reflector: The reflector is used to surround the reactor core. The reflector will also help to bounce the escaping neutrons back to the reactor core & it conserve the nuclear fuel.

Heat Exchanger: The main function of heat exchanger in nuclear power plant is to boil the cold water and produce steam at high temp & pressure. It exchange the heat from reactor to cold water

Turbine & alternator: Turbine is a mechanical device and it is mechanically coupled with alternator. The steam from heat exchanger hits the blade of turbine. turbine starts rotating along with generator or alternator also starts rotating and it generates electricity.

Condenser: The condenser receives an exhust hot steam from turbine. It condenses the steam. This condensed steam can be used as feed water to the heat exchanger.