Lecture: Energy Systems - 2

Instructor

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TRANSFORMERS

An important device used in power transmission, electronic circuits & communication systems.

$\Rightarrow$ consists of a magnetic circuit in which a time varying 'ϕ' lines link two or more coils

$\Rightarrow$ coupling can be air $\rightarrow$ air core transformer

Iron $\rightarrow$ iron core transformer

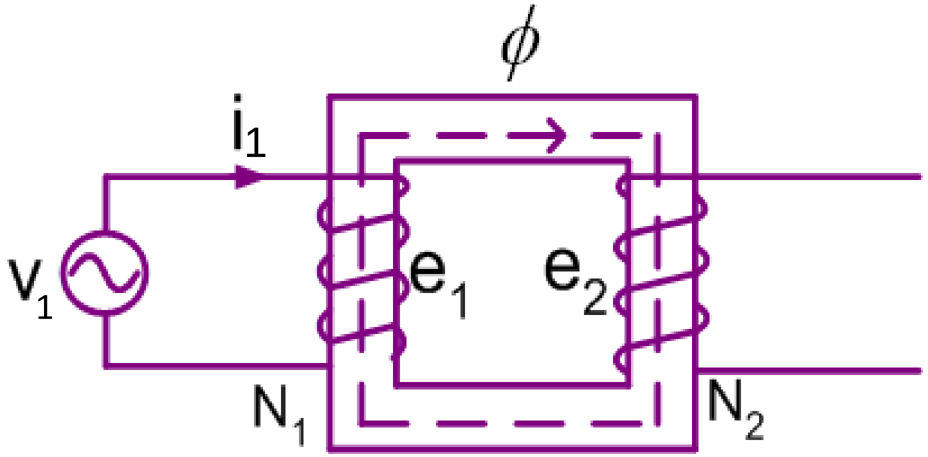
core is made up of laminations to $\downarrow$ core loss

Purpose : Transfer electric energy from one circuit to another

Electrical Energy $\longrightarrow$ Magnetic Energy $\longrightarrow$ Electrical Energy

No electrical connection between two circuits.

$\Rightarrow$ Electrically isolated



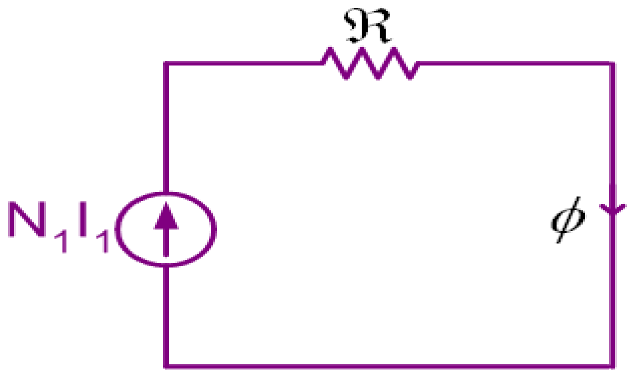
Principle of Operation:

$\Rightarrow$ magnetic circuit in which time varying flux links two or more coils

winding connected to source $\rightarrow$ Primary

winding connected to load $\rightarrow$ Secondary

Primary when connected to alternating source & secondary is open



$\Rightarrow$ no current in secondary

$\Rightarrow$ AT produced by secondary = 0

$\Rightarrow$ AT supplied is just sufficient to establish 'ϕ' in the core

$\Rightarrow$ If core is highly permeable, this AT is small
(how small is this small?)

$\Rightarrow$ since 'ϕ' is alternating $\Rightarrow$ core loss

$\Rightarrow$ source has to supply some power

$\Rightarrow$ for the present we will neglect

$\Rightarrow$ Time varying 'ϕ' links N_1 turns & voltage (e_1 /E_1) is induced

$$E_1 = 4.44 f \phi_m N_1 \qquad \phi_m \rightarrow \text{peak value of '}\phi\text{'}$$

$$E_1 \approx V_1$$

$\Rightarrow$ same 'ϕ' links the secondary

$\Rightarrow \quad e_2, E_2$ is the voltage induced in N_2

$$E_2 = 4.44 f \phi_m N_2$$

$$E_2 \approx V_2$$

$\Rightarrow E_2$ & E_1 are in phase

$$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

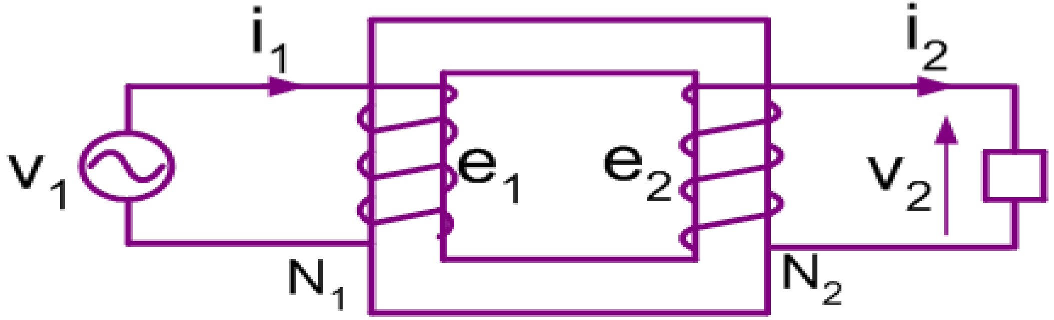
If $N_2 > N_1 \Rightarrow$ Step up transformer

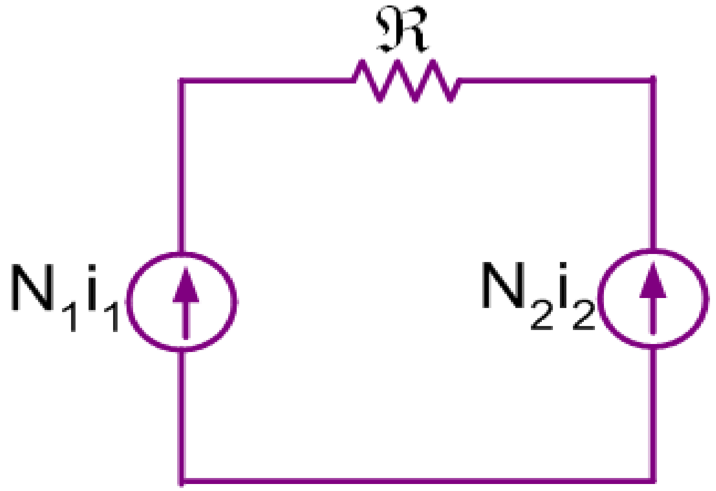
$N_2 < N_1 \Rightarrow$ Step down transformer

Connect the load to secondary

i_2 will flow

$\Rightarrow$ which sets up its own flux, ϕ_2





$\Rightarrow$ This ϕ_2 opposes the parent 'ϕ'

$\Rightarrow$ flux in the core tends to $\downarrow$

$\Rightarrow$ E_1 tends to $\downarrow$

But, V_1 is held constant

$V_1 = E_1$ & $\therefore$ 'ϕ' in the core should remain constant

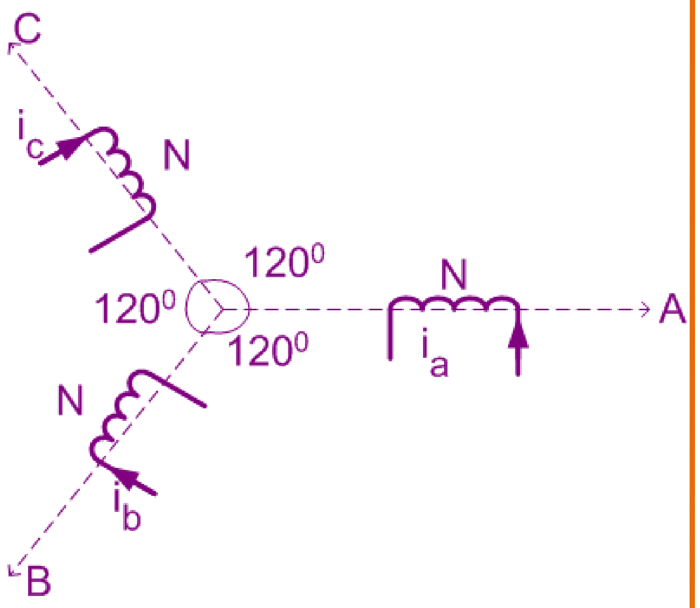
$\Rightarrow$ can happen when $i_1 \uparrow$ such that

$$N_1 I_1 - N_2 I_2 = \Re \phi$$

$\Rightarrow$ 'ϕ' in the core is determined by V_1 alone

Induction machine

- Consider 3 coils of ‘N’ turns, displaced in space by 120°
- Let i_a, i_b & i_c are given as



$$i_a = I_m \sin(\omega_s t)$$
$$i_b = I_m \sin\left(\omega_s t - \frac{2\pi}{3}\right),$$
$$i_c = I_m \sin\left(\omega_s t - \frac{4\pi}{3}\right), \text{ where } \omega_s = 2\pi f$$

- Current in each coil produces a pulsating magnetic field
- Amplitude & direction depend on the instantaneous value of ‘I’ flowing through it
- Each phase winding produces a similar magnetic field displaced by 120° in space from each other

Induction machine

Magnitude and position of the resultant field can be determined as follows

- Resolve the field produced by individual coil along x & y axes
- Determine $\sum x$ & $\sum y$ components
- Resultant, $R = \sqrt{(\sum x)^2 + (\sum y)^2}$

$\theta = \tan^{-1}\frac{\sum y}{\sum x}$, w.r.t axis of coil ‘A’

$$\sum x = Ni_a + Ni_b\cos(-120) + Ni_c\cos(-240)$$
$$= Ni_a - \frac{1}{2}Ni_b - \frac{1}{2}Ni_c$$
$$\because i_a + i_b + i_c = 0, \Rightarrow \sum x = \frac{3}{2}Ni_a$$

$$\sum y = 0 + Ni_b\sin(-120) + Ni_c\sin(-240)$$
$$= -\frac{\sqrt{3}}{2}Ni_b + \frac{\sqrt{3}}{2}Ni_c$$
$$\Rightarrow \sum y = \frac{\sqrt{3}}{2}N(i_c - i_b)$$

i_a, i_b & i_c are sinusoidal varying quantities

$\omega_s t$	i_a	i_b	i_c	Σx	Σy	R	θ
0^0	0	$\frac{-\sqrt{3}}{2} I_m$	$\frac{\sqrt{3}}{2} I_m$	0	$\frac{3}{2} N I_m$	$\frac{3}{2} N I_m$	$\frac{\pi}{2}$
30^0	$\frac{I_m}{2}$	$-I_m$	$\frac{I_m}{2}$	$\frac{3}{4} N I_m$	$\frac{3\sqrt{3}}{4} N I_m$	$\frac{3}{2} N I_m$	$\frac{\pi}{3}$
90^0	I_m	$\frac{-I_m}{2}$	$\frac{-I_m}{2}$	$\frac{3}{2} N I_m$	0	$\frac{3}{2} N I_m$	0
180^0	0	$\frac{\sqrt{3}}{2} I_m$	$\frac{-\sqrt{3}}{2} I_m$	0	$\frac{3}{2} N I_m$	$\frac{3}{2} N I_m$	$\frac{-\pi}{2}$

Observations:

- Magnitude of ‘R’ is constant and equal to $\frac{3}{2} N I_m$ where I_m is the peak
- Input ‘I’ completes 1/4 cycle, ‘R’ rotates by 90°
- Input ‘I’ completes 1/2 cycle, ‘R’ rotates by 180°

Conclusion:

- The result of displacing 3 windings by 120° in space and displacing the winding ‘I’ by 120° in time phase is a single revolving field of constant magnitude
- For a given winding arrangements speed of rotation is determined by ‘f’ of input alone

Rotor construction

squirrel cage $\rightarrow$ aluminum/ copper bars are embedded in the rotor slots and permanently shorted at both ends by Al/Cu end rings

$\Rightarrow$ electrically closed circuit

$\Rightarrow$ no additional 'R' can be connected