

**SUBJECT : 1901106 BASIC ELECTRICAL AND ELECTRONICS
ENGINEERING**

SEM /YEAR : I YEAR-MECHANICAL

UNIT I - ELECTRICAL CIRCUITS & MEASUREMENTS

PART-A

Q.No	Questions & Answers
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1. Illustrate Ohm's law.

Ohm's law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperature remain constant.

$$V=IR$$

V- Voltage

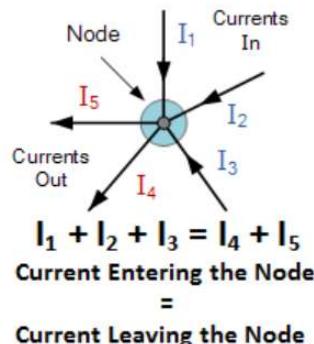
I- Current

R- Resistance

2. Illustrate Kirchhoff's laws.

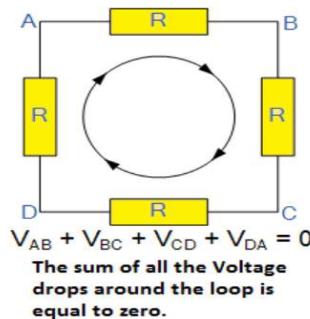
KCL:

The sum of the current flowing through the junction is equal to sum of the current flowing away from it.



KVL:

In Closed loop the sum of the potential drop is equal to potential Raise



3. Define the following terms Active & Passive elements with suitable example for each.

Active Element:

An active element is defined as the circuit component which deliver the power. It can supply energy to the circuit.

Example: Vacuum Tube, battery and semiconductor devices such as transistor, op-amp etc. are active element

Passive Element:

Any circuit element which only consumes power is called passive element. It cannot

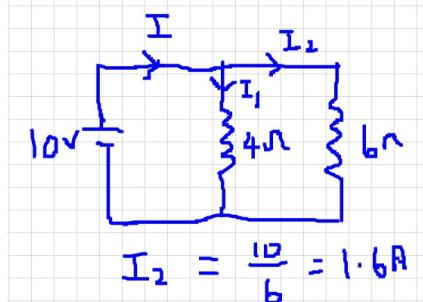
supply energy into the circuit.

Example: Resistor, Inductor, Capacitor & thermistor etc

4. Distinguish Loop and Mesh analysis.

S. No	Loop	Mesh
1	. A loop is any closed path through a circuit where no node more than once is encountered.	A mesh is a closed path in a circuit with no other paths inside it.
2	To find a loop, start at a node in the circuit, from this node, move back to the same node along a path to ensure that no node is encountered more than once	In other terms, a loop with no other loops inside it

5. Two resistances of 4Ω and 6Ω are connected in parallel across 10V battery. Calculate the current through 6Ω resistance.



6. When a resistor is placed across the 415V supply, the current is 36A. What is the value of resistor that must be placed in parallel to increase the load to 40A?

$$R = \frac{V}{I} = \frac{415}{36} = 11.5 \Omega$$

$$\text{Total Resistance} = \frac{415}{40}$$

$$\frac{1}{R_T} = \frac{1}{11.5} + \frac{1}{R_1}$$

$$\frac{1}{40} = \frac{1}{11.5} + \frac{1}{R_1}$$

$$R_1 = 108.7 \Omega$$

7. Define (i) Average value (ii) Effective (or) RMS value of An AC voltage signal.

Average Value:

The average of all the instantaneous values of an alternating voltage and current over one complete cycle is known as average value..

$$\text{Average Value} = \frac{\text{Area under one cycle}}{\text{Time Period}}$$

RMS Value:

That steady current which, when flows through a resistor of known resistance for a given period of time than as a result the same quantity of heat is produced by the alternating current when flows through the same resistor for the same period of time is called R.M.S or effective value of the alternating current.

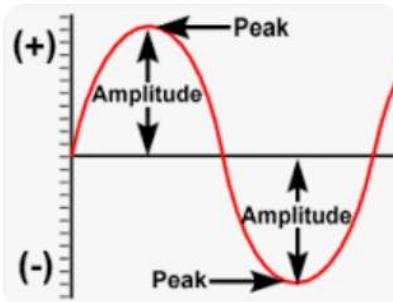
In other words, the R.M.S value is defined as the square root of means of squares of instantaneous values.

$$\text{RMS Value} = \sqrt{\frac{\text{Area of the squared curve for one cycle}}{\text{Time Period}}} =$$

- 8 Express the following terms (i) Amplitude (ii) Phase angle with suitable expression.

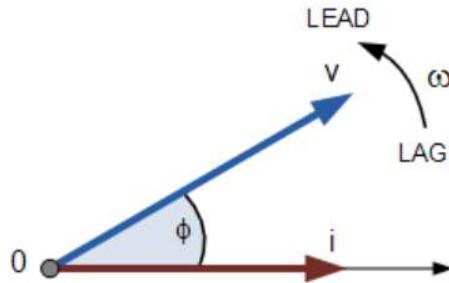
Amplitude:

Amplitude is the maximum value of current or voltage. It is represented by either of the two peaks of the sine wave. This voltage level is also referred to as the peak voltage, and can be either positive or negative.



Phase angle:

phase angle refers to the number of electrical degrees of lag or lead between the voltage and current waveforms in an ac circuit.



9. Define the terms (i) Form Factor (ii) Peak Factor.

Form Factor:

$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

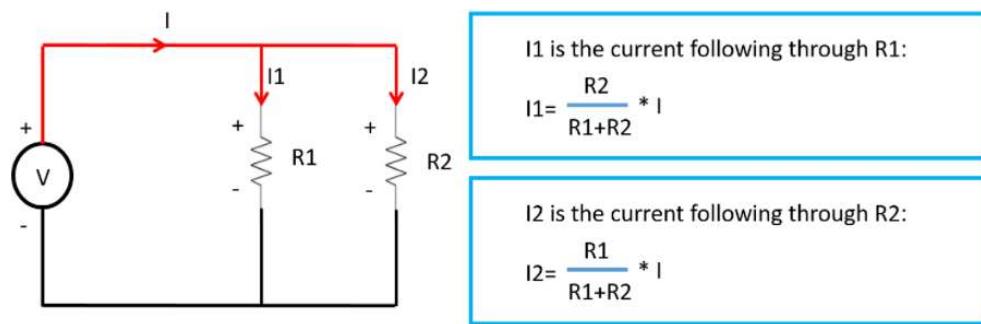
Peak factor:

$$\text{Peak Factor} = \frac{\text{Maximum Value}}{\text{RMS Value}}$$

10. Explain current division rule and voltage division rule.

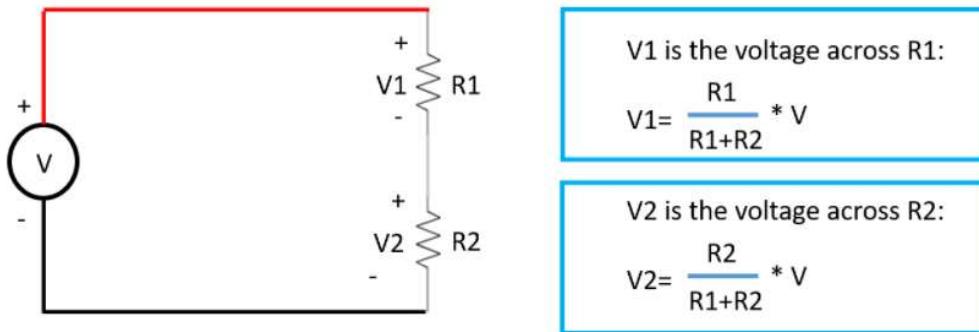
Current division Rule:

The current in any branch is equal to the ratio of opposite branch resistance to the total resistance of the circuit multiplied by the total current in the circuit.



Voltage Division Rule:

The voltage across any of the resistor in the series network is equal to the ratio of the resistance of resistor across voltage is to be a measure to the total resistance of series network multiplied by the total voltage in the circuit.



11. Explain the terms power and energy. And also write the expression for electrical power and energy.

Power :

The rate at which work is done in an electrical circuit is called power and its unit is joule per second or watt.

The power in the electrical circuit is obtained as the product of voltage(V) and current(I)

$$\text{Power} = \text{Voltage} \times \text{Current}$$

Energy:

Energy is the total amount of work done and hence is the product of power and time

$$\text{Energy} = \text{Power} \times \text{Time}$$

12. Define (i) Apparent Power (ii) power factor.

Apparent Power:

The combination of reactive power and true power is called **apparent power** and it is the product of a circuit's voltage and current, without reference to phase angle.

Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S.

$$S = P + j Q$$

S-Apparent Power

P-Real Power

Q-Reactive Power

Power factor:

Power factor is defined as the ratio of real power (P) to apparent power (S),

$$\text{Power Factor} = \frac{\text{Real Power (P)}}{\text{Apparent Power (S)}}$$

13. Explain the following terms Real (or) True (or) Average Power, Reactive Power and Apparent (or) Total Power.

Real Power(P):

The power which is actually consumed or utilised in an AC Circuit is called True power or Active power or Real power. It is measured in kilowatt (kW) or MW. It is the actual outcomes of the electrical system which runs the electric circuits or load.

Reactive Power (Q):

The power which flows back and forth that means it moves in both the directions in the circuit or reacts upon itself, is called Reactive Power. The reactive power is measured in kilo volt-ampere reactive (kVAR) or MVAR.

Apparent Power(S):

The product of root mean square (RMS) value of voltage and current is known as Apparent Power. This power is measured in kVA or MVA.

14. Summarize the advantages of 3 phase circuits over singlephase circuits.

1. A three-phase system can transmit more power as compared to a single-phase system
 2. Three phase machines have better power factor and efficiency
 3. Three phase motor have self-starting machine unlike single phase machine
 4. Generation, Transmission and distribution of power more economical
15. Compose the circuit diagram and explain the balanced load in 3-phase circuit.

A set of three impedances interconnected in the form of a star or delta form a 3-phase star or delta connected load. If the three impedances are identical and equal then it is a three phase balanced load.

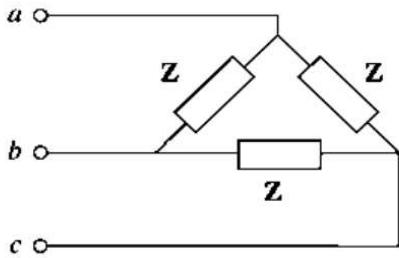


Fig.1.6

Let us consider a balanced 3-phase delta connected load

Determination of phase voltages:

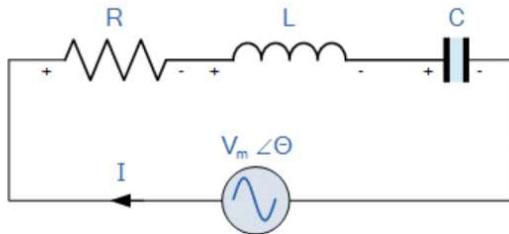
$$V_{AB} = V \angle 0^\circ, V_{BC} = V \angle -120^\circ, V_{CA} = V \angle -240^\circ = V \angle 120^\circ$$

Determination of phase currents:

Phase current = Phase voltage / Load impedance

$$I_{AB} = \frac{V_{AB}}{Z}; I_{BC} = \frac{V_{BC}}{Z}; I_{CA} = \frac{V_{CA}}{Z}$$

16. Explain the term resonance in a RLC series circuit.



In a series RLC circuit there becomes a frequency point where the inductive reactance of the inductor becomes equal in value to the capacitive reactance of the capacitor. In other words, $X_L = X_C$. The point at which this occurs is called the Resonant Frequency point, (f_r) of the circuit, and as we are analysing a series RLC circuit this resonance frequency produces a Series Resonance.

$$f_r = \frac{1}{(2\pi)\sqrt{LC}}$$

17. Formulate the formula for deflecting and controlling torque for PMMC and MI instrument.

Deflecting Torque:

This torque produces the required amount of force in the pointer to move from its 'zero' position, when the instrument is connected to the supply.

To obtain this force in an instrument, different effects of electric current use such as magnetic effect, heating effect, chemical effect etc.

Without deflecting torque pointer of an instrument cannot move for any value.

Controlling Torque:

Controlling torque is essential to control the movement of the pointer and to ensure that the magnitude of the deflection of the pointer is always the same as given value of the quantity to be measured.

The controlling force is always acts in opposite direction to the deflecting force. And also return the pointer to its initial zero position when the instrument is disconnected from the supply.

The controlling force could be produced by any one of the following method.

- Gravity control
- Spring control

18. Discuss the different types of damping force act on the ammeter and voltmeter.

- Air friction damping
- Fluid friction damping
- Eddy current damping
- Electromagnetic damping

19. List out the advantages of electro-mechanical measuring Instruments.

1. Electro Mechanical instrument with high accuracy, accurate measurement
2. It is used both AC and Dc measurements.
3. It does not depend on the earth's magnetic field.
4. It is strong, portable

20. Discuss the three torques required for the proper Operation of indicating instrument.

- Deflecting Torque
The force required for moving the pointer from its zero position
- Controlling Torque
The force required to bring the pointer to final steady state position without overshoot and to bring the pointer to zero when the deflecting force is absent
- Damping Torque
The force required to bring the pointer to final steady state position quickly without oscillations.

UNIT II - ELECTRICAL MACHINES

PART-A

Questions & Answers

Q.No

1. List any two applications of Following DC Motors (i)DC Series Motor (ii) DC Shunt Motor.

DC Series motor:

Series DC motors are generally used where high starting torque is required, and speed variations are possible. These types of direct connection motors are, for instance, used in the traction system, cranes, air compressors, vacuum cleaners, sewing machines,

DC shunt motor:

shunt motors are used wherever there is a request for stable speed. Shunt DC motors can be used in centrifugal pumps, lifts, weaving and lathe machines, blowers, fans, conveyors, spinning machines, and more

2. Define critical speed and critical resistance of a DC generator.

Critical Speed:

Critical speed is defined as the speed at which the given shunt field resistance is equal to the critical resistance.

Critical Resistance:

The critical field resistance is defined as the maximum field circuit resistance (for a given speed) with which the shunt generator would just excite.

3. Distinguish the difference between DC Motor and DCGenerator.

S.No	DC Motor	DC Generator
1	Converts electrical energy into mechanical energy	Converts mechanical energy into electrical energy
2	Fleming Left hand rule used	Fleming Right hand rule used
3	In a motor the current is to be supplied to the armature windings.	In the generator current is produced in the armature windings.
4	The Shaft of the motor is driven by the magnetic force developed between armature and field.	The Shaft is attached to the rotor and is driven by mechanical force.

4. Explain the principle of DC Motor.

The DC motor is the device which converts the direct current into the mechanical work. It works on the principle of Lorentz Law, which states that “the current-carrying conductor placed in a magnetic and electric field experience a force”. The experienced force is called the Lorentz force. The Fleming left-hand rule gives the direction of the force.

5. Define the term back EMF or Counter EMF and state its significance.

Back EMF:

When the armature of the DC motor rotates under the influence of driving torque, the armature of the conductors moves through a magnetic field inducing an emf in them. The induced emf is in the opposite direction to the applied voltage and is known as the back emf.

$$\text{Back emf } E_b = \frac{\phi ZNP}{60 A}$$

ϕ -Magnetic flux

Z-Number of conductors

P-Number of poles

A-Parallel Path

Significance of Back emf:

Back emf of DC motor regulates the armature current and it makes a motor as self regulation,

6. List the different main constructional elements of DC Machine.
 1. Yoke
 2. Poles and pole shoes
 3. Field winding
 4. Armature core
 5. Armature winding
 6. Commutator & Brushes
7. Define the following terms in DC Machine
 - (i) Commutator (ii) Brushes

Commutator:

A commutator is a rotary electrical switch that periodically reverses the direction of the current between the rotor and the external circuit.

Brushes:

Brushes in DC machine: Brushes are used to collect the current due to the induced emf from the armature coils in a DC generator. Brushes are made up of Carbon and graphite to reduce the wear and tear of the commutator.

8. In DC Generator, 8 poles, lap wound armature rotated at 350rpm to generate 260V, the useful flux/pole is 0.05Wb. If the armature has 120 slots. Calculate the number of conductors per slot.

$$\text{Generated emf } E_g = \frac{\phi Z N P}{60 A}$$

$$Z = \frac{Eg \times 60 \times A}{\phi N P}$$

$$Z = \frac{260 \times 60 \times 4}{0.05 \times 350 \times 4}$$

$$Z=891 \text{ Conductors}$$

No of conductors per slot=891/120=7Conductors

9. Explain why DC series motor should not be started without load.
speed of DC Series Motor is inversely proportional to Armature Current I_a . Therefore if the DC Series Motor is started at No Load then the speed of DC Series Motor will become dangerously high which will definitely damage the DC Series Motor.
10. List any two applications of Following DC Motors (i) DC Cumulative Compound Motor (ii) DC Differential Compound Motor

DC Cumulative Compound Motor:

Cumulative compound motors are used wherever high starting torque or pulsating loads are required. Cumulative compound motors are used to drive electric shovels, metal-stamping machine, reciprocating pumps, hoist, compressors etc.

DC Cumulative Compound Motor:

It has high starting torque and has varying speed within limits, i.e it has self-adjustable speed with change in load, Hence it is used for driving compressor, pressure, blowers, door, lifts, circular saws, passengers elevators, freight elevators

- 11 Discuss the terms with appropriate formula for Faraday's law of Electromagnetic Induction and Lenz Law.

First law: Whenever a conductor is placed in a varying magnetic field, an electromotive force is induced. If the conductor circuit is closed, a current is induced, which is called induced current.

Second law: The induced emf in a coil is equal to the rate of change of flux linkage.

$$Emf \ E = N \frac{d\Phi}{dt}$$

Lenz law: The direction of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

- 12 Mention few applications of DC Generators.

- These generators are used to charge batteries, provide lighting and provide excitation to alternators.
- They are used to provide field excitation current for regenerative braking in DC locomotives.
- They are used in DC motors where speed control is necessary.

- 13 With suitable formula explain the following terms (i) Turn ratio of transformer. (ii)

- Voltage regulation of Transformer.

Turn Ratio:

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

Voltage Regulation:

$$\% \text{ Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$$

Where

$V_{no-load}$ is the no-load voltage and

$V_{full-load}$ is the full-load voltage.

- 14 Explain why single phase induction motor is not self starting?

- A single-phase supply cannot produce rotating magnetic field rather it produces a pulsating magnetic field which does not rotate. Hence because of the pulsating magnetic field, the net torque on rotor is zero.

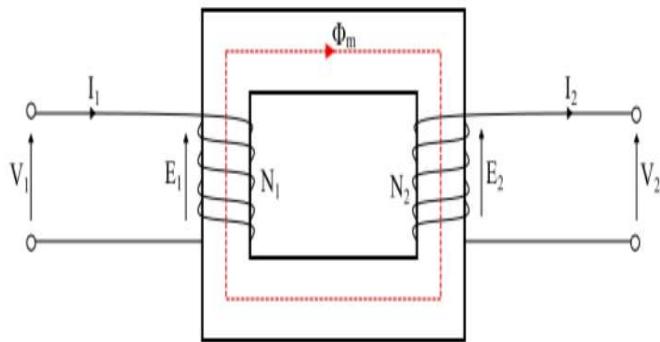
- 15 Discuss the terms (i) Efficiency (ii) All day efficiency of single phase transformer.

$$Efficiency = \frac{Output Power}{Input power} \times 100$$

Output

$$All \ day \ Efficiency = \frac{t \ in \ kwh \ for \ 24 \ hours}{Input \ in \ kwh \ for \ 24 \ hours}$$

- 16 Draw the circuit diagram of single phase transformer



V₁,I₁-Primary Input voltage and current

E₁,E₂-Induced voltage in primary and secondary

N₁,N₂-Number of turns for primary and secondary

Φ_m-Maximum flux

- 17 What is meant by transformer? Formulate the expression for step up and step down transformer according to transformation ratio.

A transformer is defined as a static electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. It is most commonly used to increase ('step up') or decrease ('step down') voltage levels between circuits with constant power.

In step up transformer the transformation ratio K>1

In step down transformer the transformation ratio K<1

- 18 Compare the following transformers (i) Core type transformer (ii) Shell type.

S.No	Core Type	Shell type
1	The winding surround the core.	The core surround the winding.
2	The lamination is cut in the form of the L strips	Lamination are cut in the form of the long strips of E and L.
3	Cross-section may be square, cruciform and three stepped	The cross section is rectangular in shape.
4	More copper loss	Less copper loss
5	Two magnetic circuit	One magnetic circuit

- 19 Formulate the EMF equation for Transformer.

$$E_1 = 4.44 f B_m A N_1 \text{ Volt}$$

E₁- Induced emf in primary winding in volt

f- Frequency of supply

B_m-Maximum Flux density

A-Area of the core

N₁-Number of primary turns

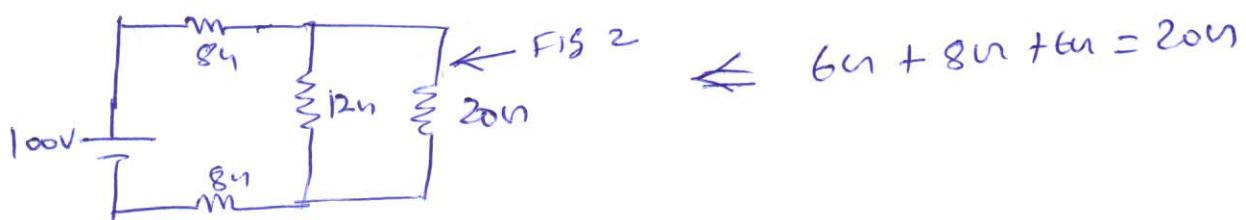
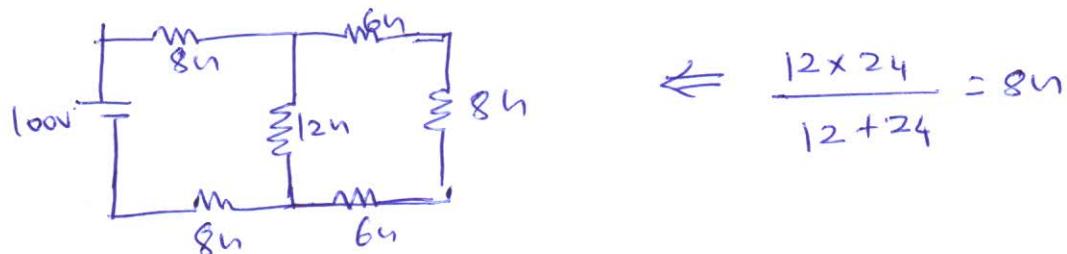
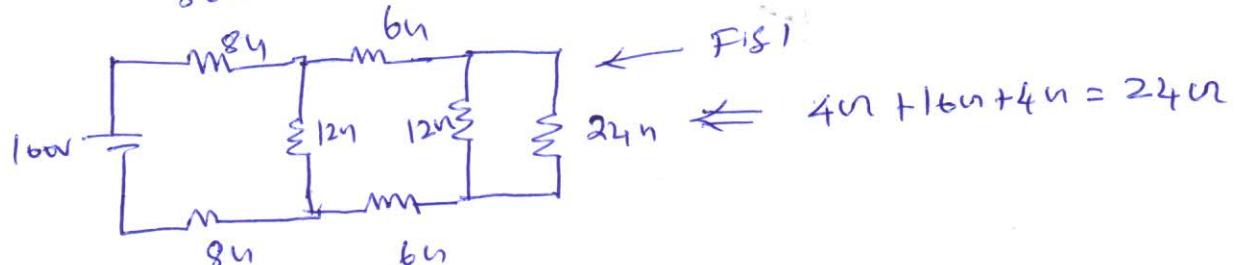
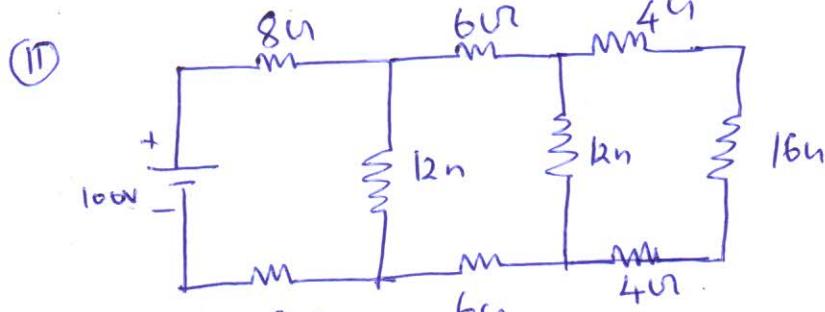
- 20 In a single phase transformer, N_p= 350 turns, N_s= 1050 turns, E_p= 400V. Calculate the value of secondary voltage (E_s).

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

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

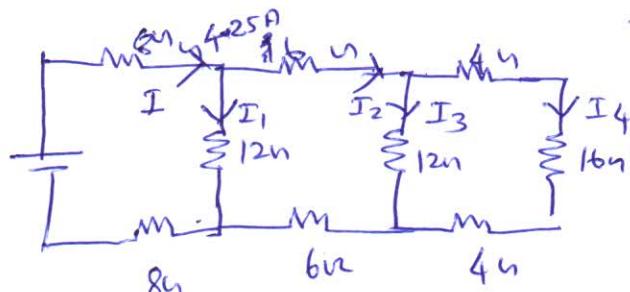
$$= 1200 \text{ V}$$

PART - B



(i) Total Resistance = 23.5Ω

(ii) Total Current = $\frac{V}{R} = \frac{100}{23.5} = 4.25A$



①

$$\begin{aligned}
 I_2 &= \frac{12}{12+20} \times I \\
 &= \frac{12}{32} \times 4.25 \quad \leftarrow \text{Ref Fig 2} \\
 &= 1.59 A
 \end{aligned}$$

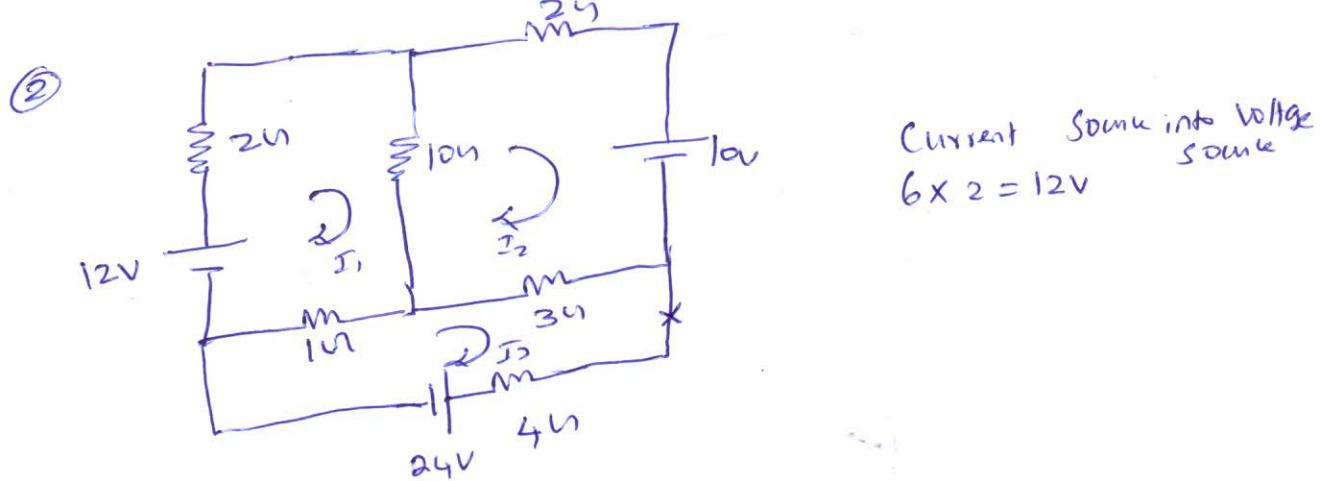
$$\begin{aligned}
 I_4 &= \frac{12}{12+24} \times I_2 \quad \leftarrow \text{Ref Fig 1} \\
 &= \frac{12}{36} \times 1.59
 \end{aligned}$$

$$I_4 = 0.53 A$$

Current through 16Ω Resistor = 0.53 A

(iii) Power delivered in 16Ω Resistor = $\frac{16}{\text{Resistance}} \times (\text{Current through resistance})^2$

$$\begin{aligned}
 &= 16 \times (0.53)^2 \\
 &= \underline{\underline{4.49 W}}
 \end{aligned}$$



Current source into voltage source
 $6 \times 2 = 12V$

Loop 1

$$-2I_1 - 10(I_1 - I_2) - 1(I_1 - I_3) + 12 = 0$$

$$-13I_1 + 10I_2 + I_3 = -12 \quad \text{---} ①$$

$$13I_1 - 10I_2 - I_3 = 12$$

Loop 2

$$-3(I_2 - I_3) - 10(I_2 - I_1) - 2I_2 + 10 = 0$$

$$-15I_2 + 10I_1 + 3I_3 = -10$$

$$15I_2 - 10I_1 - 3I_3 = 10$$

$$-10I_1 + 15I_2 - 3I_3 = -10 \quad \text{---} ②$$

Loop 3

$$-1(I_3 - I_1) - 3(I_3 - I_2) - 4I_3 - 24 = 0$$

$$-8I_3 + I_1 + 3I_2 = 24$$

$$-8I_3 + I_1 + 3I_2 = -24 \quad \text{---} ③$$

$$-I_1 - 3I_2 + 8I_3 = 24$$

Voltage equation:

$$\begin{bmatrix} 13 & -10 & -1 \\ -10 & 15 & -3 \\ -1 & -3 & 8 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 12 \\ -10 \\ -24 \end{bmatrix}$$

③

$$\Delta = \begin{vmatrix} 13 & -10 & -1 \\ -10 & 15 & -3 \\ -1 & -3 & 8 \end{vmatrix}$$

$$= 13(15 \times 8 - (-3)(-3)) + 10((-10)(8) - (-3)(-1)) - 1((-10)(-3) - (15)(-1))$$

$$= 568$$

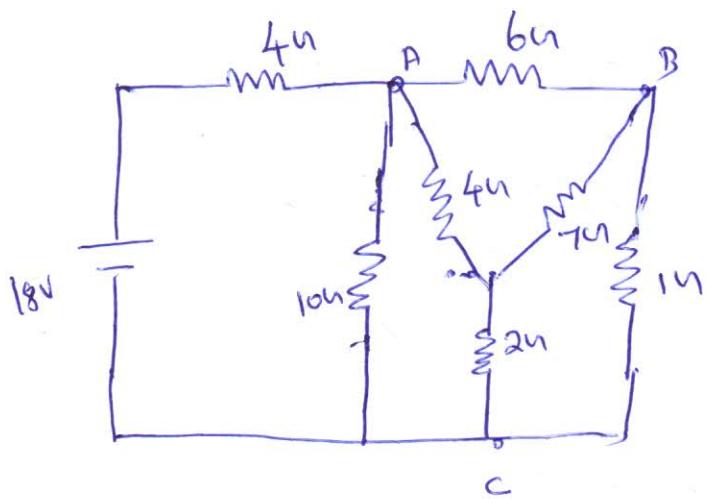
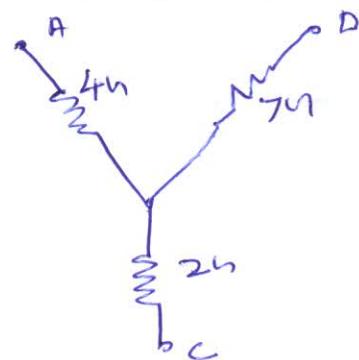
$$\Delta I_3 = \begin{vmatrix} 13 & -10 & 12 \\ -10 & 15 & -10 \\ -1 & -3 & -24 \end{vmatrix}$$

$$\Delta I_3 = -2230$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{-2230}{568} = -3.92A$$

$$\text{Current passing through } X = -\underline{\underline{3.92A}}$$

(3)

Star to Delta Transformation

$$R_{AB} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C}$$

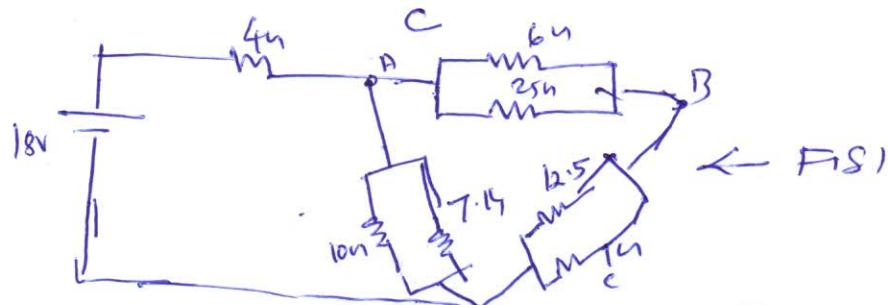
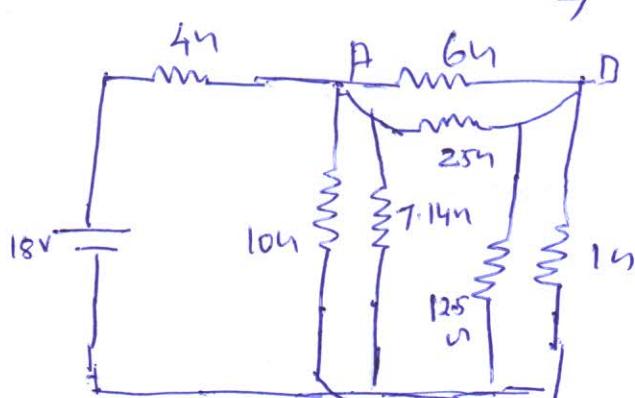
$$R_{BC} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B}$$

$$R_{CA} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A}$$

$$R_{AB} = \frac{4 \times 7 + 7 \times 2 + 2 \times 4}{2} = 25\Omega$$

$$R_{BC} = \frac{4 \times 7 + 7 \times 2 + 2 \times 4}{4} = 12.5\Omega$$

$$R_{CA} = \frac{4 \times 7 + 7 \times 2 + 2 \times 4}{7} = 7.14\Omega$$



(5)

$$\frac{10 \times 7.14}{10 + 7.14} = 4.16\Omega$$

$$\frac{6 \times 25}{6 + 25} = 4.8\Omega$$

$$\frac{12.5 \times 1}{12.5 + 1} = 0.92\Omega$$

$$4.8\Omega + 0.92\Omega \Leftarrow 4.16\Omega + 5.72\Omega = 9.88\Omega$$

$$4.16\Omega / 9.88\Omega = 0.4208\Omega$$

$$18V \parallel 2.408\Omega$$

$$18V \parallel 6.408\Omega$$

Total Resistance = 6.408Ω

Total Current in the circuit = $\frac{18}{6.408} = 2.808A$

In Fig 2 Current through 4.8Ω Resistor

$$I_{4.8\Omega} = \frac{4.164}{4.164 + 4.8 + 0.92} \times 2.808$$

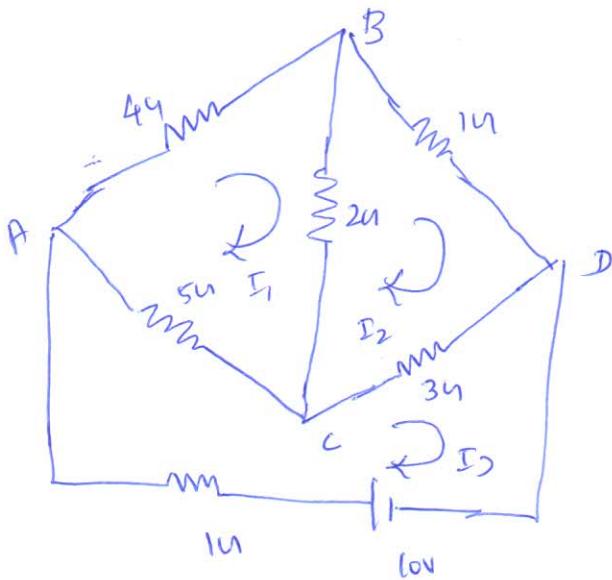
$$= 1.18A$$

In Fig 1 Current through 6Ω resistor

$$I_{6\Omega} = \frac{25}{25 + 6} \times 1.18$$

$$= 1.051A$$

(4)

Loop 1

$$-4I_1 - 2(I_1 - I_2) - 5(I_2 - I_3) = 0$$

$$-11I_1 + 2I_2 + 5I_3 = 0$$

$$11I_1 - 2I_2 - 5I_3 = 0 \rightarrow \textcircled{1}$$

Loop 2

$$-I_2 - 3(I_2 - I_3) - 2(I_2 - I_1) = 0$$

$$-6I_2 + 3I_3 + 2I_1 = 0$$

$$6I_2 - 3I_3 - 2I_1 = 0$$

$$-2I_1 + 6I_2 - 3I_3 = 0 \rightarrow \textcircled{2}$$

Loop 3

$$-I_3 - 5(I_3 - I_1) - 3(I_3 - I_2) + 10 = 0$$

$$-9I_3 + 5I_1 + 3I_2 = -10$$

$$9I_3 - 5I_1 - 3I_2 = 10$$

$$-5I_1 - 3I_2 + 9I_3 = 10 \rightarrow \textcircled{3}$$

(7)

$$\begin{bmatrix} 11 & -2 & -5 \\ -2 & 6 & -3 \\ -5 & -3 & 9 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 6 \\ 0 \\ 10 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 11 & -2 & -5 \\ -2 & 6 & -3 \\ -5 & -3 & 9 \end{vmatrix}$$

$$= 249$$

$$\Delta I_1 = \begin{vmatrix} 6 & -2 & -5 \\ 0 & 6 & -3 \\ 10 & -3 & 9 \end{vmatrix}$$

$$= 360$$

$$\Delta I_2 = \begin{vmatrix} 11 & 0 & -5 \\ -2 & 6 & -3 \\ -5 & 10 & 9 \end{vmatrix}$$

$$= 430$$

$$\Delta I_3 = \begin{vmatrix} 11 & -2 & 6 \\ -2 & 6 & 0 \\ -5 & -3 & 10 \end{vmatrix}$$

$$= 260$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{360}{249} = 1.44 A$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{430}{249} = 1.72 A$$

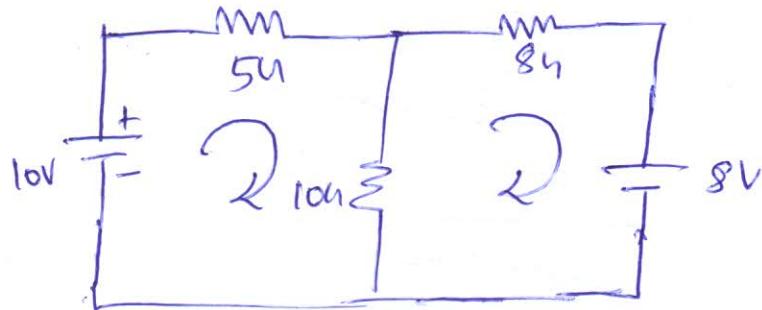
$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{260}{249} = 1.04 A.$$

$$\text{Current through } 2\Omega \text{ resistor} = I_1 - I_2 \\ = 1.44 - 1.72$$

$$= -0.28 A$$

(8)

⑤ ⑥



Loop 1

$$-5I_1 - 10(I_1 - I_2) + 10 = 0$$

$$-15I_1 + 10I_2 = -10$$

$$15I_1 - 10I_2 = 10 \quad \rightarrow \textcircled{1}$$

Loop 2

$$-8I_2 - 8 - 10(I_2 - I_1) = 0$$

$$-18I_2 + 10I_1 = 8$$

$$-10I_1 + 18I_2 = -8 \quad \rightarrow \textcircled{2}$$

$$\begin{bmatrix} 15 & -10 \\ -10 & 18 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ -8 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 15 & -10 \\ -10 & 18 \end{vmatrix} = 170$$

$$\Delta I_1 = \begin{vmatrix} 10 & -10 \\ -8 & 18 \end{vmatrix} = 100$$

$$\Delta I_2 = \begin{vmatrix} 15 & 10 \\ -10 & -8 \end{vmatrix} = -20$$

$$I_1 = \frac{100}{170} = 0.58A$$

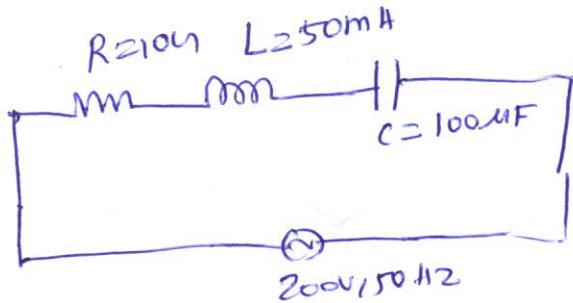
$$I_2 = \frac{-20}{170} = -0.117A$$

⑦

(5)

(6)

10



$$R = 10 \Omega$$

$$X_L = 2\pi f L = 2\pi \times 50 \times 50 \times 10^{-3}$$

$$= 15.7 \Omega$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 100 \times 10^{-6}}$$

$$= 31.83 \Omega$$

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

$$= \sqrt{10^2 + (15.7 - 31.83)^2}$$

$$Z = 18.97 \Omega$$

$$(i) \text{ Total Impedance } Z = 18.97 \Omega$$

$$(ii) \text{ Total Current } I = \frac{V}{Z} = \frac{200}{18.97}$$

$$= 10.54 A$$

$$(iii) \text{ Power } P = VI \cos \phi$$

$$\phi = \tan^{-1} \left(\frac{X_L - X_C}{R} \right)$$

$$= \tan^{-1} \left(\frac{15.7 - 31.83}{10} \right)$$

$$= 58.2^\circ$$

$$P = VI \cos \phi$$

$$= 200 \times 10.54 \times \cos(58.2)$$

$$= 1110.8 W = 1.11 kW$$

$$(iv) \text{ Power Factor } = \frac{P}{VI} = \frac{10}{18.97} = 0.52 \text{ lagged}$$

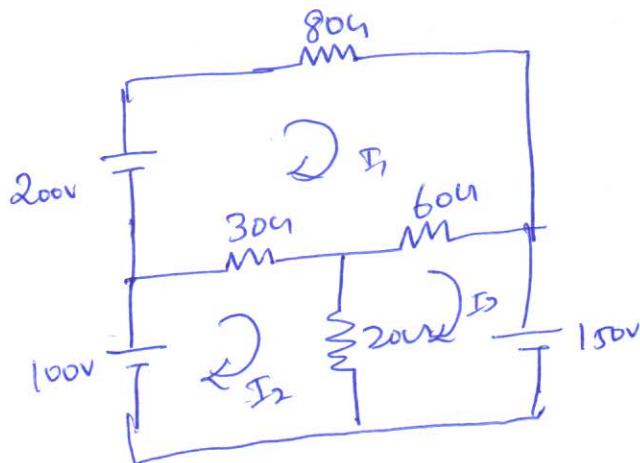
$$(v) \text{ Phase Angle } = 58.2^\circ$$

$$(vi) \text{ Voltage across each element } \Rightarrow V_R = 105.4 V$$

$$V_L = 165.47 V (I_X)$$

$$V_C = 335.48 V (I_C)$$

(7)



Loop P1

$$170I_1 - 30I_2 - 60I_3 = 200$$

Loop P2

$$-30I_1 + 50I_2 - 20I_3 = 100$$

Loop P3

$$-60I_1 - 20I_2 + 80I_3 = -150$$

Voltage equations

$$\begin{bmatrix} 170 & -30 & -60 \\ -30 & 50 & -20 \\ -60 & -20 & 80 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 200 \\ 100 \\ -150 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 170 & -30 & -60 \\ -30 & 50 & -20 \\ -60 & -20 & 80 \end{vmatrix} = 9.4 \times 10^5 \text{ or } 288,000$$

$$\Delta I_1 = \begin{vmatrix} 200 & -30 & -60 \\ 100 & 50 & -20 \\ -150 & -20 & 80 \end{vmatrix} = 54,000 \text{ or } 54,000$$

$$\Delta I_2 = \begin{vmatrix} 170 & 200 & -60 \\ -30 & 150 & -20 \\ -60 & -150 & 80 \end{vmatrix} = 9.4 \times 10^5 \text{ or } 94,000$$

$$\Delta I_3 = \begin{vmatrix} 170 & -30 & 200 \\ -30 & 50 & 100 \\ -60 & -20 & -150 \end{vmatrix} = 1.000 \times 10^5 \text{ or } 100,000$$

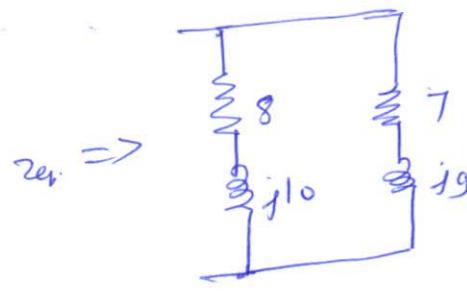
$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{54,000}{9.4 \times 10^5} = 0.575 \text{ A}, \quad I_2 = \frac{\Delta I_2}{\Delta} = \frac{94,000}{9.4 \times 10^5} = 10 \text{ A}, \quad I_3 = \frac{\Delta I_3}{\Delta} = \frac{100,000}{9.4 \times 10^5} = 1.063 \text{ A}$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{100,000}{9.4 \times 10^5} = 0.347 \text{ A}$$

(11)

(10) ⑥

(15)

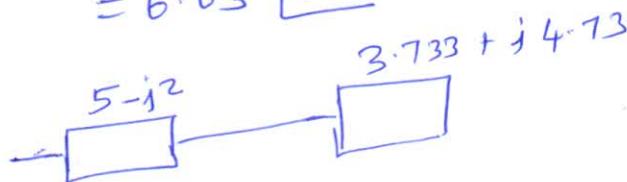


$$Z_{eq} \Rightarrow$$

$$Z_{eq} = \frac{(8+j10) \times (7+j9)}{(8+j10) + (7+j9)}$$

$$= 3.733 + j4.73 \Omega$$

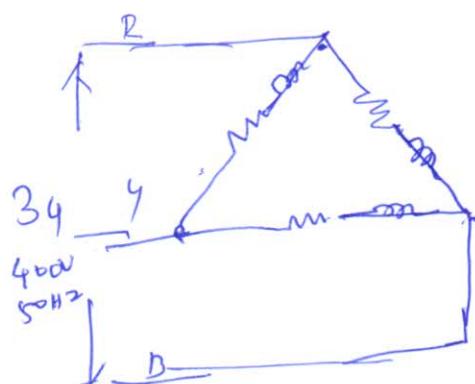
$$= 6.03 \angle 51.7^\circ$$



$$Z_{total} = 8.733 + j2.73$$

$$= 9.14 \angle 17.35^\circ$$

⑤



Motor load = 200kW
 Frequency = 50 Hz
 Efficiency = 91%
 Power factor = 0.86

$$\text{Line current } I_L = \frac{200 \times 10^3}{400} \text{ (Power)} = \frac{200}{400} \text{ (Voltage)}$$

$$= 1560 \text{ A.}$$

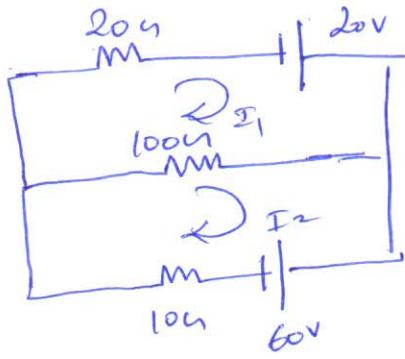
$$\text{Motor input} = \frac{\text{Motor o/p}}{\text{Efficiency}} = \frac{200}{0.91} = 219.78 \text{ kW}$$

$$\text{Total i/p power } P = \sqrt{3} V_L I_L \cos\phi$$

$$I_L = \frac{P}{\sqrt{3} V_L \cos\phi} = \frac{219.78 \times 10^3}{\sqrt{3} \times 400 \times 0.86} = 368.8 \text{ A}$$

$$\text{Current in each phase} = 368.8 / \sqrt{3} = 212.9 \text{ A}$$

⑧ (i)



$$\frac{20}{20\Omega} - 100(I_1 - I_2) + 20 = 0$$

$$-120I_1 + 100I_2 = -20 \quad (1)$$

$$120I_1 - 100I_2 = 20 \quad (2)$$

$$\frac{100}{10} - 100(I_2 - I_1) - 60 = 0$$

$$-100I_2 + 110I_1 = -60 \quad (3)$$

$$\begin{bmatrix} 120 & -100 \\ -100 & 110 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 20 \\ -60 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 120 & -100 \\ -100 & 110 \end{vmatrix} = 3200$$

$$\Delta I_1 = \begin{vmatrix} 20 & -100 \\ -60 & 110 \end{vmatrix} = -3800$$

$$\Delta I_2 = \begin{vmatrix} 120 & 20 \\ -100 & -60 \end{vmatrix} = -5200$$

$$I_1 = \frac{-3800}{3200} = -1.187 A$$

$$I_2 = \frac{-5200}{3200} = -1.625 A$$

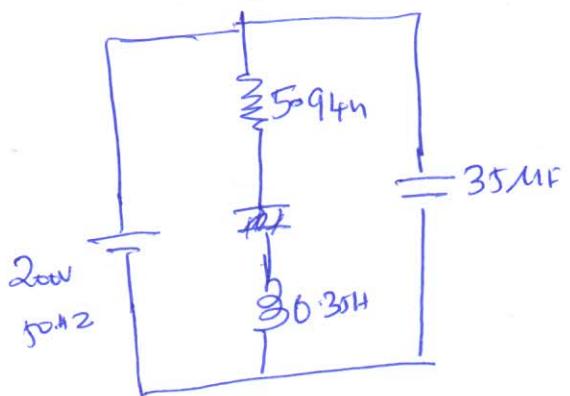
$$\text{Current through } 20\Omega \text{ resistor} = -1.187 A$$

$$\text{Current through } 100\Omega \text{ resistor} = I_1 - I_2 \\ = -1.187 + 1.625$$

$$= 0.438 A$$

$$\text{Current through } 10\Omega \text{ resistor} = -1.625 A$$

⑧ (ii)



$$R = 5.94\Omega$$

$$\begin{aligned} X_L &= 2\pi f L \\ &= 2\pi \times 50 \times 0.35 \\ &= 109.95 \Omega \end{aligned}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 35 \times 10^{-6}}$$

$$= 90.94 \Omega$$

$$R + jX_L = 5.94 + j109.95 = 110.1 \angle 86.9^\circ$$

$$\begin{aligned} Z &= (R + jX_L) \parallel X_C \\ &= (5.94 + j109.95) \parallel -j90.94 \\ &= \frac{(5.94 + j109.95) \times (-j90.94)}{5.94 + j109.95 - j90.94} \end{aligned}$$

$$= 123.8 - j487.28$$

$$Z = 502.76 \angle -75.7^\circ$$

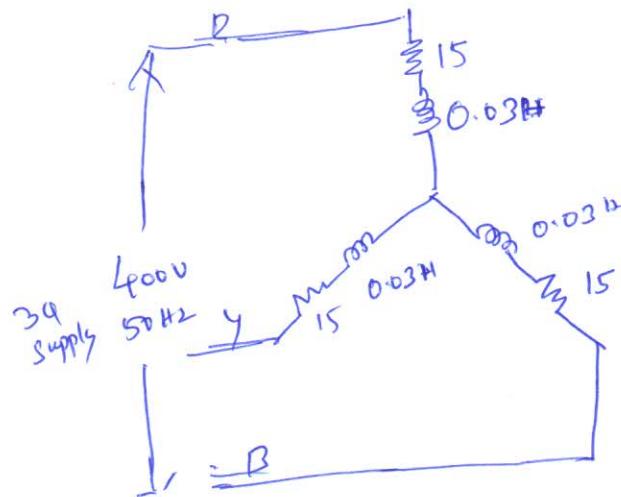
$$\text{Current } I = \frac{V}{Z} = \frac{200}{502.76} = 0.397 \text{ A}$$

$$\text{phase difference} = 75.7^\circ$$

⑨

(10)

(11)



$$Z = R + jXL$$

$$R = 15\Omega$$

$$XL = 2\pi f L = 2 \times 3.14 \times 50 \times 0.03$$

$$= 9.42\Omega$$

$$Z = 15 + j 9.42$$

$$= 17.71 \angle 32.12^\circ$$

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

$$= \frac{400}{17.71} = 22.58 \text{ A}$$

$$I_{\text{phase current}} = I_{\text{line current}} = 22.58 \text{ A}$$

$$I_{\text{ph}} = \underline{22.58 \text{ A}}$$

$$\text{Power Absorbed} = \sqrt{3} V_L I_L \cos \phi$$

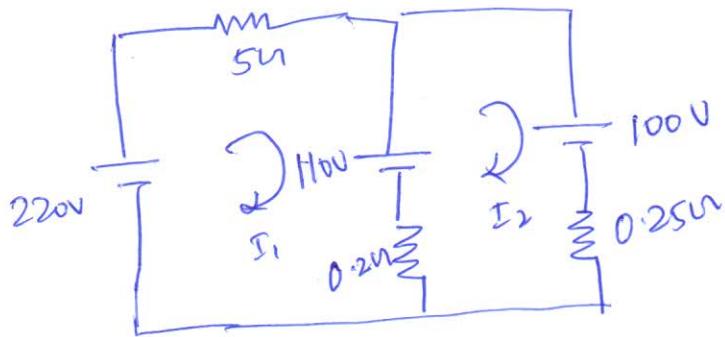
$$\cos \phi = \frac{R}{Z} = 0.84 \text{ Lag}$$

$$= \sqrt{3} \times 400 \times 22.58 \times 0.84$$

$$= \underline{13.14 \text{ kW}}$$

(16)

(13)



Loop 1

$$220 - 5I_1 - 110 - 0.2(I_1 - I_2) = 0$$

$$-5 \cdot 2 I_1 + 0.2 I_2$$

$$5 \cdot 2 I_1 - 0.2 I_2$$

$$= -110$$

$$= 110 \rightarrow ①$$

Loop 2

$$-100 - 0.25 I_2 - 0.2(I_2 - I_1) = 0$$

$$+ 110$$

$$= 20$$

$$+ 0.2 I_1 - 0.45 I_2 + 10$$

$$- 0.2 I_1 + 0.45 I_2$$

$$= 10 \rightarrow ②$$

$$\begin{bmatrix} 5 \cdot 2 & -0.2 \\ -0.2 & 0.45 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 110 \\ 10 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 5 \cdot 2 & -0.2 \\ -0.2 & 0.45 \end{vmatrix} = 2.3$$

$$\Delta I_1 = \begin{vmatrix} 110 & -0.2 \\ 10 & 0.45 \end{vmatrix} = 51.5$$

$$\Delta I_2 = \begin{vmatrix} 5 \cdot 2 & 110 \\ -0.2 & 10 \end{vmatrix} = 74$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{51.5}{2.3} = 22.39 \text{ A}$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{74}{2.3} = 32.17 \text{ A}$$

Current from 220V Battery = 22.39 A

Current from 100V " = 32.17 ACurrent from 110V " = $32.17 - 22.39 = 9.78 \text{ A}$

(17)

13) (ii) when coil connected to DC Supply

$$\text{Resistance } R = \frac{\text{Voltage}}{\text{Current}}$$
$$= \frac{24}{6} = 4\Omega$$

(ii) when coil connected to AC Supply

$$I = 6A$$

$$f = 50 \text{ Hz}$$

$$V = 30$$

$$\text{Impedance } Z = \frac{V}{I} = \frac{30}{6} = 5\Omega$$

$$\begin{aligned} \text{Reactance due to Inductance } X_L &= \sqrt{Z^2 - R^2} = \sqrt{5^2 - 4^2} \\ &= 3\Omega \end{aligned}$$

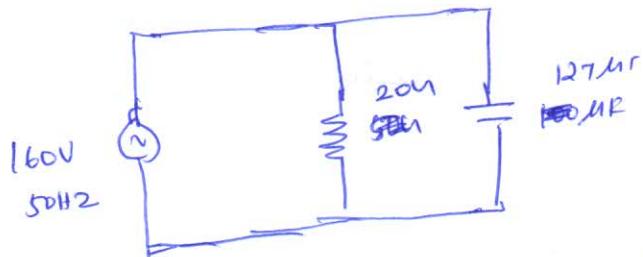
$$2\pi f L = 3$$

$$L = \frac{3}{2\pi \times 50} = 8.1 \times 10^{-6} \text{ H} = 8.1 \mu \text{H}$$

$$\text{Power factor} = \frac{R}{Z} = \frac{4}{5} = 0.8 \text{ lag}$$

PART-C

①



$$X_L = \frac{1}{2\pi f L} = \frac{1}{2\pi \times 50 \times 127 \times 10^{-6}} = 31.4 \Omega$$

$$X_C = 25.06 \Omega$$

$$\text{Capacitive Susceptance } B_C = \frac{1}{X_C} = 0.039$$

$$\text{Conductance } G = \frac{1}{R} = 0.025$$

$$\begin{aligned} \text{Total Admittance} &= \sqrt{G^2 + B_C^2} \\ &= \sqrt{0.025^2 + 0.039^2} \\ &= 0.063 \end{aligned}$$

$$\text{Total impedance } Z = \frac{1}{Y} = 15.7 \Omega$$

$$\text{Current } I = \frac{160}{15.7} = 10.19 A$$

$$\begin{aligned} \text{Power angle } \phi &= \tan^{-1} \left(\frac{b}{a} \right) \\ &= \tan^{-1} \left(\frac{25.06}{20} \right) \end{aligned}$$

$$\phi = 51.4^\circ$$

$$\begin{aligned} \text{power factor} &= \cos \phi \\ &= \cos (51.4^\circ) \end{aligned}$$

$$= 0.623 \text{ lag}$$

(17)

(2)

$$\text{power } P = \sqrt{3} V_L I_L \cos \varphi$$

$$I_L = \frac{P}{\sqrt{3} V_L \cos \varphi} = \frac{1.5 \times 10^3}{\sqrt{3} \times 400 \times 0.2} \\ = 10.82 \text{ A.}$$

$$\text{Impedance } Z = \frac{V_L}{I_L} = \frac{400}{10.82} \\ = 36.9 \Omega$$

$$\cos \varphi = \frac{R}{Z} \\ R = Z \cos \varphi = 36.9 \times 0.2 \\ = 7.38 \Omega$$

$$X_L^2 = \sqrt{Z^2 - R^2} \\ X_L = \sqrt{36.9^2 - 7.38^2}$$

$$X_L = 36.1 \Omega$$

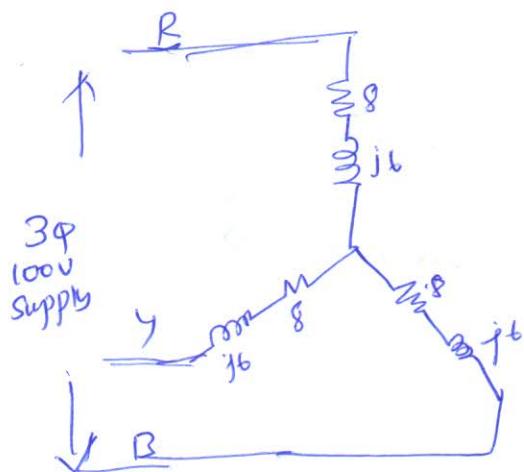
$$2\pi f L = 36.1 \Omega$$

$$L = \frac{36.1}{2\pi f} \\ = \frac{36.1}{2 \times \pi \times 50} \\ L = 0.114 \text{ H}$$

(20)

PART-C

(3)



$$\text{Line current } I_L = \frac{100}{10} = 10 \text{ A}$$

$$\text{-Ptd power } P = \sqrt{3} V_L I_L \cos \phi$$

$$\cos \phi = \frac{R}{Z} = \frac{8}{10} = 0.8 \text{ lag}$$

$$P = \sqrt{3} \times 100 \times 10 \times 0.8 \\ = 1.385 \text{ kW}$$

Answer

$$I_L = 10 \text{ A}$$

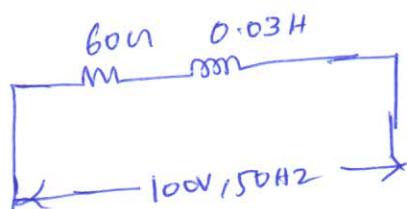
$$\cos \phi = 0.8$$

$$\text{power } P = 1.385 \text{ kW}$$

(2)

PART-C

(5)



$$X_L = 2\pi f L = 2\pi \times 50 \times 0.03 \\ = 4.7156 \Omega$$

$$Z = \sqrt{R^2 + X_L^2} \\ = \sqrt{60^2 + 4.7156^2}$$

$$Z = 60.14 \Omega$$

$$\cos \phi = \frac{R}{Z} = 0.99$$

$$\text{Current } I = \frac{100}{60.14} = 1.662 A$$

$$\phi = \tan^{-1} \frac{b}{s} = 3.96^\circ$$

(22)

UNIT-11

PART-B

③ (ii)

$$p = 4$$

$$z = 65 \times 12 \times 2 = 1560$$

$$N = 1200$$

$$\phi = 0.02 \text{ Weber}$$

$$A = 2$$

$$E_g = \frac{\phi z N}{60} \left(\frac{P}{A} \right)$$

$$= \frac{0.02 \times 1560 \times 1200}{60} \left(\frac{4}{2} \right)$$

$$= 1248 \text{ V}$$

⑧

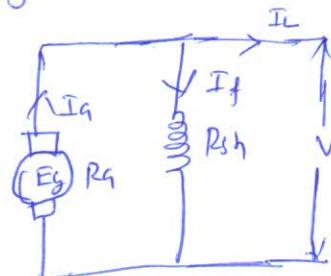
$$P = 25 \text{ kW}$$

$$V = 250 \text{ V}$$

$$R_a = 0.06 \Omega$$

$$R_{sh} = 100 \Omega$$

(i) As a generator:



$$R_{sh} \neq I_f = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5 \text{ A}$$

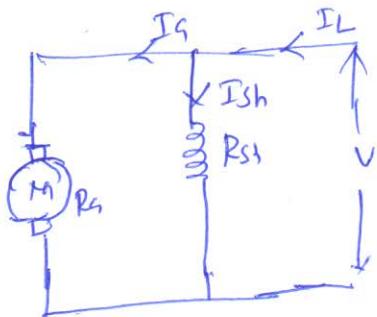
$$I_L = \frac{P}{V} = \frac{25 \times 10^3}{250} = 100 \text{ A}$$

$$I_a = I_L + I_f = 100 + 2.5 = 102.5 \text{ A}$$

$$E_g = V + I_a R_a \\ = 250 + 102.5 \times 0.06 = 256.15 \text{ V}$$

$$\text{Power developed} = E_g I_a = 256.15 \times 102.5 \\ = 26.25 \text{ kW}$$

(ii) AS a motor



$$R_{sh} = 100\Omega$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5A$$

$$I_L = 100A$$

$$I_q = I_L - I_{sh} = 97.5A$$

$$E_b = V - I_q R_q$$

$$= 250 - (97.5 \times 0.06)$$

$$E_b = 244.15V$$

$$\text{power developed } P_m = E_b I_q$$

$$= 244.15 \times 97.5$$

$$= 23.8kW$$

(10)

(ii)

$$V_1 = 2000V$$

$$V_2 = 250V$$

$$f = 50Hz$$

$$A = 36cm^2 = 36 \times 10^{-4} m^2$$

$$\text{flux density } B = 6wb/m^2$$

$$F_t = 4.44 f q N_1$$

$$\text{Flux } \phi = \text{Flux density} \times \text{Area} = 6 \times 36 \times 10^{-4}$$

$$= 0.0216 wb$$

$$2000 = 4.44 \times 50 \times 0.0216 \times N_1$$

$$\underline{N_1 = 417 \text{ turns}}$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

$$\frac{250}{2000} = \frac{N_2}{417}$$

$$N_2 = 417 \times \frac{250}{2000}$$

$$\underline{N_2 = 52 \text{ turns}}$$

(12)

(ii)

$$V_1 = 5000 \text{ V}$$

$$V_2 = 250 \text{ V}$$

$$\phi_\varphi = 0.06$$

$$\phi_f = 50 \text{ Hz}$$

$$E_1 = 4.44 f \phi N_1$$

$$5000 = 4.44 \times 50 \times 0.06 \times N_1$$

$$N_1 = \frac{5000}{4.44 \times 50 \times 0.06}$$

$$= 375 \text{ turns}$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\frac{250}{5000} = \frac{N_2}{375}$$

$$N_2 = 375 \times \frac{250}{5000}$$

$$= 19 \text{ turns}$$

(25)

(7) (i)

$$V = 200V$$

$$I_L = 100A$$

$$N = 750 \text{ RPM}$$

$$R_a = 0.1\Omega$$

$$R_{sh} = 4\Omega$$

$$T_a = 9.55 \frac{E_b I_a}{N} \text{ N-m}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{40} = 5A.$$

$$I_a = I_L - I_{sh}$$

$$= 100 - 5$$

$$= 95A.$$

$$E_b = V - I_a R_a$$

$$= 200 - 95 \times 0.1$$

$$= 190.5V$$

$$T_a = 9.55 \times \frac{190.5 \times 95}{750}$$

$$= 230.44 \text{ Nm}$$

PART-C

$$\textcircled{2} \quad N_1 = 400$$

$$N_2 = 1000$$

$$f = 50 \text{ Hz}$$

$$V_1 = 520 \text{ V}$$

$$A = 60 \text{ cm}^2 = 60 \times 10^{-4} \text{ m}^2$$

$$V_1 = 4.44 f B_m A \times N_1$$

$$520 = 4.44 \times 50 \times B_m \times 60 \times 10^{-4} \times 400$$

$$B_m = \frac{520}{4.44 \times 50 \times 60 \times 10^{-4} \times 400}$$

$$\boxed{B_m = 0.975 \text{ wb/m}^2}$$

$$K = \frac{N_2}{N_1} = \frac{1000}{400} = 2.5$$

$$\frac{V_2}{V_1} = K$$

$$V_2 = K \times V_1$$

$$= 2.5 \times 520$$

$$\boxed{V_2 = 1300 \text{ V}}$$

UNIT-1

SINGLE-PHASE INDUCTION MOTORS

1.1 INTRODUCTION:

There are two basic reasons for the use of single-phase motors rather than 3-phase motors.

1. For reason of economy, most houses, offices and also rural areas are supplied with single phase a.c, as power requirements of individual load items are rather small.
2. The economics of the motor and its branch circuit.
 - Fixed loads requiring not more than 0.5KW can generally be served most economically with single phase power and a single phase motor.
 - Single phase motors are simple in construction, reliable, easy to repair and comparatively cheaper in cost and therefore, find wide use in fans, refrigerators, vacuum cleaners, washing machines, other kitchen equipment, tools, blowers, centrifugal pumps, small farming appliances etc.

Because of above reasons motors of comparatively small ratings (mostly in fractional KW ratings) are manufactured in large number to operate on single phase ac at standard frequencies. An indication of the number of such motors can be had from the fact that the sum of total of all fractional kilowatt motors in use today far exceeds the total of integral kilowatt motors of all types.

1.2 TYPES OF SINGLE-PHASE MOTOR:

The Single phase motors may be of the following types:

1. **Single-phase Induction Motors:**
 - A. Split-phase motors
 - (i) Resistance-start motor
 - (ii) Capacitor-start motor
 - (iii) Permanent-split (single-value) capacitor motor
 - (iv) Two-value capacitor motor.
 - B. Shaded-pole induction motor.

- C. Reluctance-start induction motor.
- D. Repulsion-start induction motor.

2. Commutator-Type, Single-Phase Motors:

- A. Repulsion motor.
- B. Repulsion-induction motor.
- C. A.C series motor.
- D. Universal motor.

3. Single-phase Synchronous Motors:

- A. Reluctance motor.
- B. Hysteresis motor.
- C. Sub-synchronous motor.

1.3 SINGLE-PHASE INDUCTION MOTORS

Applications and Disadvantages:

1.31 Applications:

- Single phase induction motors are in very wide use in industry especially in fractional horse-power field.

They are extensively used for electrical drive for low power constant speed apparatus such as machine tools, domestic apparatus and agricultural machinery in circumstances where a three-phase supply is not readily available.

- Single phase induction motors sizes vary from 1/400 kw to 1/25 kw are used in toys, hair dryers, vending machines etc.
- Universal motor is widely used in portable tools, vacuum cleaners& kitchen equipment.

1.32 Disadvantages:

Though these machines are useful for small outputs, they are not used for large powers as they suffer from many disadvantages and are never used in cases where three-phase machines can be adopted.

The main disadvantages of single-phase induction motors are:

1. Their output is only 50% of the three-phase motor, for a given frame size and temperature rise.

2. They have lower power factor.
3. Lower efficiency.
4. These motors do not have inherent starting torque.
5. More expensive than three-phase motors of the same output.
6. Low overload capacity.

1.4 CONSTRUCTION OF SINGLE PHASE INDUCTION MOTOR:

Single phase induction motor is very simple and robust in construction. The stator carries a distributed winding in the slots cut around the inner periphery. The stator conductors have low resistance and they are winding called Starting winding is also mounted on the stator. This winding has high resistance and its embedded deep inside the stator slots, so that they have considerable inductance. The rotor is invariably of the squirrel cage type. In practice, in order to convert temporarily the single phase motor into two-phase motor, auxiliary conductors are placed in the upper layers of stator slots. The auxiliary winding has a centrifugal switch in series with it. The function of the switch is to cut off the starting winding, when the rotor has accelerated to about 75% of its rated speed. In capacitor-start motors, an electrolytic capacitor of suitable capacitance value is also incorporated in the starting winding circuit.

The main stator winding and auxiliary (or starting) winding are joined in parallel, and there is an arrangement by which the polarity of only the starting winding can be reversed. This is necessary for changing the direction of rotation of the rotor.

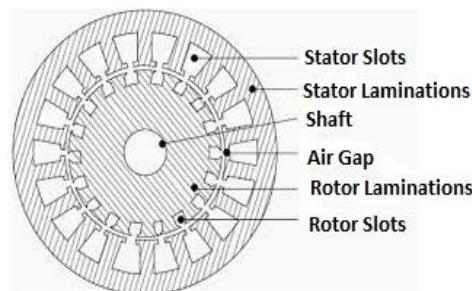


Fig: 1.41

A 1-phase induction motor is similar to a 3-phase squirrel cage induction motor in physical appearance. The rotor is same as that employed in 3-phase squirrel cage induction motor. There is uniform air gap between stator and rotor but no electrical connection between them.

Although single phase induction motor is more simple in construction and is cheaper than a 3-phase induction motor of the same frame size, it is less efficient and it operates at lower power factor.

1.5 WORKING OF SINGLE-PHASE INDUCTION MOTOR:

A single phase induction motor is inherently not self-starting can be shown easily.

Consider a single phase induction motor whose rotor is at rest. Let a single phase a.c. source be connected to the stator winding (it is assumed that there is no starting winding). Let the stator be wound for two poles.

When power supply for the stator is switched on, an alternating current flows through the stator winding. This sets up an alternating flux. This flux crosses the air gap and links with the rotor conductors. By electromagnetic induction e.m.f.'s are induced in the rotor conductors. Since the rotor forms a closed circuit, currents are induced in the rotor bars. Due to interaction between the rotor induced currents and the stator flux, a torque is produced. It is readily seen that if all rotor conductors in the upper half come under a stator N pole, all rotor conductors in the lower half come under a stator S pole. Hence the upper half of the rotor is subjected to a torque which tends to rotate it in one direction and the lower half of the rotor is acted upon by an equal torque which tends to rotate it in the opposite direction. The two equal and opposite torques cancel out, with the result that the net driving torque is zero. Hence the rotor remains stationary. Thus the single phase motor fails to develop starting torque.

This argument holds good irrespective of the number of stator poles and the polarity of the stator winding. The net torque acting on the rotor at standstill is zero.

If, however, the rotor is in motion in any direction when supply for the stator is switched on, it can be shown that the rotor develops more torque in that direction. The net torque then, would have non-zero value, and under its impact the rotor would speed up in its direction.

The analysis of the single phase motor can be made on the basis of two theories:

- i. Double revolving field theory, and
- ii. Cross field theory.

1.51 DOUBLE REVOLVING FIELD THEORY:

This theory makes use of the idea that an alternating uni-axial quantity can be represented by two oppositely-rotating vectors of half magnitude. Accordingly, an alternating sinusoidal flux can be represented by two revolving fluxes, each equal to half the value of the alternating flux and each rotating synchronously ($N_s = \frac{120f}{P}$) in opposite direction.

As shown in figure: (a) let the alternating flux have a maximum value of ϕ_m . Its component fluxes A and B will each equal to $\phi_m/2$ revolving in anti-clockwise and clockwise directions respectively.

After some time, when A and B would have rotated through angle $+θ$ and $-θ$, as in figure: (b), the resultant flux would be

$$= 2 * \frac{\phi_m}{2} \cos \frac{2\theta}{2} = \phi_m \cos \theta$$

After a quarter cycle of rotation, fluxes A and B will be oppositely-directed as shown in figure: (c) so that the resultant flux would be zero.

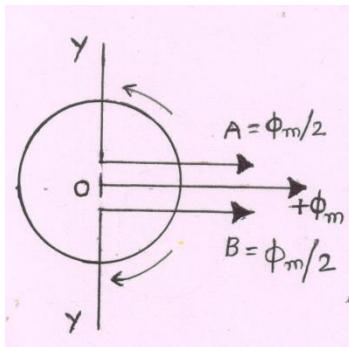


Fig: 1.51(a)

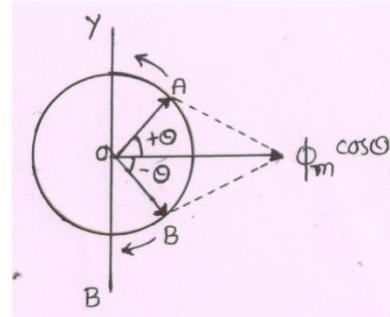


Fig: 1.51(b)

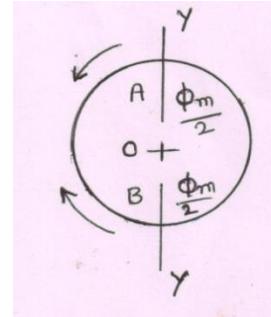


Fig: 1.51 (c)

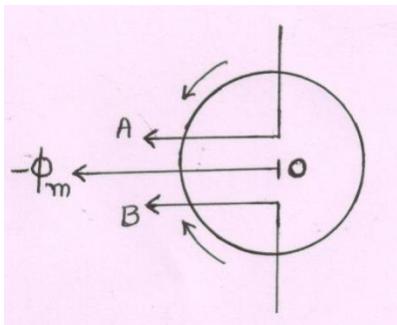


Fig: 1.51 (d)

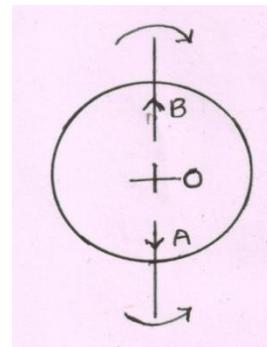


Fig: 1.51(e)

After half a cycle, fluxes A and B will have a resultant of $-2 \frac{\phi_m}{2} = -\phi_m$. After three

quarters of a cycle, again the resultant is zero, as shown in figure: (e) and so on. If we plot the values of resultant flux against Θ between limits $\Theta=0^0$ to $\Theta=360^0$, then a curve similar to the one shown in figure: (f) is obtained. That is why an alternating flux can be looked upon as

composed of two revolving fluxes, each of half the value and revolving synchronously in opposite directions.

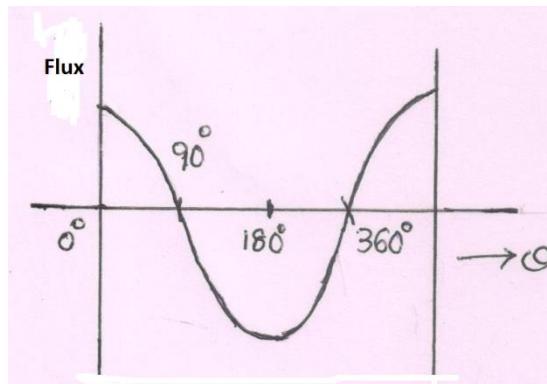


Fig: 1.51(f)

It may be noted that if the slip of the rotor is S with respect to the forward rotating flux (i.e. one which rotates in the same direction as rotor) then its slip with respect to the backward rotating flux is $(2-S)$.

Each of the two component fluxes, while revolving round the stator, cuts the rotor, induces an e.m.f. and this produces its own torque. Obviously, the two torques (called forward and backward torques) are oppositely-directed, so that the net or resultant torque is equal to their difference as shown in fig: (g)

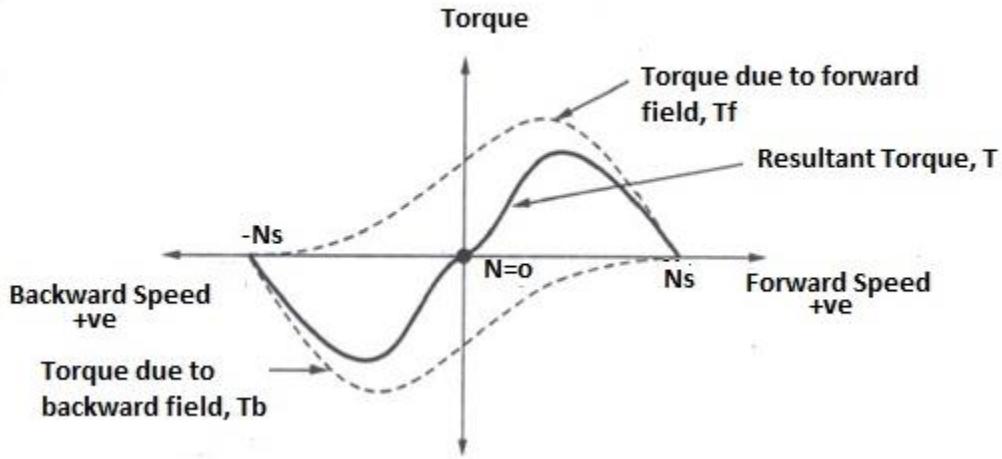


Fig: 1.51(g) Torque-Speed characteristics

Now, power developed by a rotor is $P_g = \left(\frac{1-s}{s}\right) I_2^2 R_2$

If N is the rotor r.p.s., then torque is given by, $T_g = \frac{1}{2\pi N} \left(\frac{1-s}{s}\right) I_2^2 R_2$

Now, $N = N_s (1-s)$

$$\text{Therefore, } T_g = \frac{1}{2\pi N_s} \frac{I_2^2 R_2}{s} = k \frac{I_2^2 R_2}{s}$$

Hence, the forward and backward torques are given by

$$T_f = k \frac{I_2^2 R_2}{s} \quad \text{and} \quad T_b = -k \frac{I_2^2 R_2}{(2-s)}$$

$$\text{or} \quad T_f = \frac{I_2^2 R_2}{s} \text{ synch. Watt} \quad \text{and} \quad T_b = -\frac{I_2^2 R_2}{(2-s)} \text{ synch. Watt}$$

$$\text{Total torque} \quad T = T_f + T_b$$

Fig: (g) shows both torques and the resultant torque for slips between zero and +2. At standstill, $S=1$ and $(2-S)=1$. Hence, T_f and T_b are numerically equal but, being oppositely directed, produce no resultant torque. That explains why there is no starting torque in a single-phase induction motor.

However, if the rotor is started somehow, say, in the clockwise direction, the clockwise torque starts increasing and, at the same time, the anticlockwise torque starts decreasing. Hence, there is a certain amount of net torque in the clockwise direction which accelerates the motor to full speed.

1.6 EQUIVALENT CIRCUIT:

The equivalent circuit of a single phase induction motor can be developed on the basis of two revolving field theory. To develop the equivalent circuit it is necessary to consider standstill or blocked rotor conditions.

The motor with a blocked rotor merely acts like a transformer with its secondary short circuited and its equivalent circuit will be as shown in fig: 1.6 (a), E_m being e.m.f. induced in the stator.

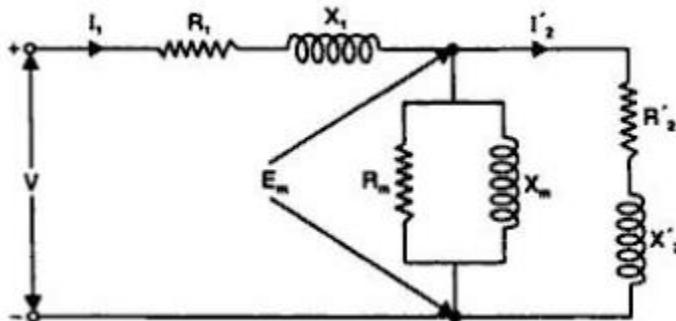


Fig:1.6 (a) Equivalent Circuit of a Single Phase Induction Motor

The motor may now be viewed from the point of view of the two revolving field theory. The two flux components induce e.m.f. E_{mf} and E_{mb} in the respective stator winding. Since at standstill the two oppositely rotating fields are of same strength, the magnetizing and rotor impedances are divided into two equals halves connected in series as shown in figure:1.6(b)

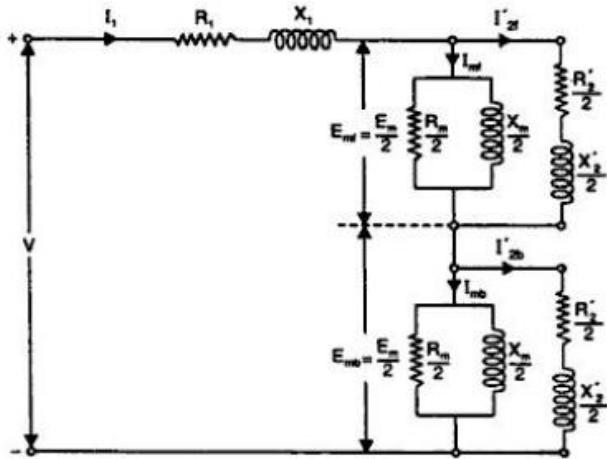


Fig:1.6 (b) Equivalent Circuit of Single Phase Induction Motor at Standstill on the basis of Two Revolving Field Theory

When the rotor runs at speed N with respect to forward field, the slip is S w.r.t. forward field and $(2-S)$ w.r.t. backward field and the equivalent circuit is as shown in fig:1.6(c)

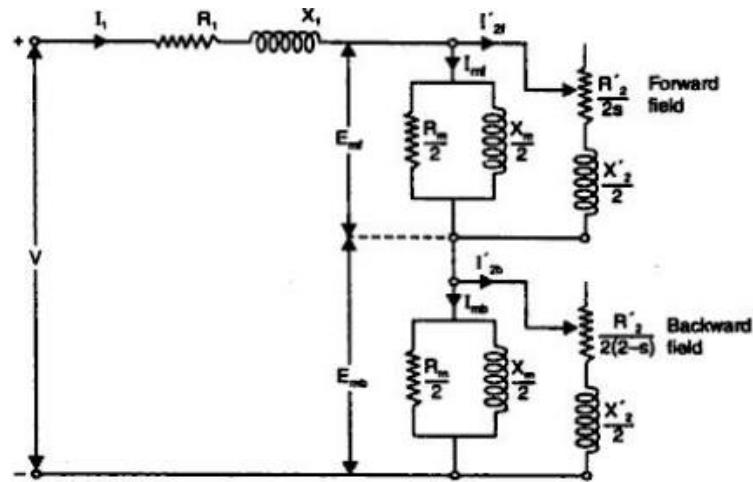


Fig:1.6 (c) Equivalent Circuit of a Single Phase Induction Motor Under Normal Operating Conditions

If the core losses are neglected the equivalent circuit is modified as shown in fig:1.6(d). The core losses, here, are handled as rotational losses and subtracted from the power converted into mechanical power; the amount of error thus introduced is relatively small.

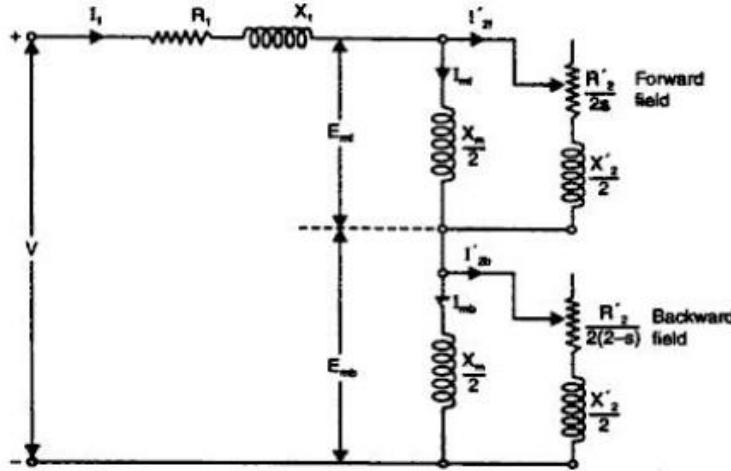


Fig:1.6 (d) Approximate Equivalent Circuit of a Single Phase Induction Motor Under Normal Operating Conditions

1.7 STARTING METHODS OF SINGLE-PHASE INDUCTION MOTORS:

A single-phase induction motor with main stator winding has no inherent starting torque, since main winding introduces only stationary, pulsating air-gap flux wave. For the development of starting torque, rotating air-gap field at starting must be introduced. Several methods which have been developed for the starting of single-phase induction motors, may be classified as follows:

- a) Split-phase starting.
- b) Shaded-pole starting.
- c) Repulsion-motor starting and
- d) Reluctance starting.

A single-phase induction motor is commonly known by the method employed for its starting. The selection of a suitable induction motor and choice of its starting method, depend upon the following:

- (i) Torque-speed characteristic of load from standstill to the normal operating speed.
- (ii) The duty cycle and
- (iii) The starting and running line-current limitations as imposed by the supply authorities.

1.7 (a) SPLIT-PHASE STARTING:

Single-phase induction motors employing this method of starting are called Split-phase motors. All the split-phase motors have two stator windings, a main (or running) winding and an auxiliary (or starting) winding. Both these windings are connected in parallel but their magnetic axes are space displaced by 90^0 electrical.

It is known that when two windings spaced 90^0 apart on the stator, are excited by two alternating e.m.f. that are 90^0 displaced in time phase, a rotating magnetic field is produced. If two windings so placed are connected in parallel to a single phase source, the field produced will alternate but will not revolve since the two windings are equivalent to one single phase winding. If impedance is connected in series with one of these windings, the currents may be made to differ in time phase, thereby producing a rotating field. This is the principle of phase splitting. Split phase motors are of following types.

1. Resistor-split phase motors
2. Capacitor split-phase motors
3. Capacitor start and run motors
4. Capacitor-run motors

1.71 RESISTOR SPLIT-PHASE MOTORS:

The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90^0 electrical from the main winding [See figure: 1.71(a)] and operates only during the brief period when the motor starts up. The two windings are so designed that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance as shown in the schematic connections in figure: 1.71(b). Consequently, the currents flowing in the two windings have reasonable phase difference (25^0 to 30^0) as shown in the phasor diagram in figure: 1.71(c).

Operation

- (i) When the two stator windings are energized from a single-phase supply, the main winding carries current I_m while the starting winding carries current I_s

- (ii) Since main winding is made highly inductive while the starting winding highly resistive, the currents I_m and I_s have a reasonable phase angle α (25° to 30°) between them as shown in figure: 1.71(c). Consequently, a weak revolving field approximating to that of a 2-phase machine is produced which starts the motor. The starting torque is given by;

$$T_s = k I_m I_s \sin\phi$$

Where k is a constant whose magnitude depends upon the design of the motor . When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

Characteristics:

- (i) The starting torque is 15 to 2 times the full-load torque (starting current is 6 to 8 times the full-load current).
- (ii) Due to their low cost, split-phase induction motors are most popular single phase motors in the market.
- (iii) Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

An important characteristic of these motors is that they are essentially constant-speed motors. The speed variation is 2-5% from no-load to full-load

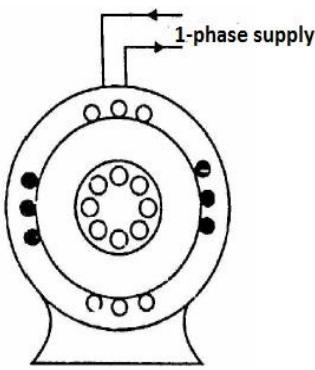


Fig: 1.71(a)

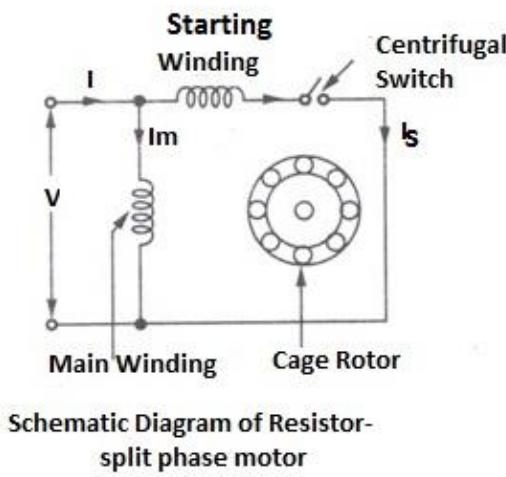


Fig: 1.71(b)

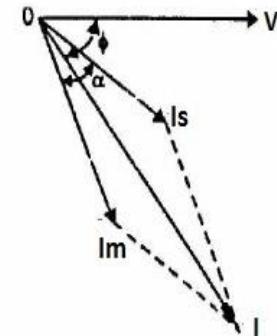
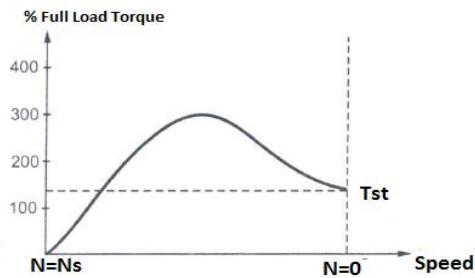


Fig: 1.71(c)



Applications:

These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:

- Fans
- washing machines
- oil burners
- Small machine tools etc.

The power rating of such motors generally lies between 60 W and 250 W .

1.72 Capacitor split-phase motors (or) Capacitor start motors:

The capacitor split-phase motor is identical to a resistor split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding as shown in figure: 1.72(a).The value of capacitor is so chosen that I_s leads I_m by about 80° (i.e., $\phi \sim 80^\circ$) which is considerably greater than 25° found in resistor split-phase motor [See figure: 1.72(b)].Consequently, starting torque ($T_s = k I_m I_s \sin\phi$) is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics

- (i) Although starting characteristics of a capacitor-start motor are better than those of a resistor split-phase motor, both machines possess the same running characteristics because the main windings are identical.
- (ii) The phase angle between the two currents is about 80° compared to about 25° in a resistor split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a resistor split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.

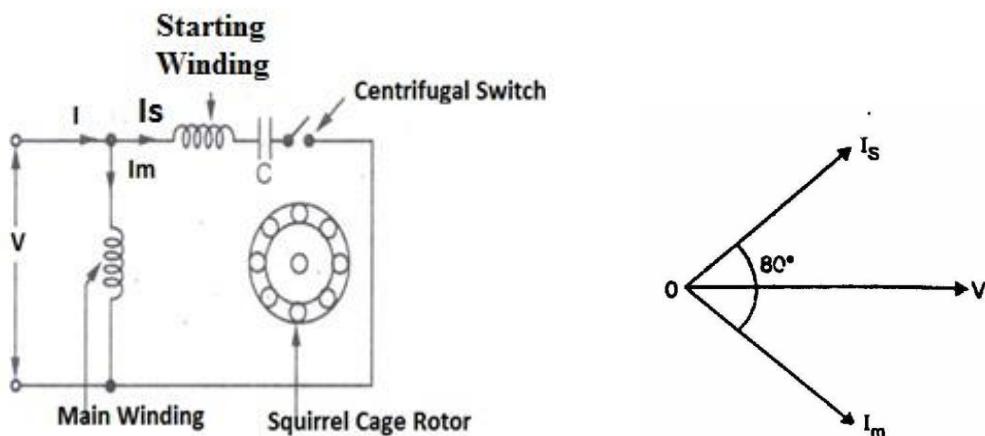
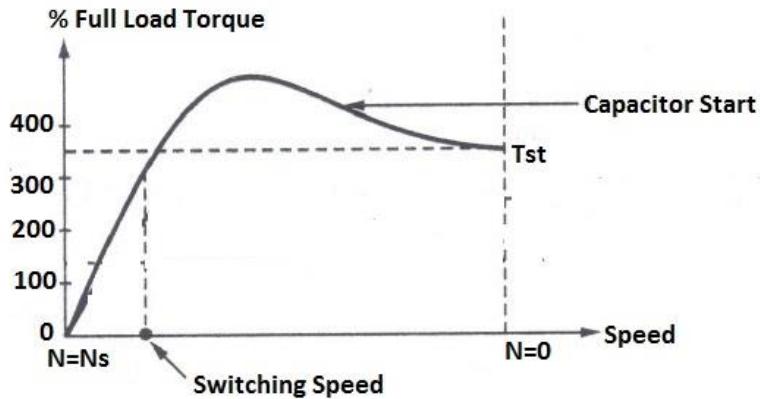


Fig: 1.72(a)

Fig: 1.72(b)



Applications:

Since the motors possess high-starting torque, these motors are used for

- Refrigerators
- Air-conditioners
- Compressors
- Reciprocating pumps
- Other loads requiring high-starting torques.

The power rating of such motors lies between 120 W and 750W.

1.73 Capacitor-Start and Capacitor-Run motors:

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used.

- (i) In one design, a single capacitor C is used for both starting and running as shown in fig: 1.73(a). This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.
- (ii) In the other design, two capacitors C_1 and C_2 are used in the starting winding as shown in fig: 1.73(b).. The smaller capacitor C_1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C_2 is connected in parallel with C_1 for optimum starting and remains in the circuit during starting. The starting capacitor C_1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

Characteristics

- (i) The starting winding and the capacitor can be designed for perfect 2-phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.
- (ii) Because of constant torque, the motor is vibration free.

Applications:

- a. Hospitals
- b. Studios and
- c. Other places where silence is important.

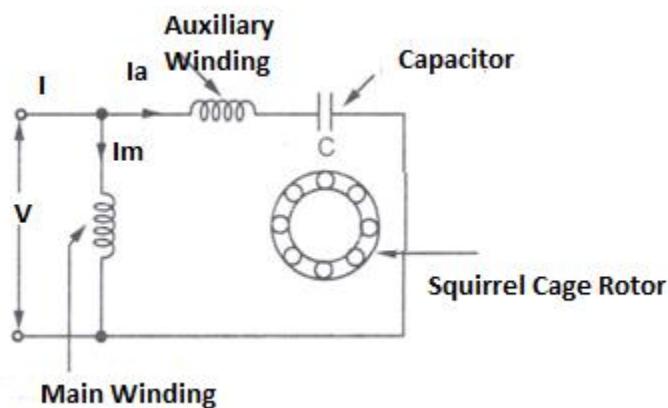


Fig: 1.73(a)

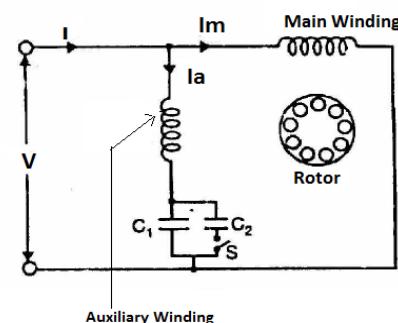


Fig: 1.73 (b)

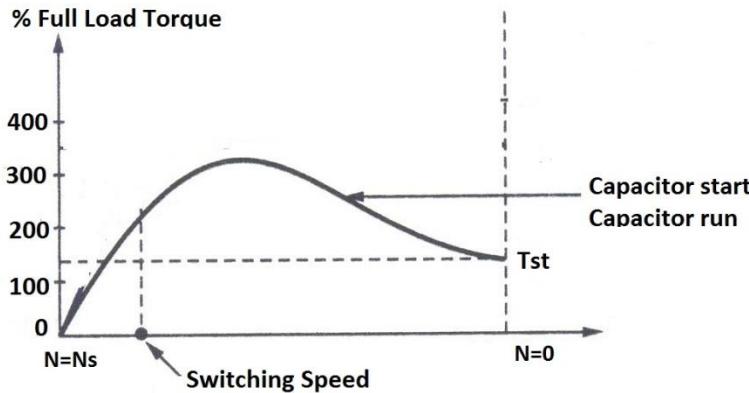
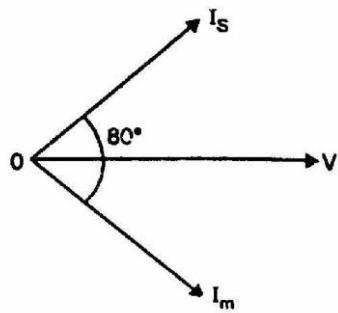


Fig: 1.73 (c)

Fig: 1.73 (d)

The power rating of such motors lies between 100 to 400 watts

1.74 Capacitor-run motors:

This motor is also called permanent split capacitor motor. The same capacitor is kept permanently in series with auxiliary winding both at starting and under running conditions as illustrated in figure: 1.74 (a). There is no centrifugal switch. At a particular desired load, the capacitor and auxiliary winding can be so designed as to result in 90° time-phase displacement between the two winding currents. In such a case, the motor would operate as a balanced two phase induction motor, backward rotating flux would, therefore, be absent and the motor would have improved efficiency and better operating power factor. Since backward rotating field can be reduced to zero, the pulsating torque due to interaction between forward and backward rotating fields is absent and this results in a quiet motor.

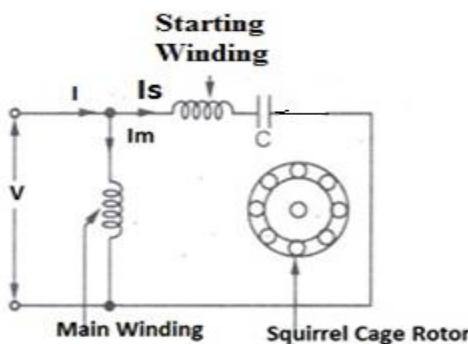


Fig: 1.74 (a)

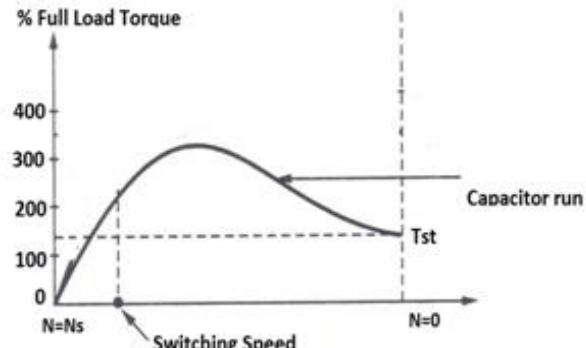


Fig: 1.74 (b)

In these motors, the value of permanent capacitor is so chosen as to obtain a compromise between the best starting and running conditions. A typical torque-speed characteristic is shown in fig: 1.74 (b)

These motors are used where quiet operation is essential as in

- Offices
- Class rooms
- Theaters
- Ceiling fans, in which the value of capacitance varies from 2 to $3\mu F$.

1.8 Shaded-Pole Motor:

The shaded-pole motor is very popular for ratings below 0.05 H.P. (~ 40 W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in figure: 1.8(a). A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.

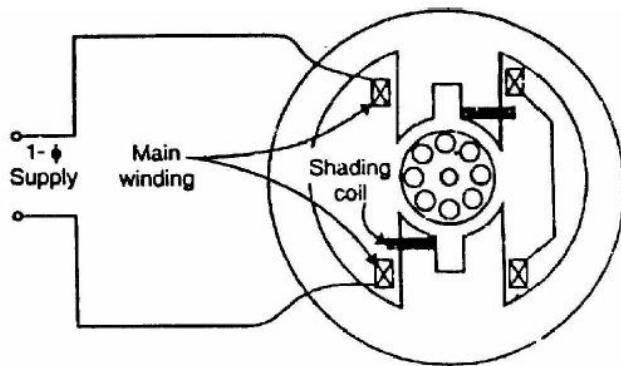


Fig: 1.8(a)

The operation of the motor can be understood by referring to figure: 1.8(b) which shows one pole of the motor with a shading coil.

- (i) During the portion OA of the alternating-current cycle [See figure: 1.8(b)(i)], the flux begins to increase and an e.m.f. is induced in the shading coil. The resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux. Thus the flux in the shaded portion of the pole is weakened while that in the unshaded portion is strengthened as shown in figure: 1.8(b)(ii)
- (ii) During the portion AB of the alternating-current cycle, the flux has reached almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform [See figure: 1.8(b)(iii)] since no current is flowing in the shading coil. As the flux decreases (portion BC of the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in figure: 1.8(b)(iv)

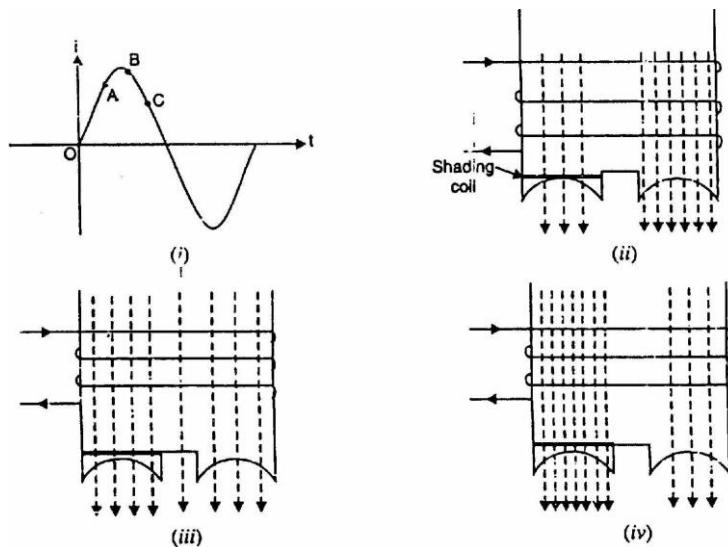


Fig: 1.8(b)

- (iii) The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion. This shifting flux is like a rotating weak field moving in the direction from unshaded portion to the shaded portion of the pole.
- (iv) The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed. As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action. The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

Characteristics

- (i) The salient features of this motor are extremely simple construction and absence of centrifugal switch.
- (ii) Starting torque, efficiency and power factor are very low

Applications:

These motors are only suitable for low power applications e.g., to drive:

- a. small fans
- b. Toys
- c. Hair driers
- d. Desk fans etc.

The power rating of such motors is upto about 30 W.

1.9 A.C. SERIES MOTOR (or) UNIVERSAL MOTOR:

A d.c. series motor will rotate in the same direction regardless of the polarity of the supply. One can expect that a d.c. series motor would also operate on a single-phase supply. It is then called an a.c. series motor. However, some changes must be made in a d.c. motor that is to operate satisfactorily on a.c. supply. The changes effected are:

- (i) The entire magnetic circuit is laminated in order to reduce the eddy current loss. Hence an a.c. series motor requires a more expensive construction than a d.c. series motor.
- (ii) The series field winding uses as few turns as possible to reduce the reactance of the field winding to a minimum. This reduces the voltage drop across the field winding.
- (iii) A high field flux is obtained by using a low-reluctance magnetic circuit.
- (iv) There is considerable sparking between the brushes and the commutator when the motor is used on a.c. supply. It is because the alternating flux establishes high currents in the coils short-circuited by the brushes. When the short-circuited coils break contact from the commutator, excessive sparking is produced. This can be eliminated by using high-resistance leads to connect the coils to the commutator segments.

Construction:

The construction of an a.c. series motor is very similar to a d.c. series motor except that above modifications are incorporated [See figure:1.91]. such a motor can be operated either on a.c. or d.c. supply and the resulting torque-speed curve is about the same in each case. For this reason, it is sometimes called a universal motor.

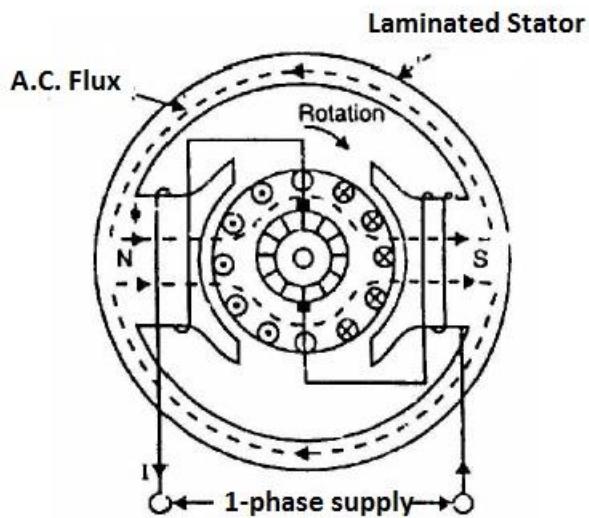


Fig: 1.91

Operation

When the motor is connected to an a.c. supply, the same alternating current flows through the field and armature windings. The field winding produces an alternating flux Φ that reacts with the current flowing in the armature to produce a torque. Since both armature current and flux reverse simultaneously, the torque always acts in the same direction. It may be noted that no rotating flux is produced in this type of machines; the principle of operation is the same as that of a d.c. series motor.

Characteristics

The operating characteristics of an a.c. series motor are similar to those of a d.c. series motor.

- (i) The speed increases to a high value with a decrease in load. In very small series motors, the losses are usually large enough at no load that limits the speed to a definite value (1500 - 15,000 r.p.m.).
- (ii) The motor torque is high for large armature currents, thus giving a high starting torque.
- (iii) At full-load, the power factor is about 90%. However, at starting or when carrying an overload, the power factor is lower.

Applications

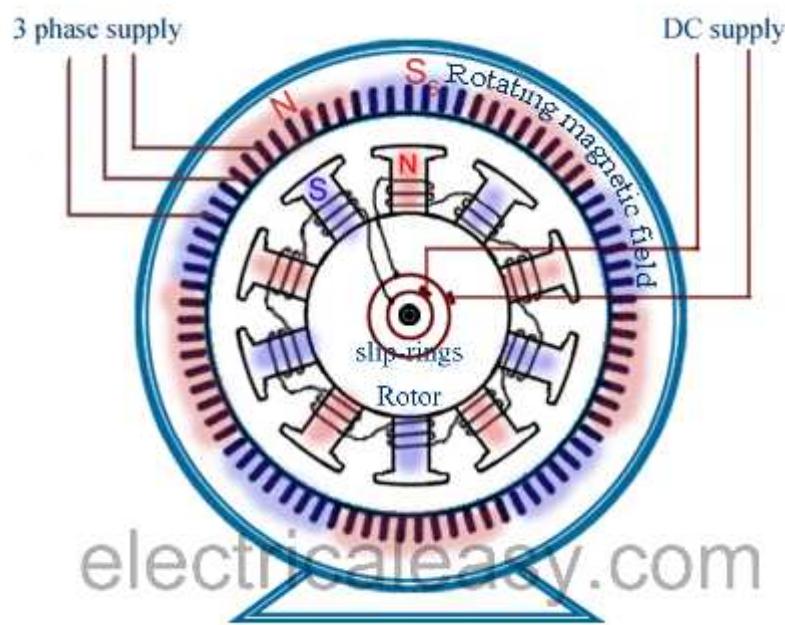
The fractional horsepower a.c. series motors have high-speed (and corresponding small size) and large starting torque. They can, therefore, be used to drive:

- a) high-speed vacuum cleaners

- b) sewing machines
- c) electric shavers
- d) drills
- e) Machine tools etc.

Synchronous motor and **induction motor** are the most widely used types of AC motor. Construction of a synchronous motor is similar to an **alternator (AC generator)**. A same **synchronous machine** can be used as a synchronous motor or as an alternator. Synchronous motors are available in a wide range, generally rated between 150kW to 15MW with speeds ranging from 150 to 1800 rpm.

Construction of synchronous motor

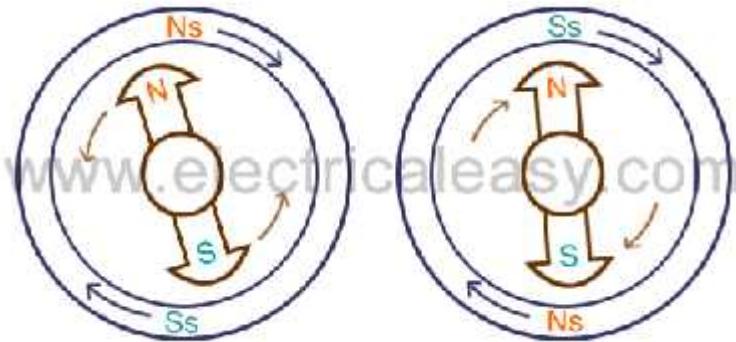


The **construction of a synchronous motor** (with salient pole rotor) is as shown in the figure at left. Just like any other motor, it consists of a stator and a rotor. The stator core is constructed with thin silicon lamination and insulated by a surface coating, to minimize the **eddy current and hysteresis losses**. The stator has axial slots inside, in which three phase stator winding is placed. The stator is wound with a three phase winding for a specific number of poles equal to the rotor poles.

The **rotor in synchronous motors** is mostly of salient pole type. DC supply is given to the rotor winding via slip-rings. The direct current excites the rotor winding and creates electromagnetic poles. In some cases permanent magnets can also be used. The figure above illustrates the **construction of a synchronous motor** very briefly.

Working of synchronous motor

The stator is wound for the similar number of poles as that of rotor, and fed with three phase AC supply. The 3 phase AC supply produces **rotating magnetic field** in stator. The rotor winding is fed with DC supply which magnetizes the rotor. Consider a two pole **synchronous machine** as shown in figure below.



- Now, the stator poles are **revolving with synchronous speed** (lets say clockwise). If the rotor position is such that, N pole of the rotor is near the N pole of the stator (as shown in first schematic of above figure), then the poles of the stator and rotor will repel each other, and the *torque produced will be anticlockwise*.
- The stator poles are rotating with synchronous speed, and they rotate around very fast and interchange their position. But at this very soon, rotor can not rotate with the same angle (due to inertia), and the next position will be likely the second schematic in above figure. In this case, poles of the stator will attract the poles of rotor, and *the torque produced will be clockwise*.
- Hence, the rotor will undergo to a rapidly reversing torque, and the motor will not start.

But, if the rotor is rotated upto the synchronous speed of the stator by means of an external force (in the direction of **revolving field** of the stator), and the rotor field is excited near the synchronous speed, the poles of stator will keep attracting the opposite poles of the rotor (as the rotor is also, now, rotating with it and the position of the poles will be similar throughout the cycle). Now, the rotor will undergo unidirectional torque. The opposite poles of the stator and rotor will get locked with each other, and the rotor will rotate at the synchronous speed.

Characteristic features of a synchronous motor

- Synchronous motor will run either at synchronous speed or will not run at all.
- The only way to change its speed is to change its supply frequency. (As $N_s = 120f / P$)
- Synchronous motors are not self starting. They need some external force to bring them near to the synchronous speed.
- They can operate under any power factor, lagging as well as leading. Hence, synchronous motors can be used for power factor improvement.

Application of synchronous motor

- As synchronous motor is capable of operating under either leading and lagging power factor, it can be used for power factor improvement. A synchronous motor under no-load with leading power factor is connected in power system where static capacitors can not be used.
- It is used where high power at low speed is required. Such as rolling mills, chippers, mixers, pumps, pumps, compressor etc.

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