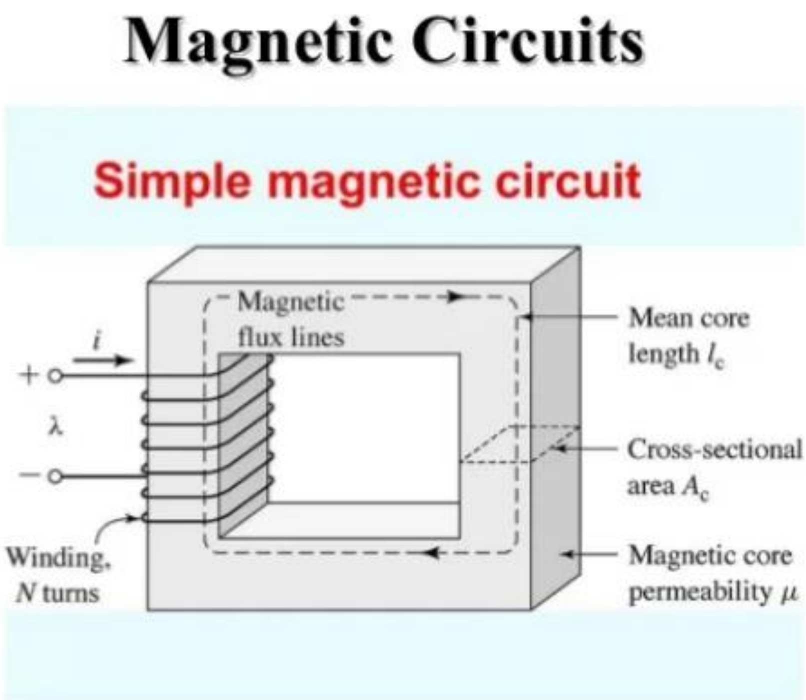
Magnetic circuits:

A magnetic circuit has a closed path, through which magnetic flux will flow.



Magnetic flux

The magnetic lines of force passing through a magnetic circuit is known as magnetic flux. It is denoted by a symbol ϕ and given by a formula $\phi = BA$, where B is the magnetic flux density and A is the area of the cross-section in m^2. The unit of magnetic flux is weber.

Magneto-motive force

Magneto-motive force or MMF is the cause for producing the magnetic flux. The MMF in a magnetic circuit depends on the number of turns(N) and the amount of current(I) flowing through it.

Magnetic flux density

It is the amount of magnetic flux per unit area at right angles to the flux. The unit of magnetic flux density is weber/m^2 and denoted by B. The formula is given by,

$$B = \frac{\phi}{a}$$

Magnetic field intensity

Magnetizing force or Magnetic field intensity or magnetic field strength is the MMF required to magnetize a unit length of the magnetic flux path. The unit of magnetic field intensity is AT/m and is denoted by H.

$$H = \frac{NI}{l}$$

Reluctance

It is the opposition that the magnetic circuit offers for the flow of magnetic flux. We can also define the reluctance as the ratio of magneto-motive force to the magnetic flux. It is denoted by S and its unit is ampere-turns per weber.

$$Reluctance(S) = \frac{MMF}{flux}$$

Permeance

Permeance is the reciprocal of reluctance. The ease with which the flux can pass through the material is known as permeance. Weber/AT is the unit of permeance.

$$Permeance = \frac{1}{reluctance}$$

Analogy between Magnetic circuit and Electric Circuit

Magnetic Circuit	Electric Circuit
A closed path for a magnetic flux forms a magnetic circuit.	A closed path for an electric current form an electric circuit.
Magnetic flux does not flow in a magnetic circuit.	Electric current always flows in an electric circuit.
MMF is the cause for producing flux.	EMF is the cause for producing current.
Weber is the unit of flux.	Ampere is the unit of current.
$Flux = \frac{mmf}{reluctance}$	$Current = \frac{emf}{resistance}$
Reluctance opposes the flow of flux.	Resistance opposes the flow of current.
$Reluctance = \frac{l}{\mu_0 \mu_r a}$	$Resistance = \frac{\rho l}{a}$
$Permeance = \frac{1}{reluctance}$	$Conductance = \frac{1}{resistance}$
Flux density, $B = \frac{\phi}{a}$	Current density, $J = \frac{I}{a}$
Magnetic field intensity, $H = \frac{NI}{l}$	Electric field intensity, $E = \frac{V}{d}$
Magnetic flux lines flow from the North pole to the South pole.	Electric current flows from the positive to negative terminal.

Self inductance and mutual inductances

Self Inductance [L]

The self inductance of the coil is defined as the flux linkage produced in the coil per unit current in the same coil. It is also defined as the weber turns produced per unit current in the coil. Its unit is Henry. Fig. 5.13 shows the coil of N turns carrying current i.

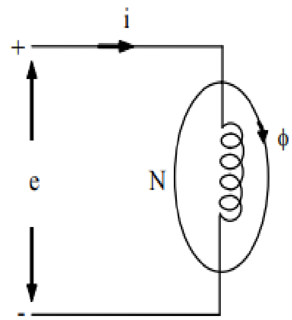


Fig. 5.13 Self Inductance

$\phi \rightarrow$ flux produced in webers.

If the current **i** through the coil changes, then the flux also changes. According to faraday's law of electromagnetic induction, an emf is induced in the circuit. This emf is equal to rate of change of flux linkage.

i.e., $e \, \alpha \, \frac{d\phi}{dt}$

$\Rightarrow \quad e = -N\frac{d\phi}{dt}$

----------(18)

where, $e \rightarrow$ induced emf

$N \rightarrow$ number of turns of the coil.

$\frac{d\phi}{dt} \rightarrow$ rate of change of flux

The negative sign indicates that the emf induced is opposite to the flux causing it.

The induced emf is also proportional to rate of change of current causing the flux ϕ.

$$\text{i.e. } e \propto \frac{di}{dt}$$

$$\Rightarrow e = -L\frac{di}{dt} \qquad \text{----------(19)}$$

where, $L \rightarrow$ self inductance of the coil.

$\frac{di}{dt} \rightarrow$ Rate of change of current.

The negative sign indicates that the emf induced is opposite to the current causing it.

Equating (18) & (19), $L\frac{di}{dt} = N\frac{d\phi}{dt}$

$$\Rightarrow \quad L = N\frac{d\phi}{di}$$

If the permeability is constant then, we can write that,

$$L = N\frac{\phi}{i}$$

Mutual Inductance [M]

The mutual inductance is defined as the ability of one coil to produce emf in other coil by induction when the current in the first changes.

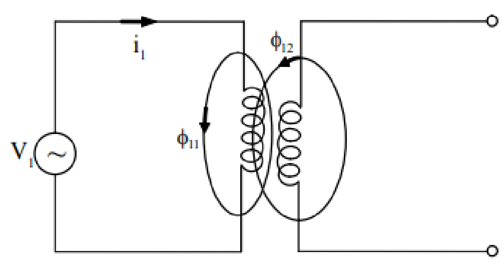


Fig. 5.14 (a) Mutual Inductance

It is also defined as the weber turns in one coil per ampere current in other coil. It is measured in Henry.

Consider the circuit shown in fig. 5.14(a). If a varying voltage source V_1 is connected to coil 1, it produces a varying current i_1. Let the number of turns in coil 1 be N_1. The number of turns in coil 2 be N_2. The varying current i_1, in coil produces a changing flux ϕ_1 in it.

The flux ϕ_1 is divided into two parts, $\phi_1 = \phi_{11} + \phi_{12}$ where $\phi_{11} \rightarrow$ part of flux ϕ_1 which links only with coil1, $\phi_{12} \rightarrow$ part of flux ϕ_1 which links with both coil1 & coil 2.

Let the induced emf in coil 2 be e_2. The induced emf e_2 is proportional to the rate of change of flux in the coil 2.

i.e; $$e_2 \alpha \frac{d\phi_{12}}{dt}$$

$$e_2 = -N_2 \frac{d\phi_{12}}{dt} \qquad \text{--------(20)}$$

where, $N_2 \rightarrow$ Number of turns in coil 2.

$\frac{d\phi_{12}}{dt} \rightarrow$ rate of change of flux linking coil 1 & coil 2.

The induced emf is also proportional to rate of change of current causing the flux ϕ_{12}. The current causing the flux ϕ_{12} is i_1

$$e_2 \alpha \frac{di_1}{dt}$$

$$e_2 = -M \frac{di_1}{dt} \qquad \text{----------(21)}$$

where, $M \rightarrow$ Mutual inductance between coil 1 & coil 2.

$\frac{di_1}{dt} \rightarrow$ Rate of change of current i_1,

Equating equation (20) & (21), $-N_2 \frac{d\phi_{12}}{dt} = -M \frac{di_1}{dt}$

$$\Rightarrow M = N_2 \frac{d\phi_{12}}{di_1}$$

For constant permeability, $M = N_2 \frac{\phi_{12}}{i_1}$ ----------(22)

If the voltage source is connected to coil 2, the circuit becomes, as shown in fig. 5.14 (b). The varying voltage V_2 produces a varying current i_2. Let the number of turns in coil1 be N_1 & the number of turns in coil 2 be N_2. The varying current i_2 in coil 2 produces a changing flux ϕ_2 in it.

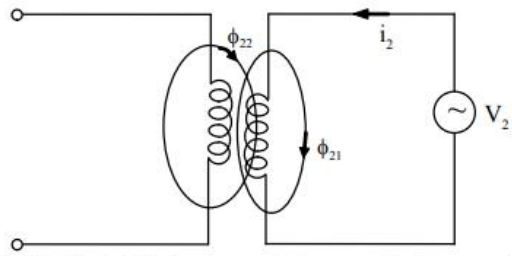


Fig. 5.14 (b) Mutual Inductance with source in the second coil

The flux ϕ_2 is divided into two parts, $\phi_2 = \phi_{22} + \phi_{21}$

where $\phi_{22} \rightarrow$ part of flux ϕ_2 links only with coil 2

$\phi_{21} \rightarrow$ part of flux ϕ_2 links with coil 2 and coil 1.

Let $e_1 \rightarrow$ induced emf in coil 1

The induced emf e_1, is proportional to the rate of change of flux in coil 1.

i.e., $e_1 \, \alpha \, \frac{d\phi_{21}}{dt}$

$$\Rightarrow \quad e_1 = -N_1 \frac{d\phi_{21}}{dt} \qquad \text{------------(23)}$$

where, $N_1 \rightarrow$ Number of turns in coil1.

$\frac{d\phi_{21}}{dt} \rightarrow$ Rate of change of flux linking coil 2 and coil 1.

The induced emf is also proportional to the rate of change of current causing the flux ϕ_{21}. The current causing the flux ϕ_{21} is i_2.

i.e., $e \, \alpha \, \frac{di_2}{dt}$

$$\Rightarrow e = -M \frac{di_2}{dt} \qquad \text{------------(24)}$$

where, $M \rightarrow$ Mutual inductance between coil 2 and coil 1.

$\frac{di_2}{dt} \rightarrow$ Rate of change of current i_2.

Equating eq. (4) and (5) $-N_1 \frac{d\phi_{21}}{dt} = -M \frac{di_2}{dt}$

$$\Rightarrow \quad M = N_1 \frac{d\phi_{21}}{di_2}$$

when permeability is constant, $M = \frac{N_1 \phi_{21}}{i_2}$ -------------(25)

Coupling Coefficient [K]

It is also known as coefficient of coupling or magnetic coupling coefficient or coefficient of magnetic coupling.

It is defined as the fraction of the total flux produced by one coil linking the other coil.

i.e., $K = \frac{\phi_{12}}{\phi_1} = \frac{\phi_{21}}{\phi_2}$ -------------(26)

Multiplying equation (22) & (25), $M^2 = \left(\frac{N_2 \phi_{12}}{i_1}\right)\left(\frac{N_1 \phi_{21}}{i_2}\right)$ -------------(27)

From equation (26), substitute $\phi_{12} = k\phi_1;\ \phi_{21} = k\phi_2$ in equation (27)

$$M^2 = \left(\frac{N_2 k\phi_1}{i_1}\right)\left(\frac{N_1 k\phi_2}{i_2}\right) \Rightarrow M^2 = K^2\left(\frac{N_1 \phi_1}{i_1}\right)\left(\frac{N_2 \phi_2}{i_2}\right) \quad \text{-------------(28)}$$

we know that $L = \frac{N\phi}{i} \Rightarrow L_1 = \frac{N_1 \phi_1}{i_1}$ and $L_2 = \frac{N_2 \phi_2}{i_2}$

Substituting L_1 and L_2 in (28) $M^2 = K^2 L_1 L_2$

$\Rightarrow M = K\sqrt{L_1 L_2}$

K value depends on the spacing between coils. As spacing increases K decreases. It is also depends on coil orientation and permeability. K is always positive and its maximum value is 1.

The maximum mutual inductance ocurs when K = 1

i.e. $M_{max} = 1\sqrt{L_1 L_2} = \sqrt{L_1 L_2}$

For iron-core coupled circuits, K may be as high as 0.99 and is between 0.4 to 0.8 for air core coupled circuit.

1. Find the maximum value of mutual inductance of two inductively coupled coils with L_1 = 100mH & L_2 = 25 mH.

Solution :

The mutual inductance between the two inductively coupled coil is, $M = K\sqrt{L_1, L_2}$.

The value of the mutual inductance is maximum only if the co-efficient of coupling K is equal to 1. Hence, the maximum mutual inductance between the two inductively coupled coils is,

$M = 1\sqrt{L_1, L_2} = \sqrt{(100 \times 10^{-3})(25 \times 10^{-3})}$

$\therefore M = 50\text{mH}$.

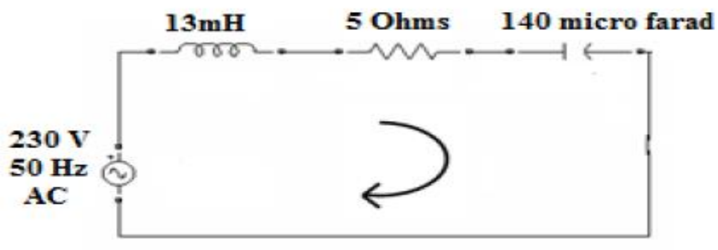
Unit 2

Two marks Questions

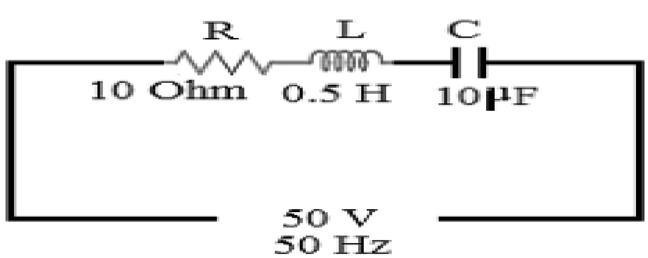
1. Define RMS value and Average Value
2. Define Power and Power factor.
3. What is meant by Real and Reactive Power?
4. Define peak value.
5. What is meant by real power and reactive power?
6. What is a rectifier?
7. What is an inverter?
8. What is meant by flux and flux density?
9. Define self-inductance of a coil.
10. Define mutual-inductance of a coil.

16 marks Questions

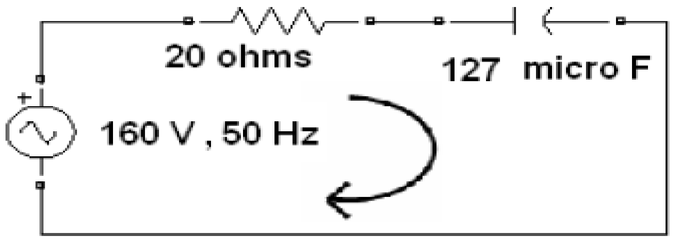
1. Identify the total impedance, current, phase angle θ, and the voltage across each element for the circuit shown below.



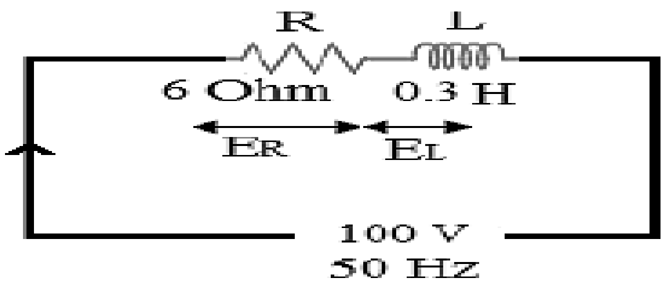
2. Identify the total impedance, current, phase angle θ, and the voltage across each element for the circuit shown



3. Identify the total impedance, current, phase angle θ, power factor, Power and the voltage across each element for the circuit shown below.



4. Identify the total impedance, current, phase angle θ, power factor ,Power and the voltage across each element for the circuit shown



5. Explain the half wave rectifier with neat diagram and waveform also derive the expression for average output voltage.
6. Explain the full wave rectifier with neat diagram and waveform also derive the expression for average output voltage.
7. Explain the mutual-inductance of a coil also derive the expression to find L and coefficient of coupling K.
8. Explain the self-inductance of a coil also derive the expression to find L and coefficient of coupling K.