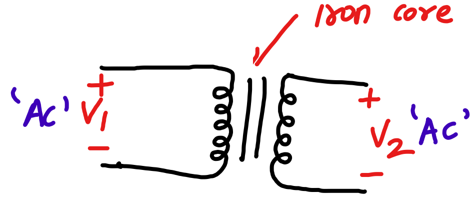
EEEE lec 43a 22/6/23

Module 4.1 : Single phase transformer, construction and principle of working, emf equation of a transformer, losses in transformer, equivalent circuit of Ideal & Practical transformer, voltage regulation & efficiency of transformer, phasor diagram at various loading condition

Transformer converts AC voltage into another AC voltage

* Single phase transformer :



Transformer symbol

A) Introduction to transformers

i) A 'transformer' is a static device by means of which 'electric power' from one circuit can be 'transferred' to another circuit without change in frequency

ii) Transformer can raise or lower AC voltage in the circuit → with a corresponding decrease or increase in AC current

iii) Transformer works on the principle of 'mutual inductance'

"A transformer is an electrical device that use electromagnetic induction → to pass an AC signal from one electric circuit to another → often changing the voltage and current."

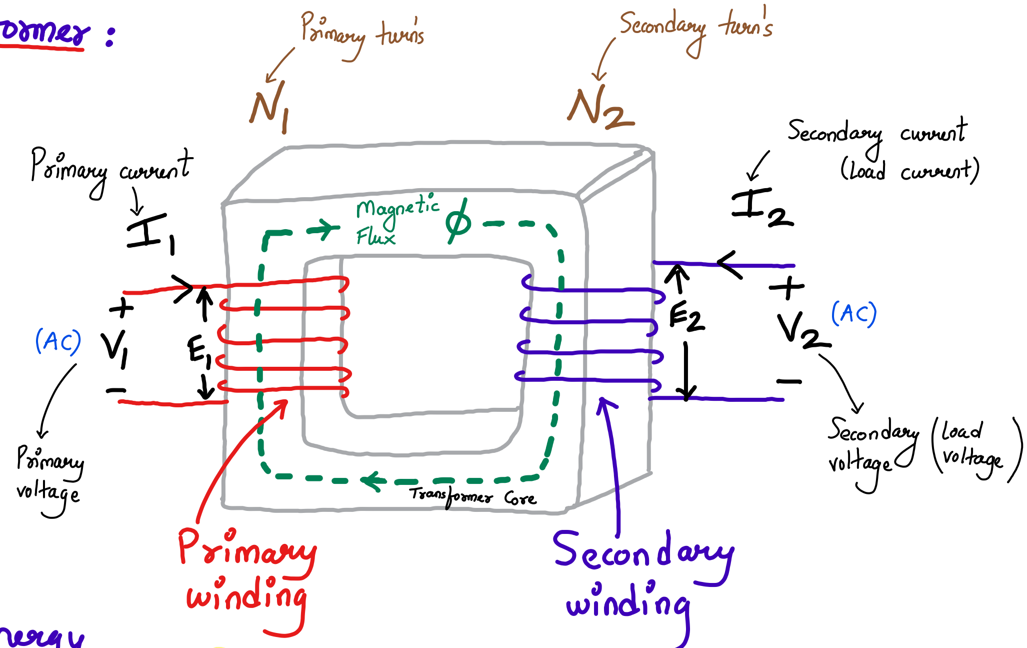
B) Working principle of Transformer :

① A transformer consists of two inductive coils/windings placed on a common core.

② Winding's are electrically isolated from each other

③ Primary winding → electrical energy is fed to it

Secondary winding → Electrical energy is drawn out from it



Transformer

④ When an AC voltage 'V_1' is applied to the primary winding of a transformer → an AC current 'I_1' flow's through it producing alternating flux (ϕ) in the core.

⑤ This flux (ϕ) Links with the primary winding and according to Faraday's law of electro-magnetic induction → an emf 'E_1' is induced in the primary coil, which is given by,

N_1 : No. of primary winding turns

$$\boxed{E_1 = -N_1 \frac{d\phi}{dt}} \text{ Volt} \quad — ①$$

$$\boxed{E_1 = -V_1}$$

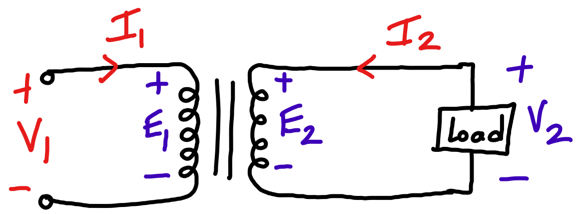
→ The induced emf (E_1) in the primary winding is nearly equal to & opposite to applied AC voltage (V_1)

⑥ Assuming negligible leakage flux → almost whole flux (ϕ) produced by the primary winding Links with the secondary winding

⑦ Hence, an emf 'E_2' is produced in the secondary winding, which is given by,

$$\boxed{E_2 = -N_2 \frac{d\phi}{dt} \text{ Volt}} \quad \text{— (2)}$$

(8) The emf 'E_1' is called 'self-induced emf', while the emf 'E_2' is 'mutually induced emf'.



(9) If the secondary winding is closed through the load $\longrightarrow$ a current I_2 flows through the secondary winding

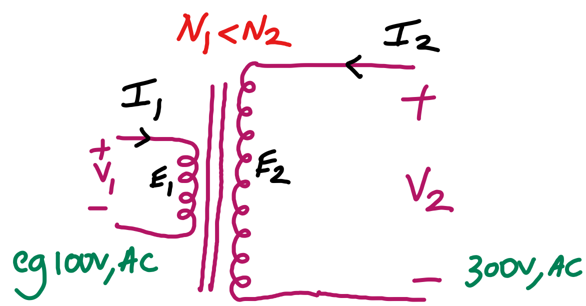
Thus, energy is transferred from the primary winding to the secondary winding

(10) From equation (1) and (2),

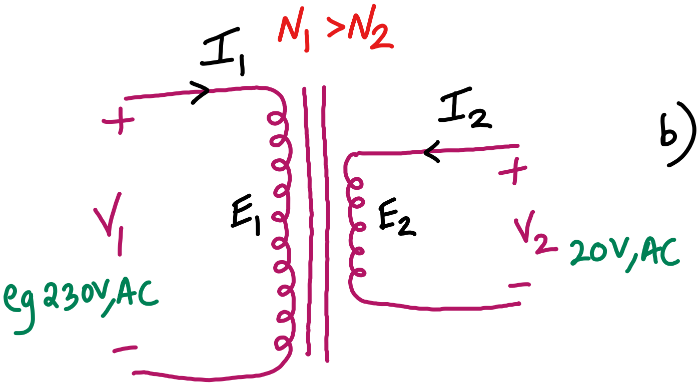
$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K \longrightarrow \text{transformer ratio 'K'}$$

$$E_1 = -N_1 \frac{d\phi}{dt} \quad , \quad E_2 = -N_2 \frac{d\phi}{dt}$$

a) If N_2 is greater than N_1, then $E_2 > E_1$. Such a transformer is called a 'Step-up transformer'



'Step-up transformer'



'Step-down transformer'

b) If N_2 is less than N_1, then $E_2 < E_1$

Such a transformer is called a 'Step-down transformer'

c) Construction of transformer:

i) A transformer mainly consists of an iron core, primary and secondary windings wound over the core.

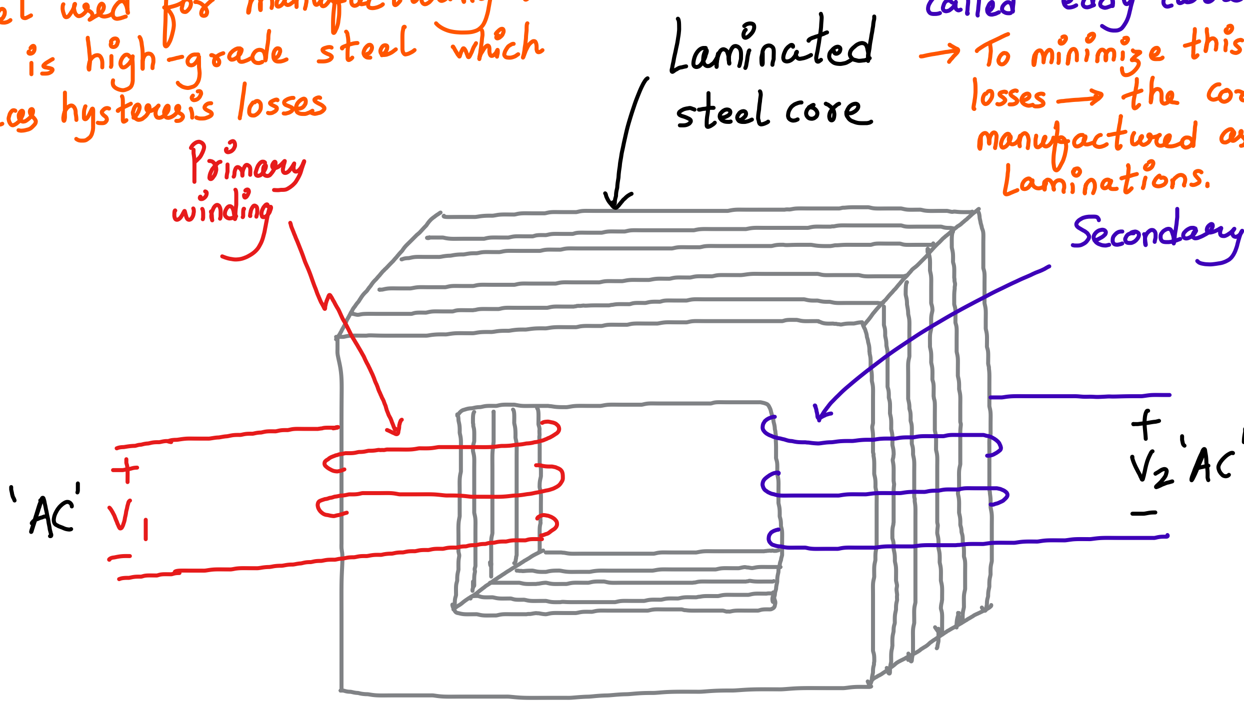
→ Steel used for manufacturing the core is high-grade steel which reduces hysteresis losses

ii) Core: A core is rectangular in shape and is Laminated.

→ Due to alternating flux → eddy currents are induced in the core

→ These eddy currents cause considerable loss of power in the core itself called 'eddy current loss'

→ To minimize this eddy current losses → the core is manufactured as stack of Laminations.



iii) Windings:

→ One winding is connected to the source of the electrical energy (called 'primary winding'), while the other winding is connected to the load (called 'secondary winding')

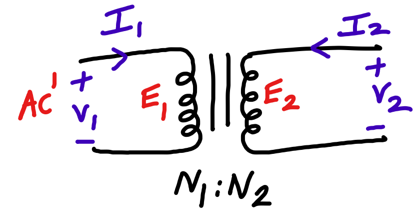
→ In core type transformer, the two parts of each windings are electrically connected in series
i.e here winding enclose the "whole core"

→ This arrangement gives good magnetic coupling between the primary and secondary windings

→ Each winding is properly insulated from each other as well as the core

→ Depending upon the core & winding arrangement → the transformer construction is classified as
a) Core type ✓
b) Shell type

D) EMF equation of a transformer :



① Normally, sinusoidal AC voltage is applied to the primary winding $\longrightarrow$ This produces the flux in the core, which also varies sinusoidally.

② Let the equation of the sinusoidal AC flux in the core be,

$$\phi = \phi_m \sin\omega t \quad \text{— ③}$$

③ According to Faraday's law of electromagnetic induction $\longrightarrow$ the self-induced emf in primary winding is given by,

$$E_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin\omega t) = N_1 \phi_m \cos\omega t$$

$$\therefore \boxed{E_1 = N_1 \phi_m \sin(\omega t - 90^\circ) \times \omega} \quad \text{— ④}$$

④ From equation ③ and ④ $\longrightarrow$ it may be noted that the self-induced emf (E_1) lags behind the flux (ϕ) by 90°

⑤ Comparing equation 4 with the standard sinusoidal form (i.e $E = E_m \sin(\omega t \pm \phi)$), maximum value of the induced emf is given by,

$$\boxed{E_m = N_1 \phi_m \omega} \quad \text{— ⑤}$$

⑥ Hence, rms value of the induced emf in the primary winding is given by,

$$E_1 = \frac{E_m}{\sqrt{2}} = \frac{N_1 \phi_m 2\pi f}{\sqrt{2}} \qquad \omega = 2\pi f$$

$$\text{i.e } \boxed{E_1 = 4.44 f N_1 \phi_m} \quad \text{— ⑥}$$

where,
ϕ_m – max flux in Wb
f – supply frequency

⑦ Similarly, rms value of the induced emf in secondary winding is given by,

$$\boxed{E_2 = 4.44 f N_2 \phi_m} \quad \text{— ⑦}$$

⑧ Equation ⑥ and ⑦ are called "emf equations" of the transformer

i) $\frac{E_1}{E_2} = \frac{\cancel{4.44 f} N_1 \cancel{\phi_m}}{\cancel{4.44 f} N_2 \cancel{\phi_m}}$; $\frac{E_1}{E_2} = \frac{N_1}{N_2} \rightarrow \boxed{\frac{E_2}{E_1} = \frac{E_2}{N_1} = K}$ → transformer ratio

ii) Neglecting small primary and secondary voltage drop's,

$V_1 \approx E_1$ & $V_2 \approx E_2$

$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = K$

⑨ In transformer, if losses are considered negligible → hence, input and output can be approximately equalled

$\underline{\underline{V_1 I_1}} = \underline{\underline{V_2 I_2}}$ $\boxed{\frac{I_1}{I_2} = \frac{V_2}{V_1} = K}$

⑩ ∴ Different forms of the transformation ratio are,

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = K}$$

For step-up transformer → $N_2 > N_1$ → $K > 1$

For step-down transformer → $N_2 < N_1$ → $K < 1$

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E) Actual (Practical) and Ideal transformers :

Practical transformer	Ideal transformer
i) There are copper and eddy current losses	i) There is no loss
ii) There is leakage in flux	ii) There is no leakage in flux
iii) It's windings contain ohmic resistance	iii) It's windings consist of purely inductive coils, wound on lossless core
iv) Voltage regulation is never 0%	iv) Voltage regulation is 0%
v) Efficiency is 93–97%	v) Efficiency is 100%
vi) All constructed transformers are practical transformers	vi) It is impossible to construct an ideal transformer.

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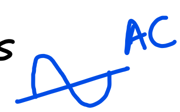
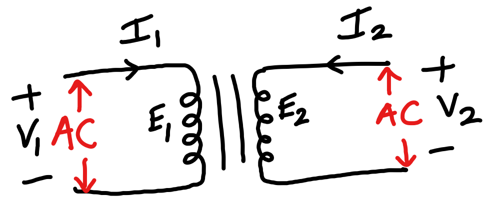
F) Why transformers do not work with DC input ?

i) The direction of current flow is changed in AC





ii) When AC flows through primary winding current is induced in the secondary winding due to mutual induction

iii) There is no mutual induction in DC → as it's direction does not change

iv) So, a transformer cannot work with DC input

v) ∴ If DC is applied as input → there is no output obtained rather it end's up heating up the transformer due to resistance of primary winding

vi) Thus, transformers do not allow DC input to flow through. This is known as '<u>DC isolation</u>'

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