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FIRST/SECOND SEMESTER

Electrical Science

(ES-107/108)

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Group	Code	Paper	L	P	Credits
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BS	BS105	Applied Physics-I	3	–	3
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BS	BS111	Applied Mathematics-I	4	–	4
HS HS HS	HS113 HS115 HS117	**Group 1 or Group 2 shall be offered: Group 1: Communications Skills Or Group 2: Indian Constitution Human Values and Ethics	3 2 1	– –	3 2 1
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*For a particular batch of a programme of study one out of these two papers shall be taught in the first semester while the other shall be taught in the 2nd semester. Students who have to re-appear can only reappear in the odd semester. If originally offered to the student in the 1st semester and similarly for the students who study the paper in the second semester. The institution shall decide which paper to offer in which semester.

**For a particular batch of a programme of study either the paper on "Communications Skills" (Group 1), or Group 2 : papers ("Indian Constitution" and "Human values and ethics") shall be taught in the first semester while the other group shall be taught in the 2nd semester. Students who have to re-appear can only reappear in the odd semester if originally offered to the student in the 1st semester and similarly for the students who study the paper(s) in the second semester. The institution shall decide which paper group to offer in which semester.

SYLLABUS (From Academic Session 2021-22)
Electrical Science [ES-107/108]

Marking Scheme:

(a) Teacher Continuous Evaluation: 25 marks

(b) Term End Theory Examination : 75 marks

UNIT I

DC Circuits: Passive circuit components, Basic laws of Electrical Engineering, Temperature Resistance Coefficients. voltage and current sources, Series and parallel circuits, power and energy, Kirchho's Laws, Nodal & Mesh Analysis, delta-star transformation, superposition theorem, Thevenin's theorem, Norton's theorem, maximum power transfer theorem. Time domain analysis of first Order RC & LC circuits. **[9 Hrs.][T1]**

UNIT II

AC Circuits: Representation of sinusoidal waveforms, peak and rms values, phasor representation, real power, reactive power, apparent power, power factor. Analysis of single-phase ac circuits consisting of R, L, C, RL, RC, RLC combinations (series and parallel), resonance. Three phase balanced citcuits, voltage and current relations in star and delta connections.

[9 Hrs.] [T1]

UNIT III

D.C. Generators & Motors: Principle of operation of Generators & Motors, Speed Control of shunt motors, Flux control, Rheostatic control, voltage control, Speed control of series motors.

A.C. Generators & Motors: Principle of operation, Revolving Magnetic field, Squirrel cage and phase wound rotor, Starting of Induction motors, Direct on line and Star Delta Starters, Synchronous machines. **[9 Hrs.][T1]**

UNIT IV

Transformers: Construction and principle of operation, equivalent circuit, losses in transformers, regulation and efficiency. Auto-transformer and three-phase transformer connections.

Measuring Instruments: Electromagnetism, Different Torques in indicating instruments, Moving Iron Instruments: Construction & Principle, Attraction and Repulsion type; Moving Coil instruments: Permanent Magnet type; Dynamometer type Instruments. **[9 Hrs.] [T1]**

SYLLABUS

ELECTRICAL TECHNOLOGY (ETEE-107)

Applicable from the Academic Session 2014-15

UNIT – I DC Circuits

Introduction of Circuit parameters and energy sources (Dependent and Independent), Mesh and Nodal Analysis, Superposition, Thevenin's, Norton's, Reciprocity, Maximum Power Transfer and Millman's Theorems, Star-Delta Transformation and their Applications to the Analysis of DC circuits. [T1],[T2] **[No. of Hrs. 11]**

UNIT – II A.C. Circuits

A.C. Fundamentals, Phasor representation, Steady State Response of Series and Parallel R-L, R-C and R-L-C circuits using j-notation, Series and Parallel resonance of RLC Circuits, Quality factor, Bandwidth, Complex Power, Introduction to balanced 3-phase circuits with Star-Delta Connections. [T1],[T2] **[No. of Hrs. 14]**

UNIT – III Measuring Instruments

Basics of measuring instruments and their types, Working principles and applications of moving coil, moving iron (ammeter & voltmeter) and Extension of their ranges, dynamometer-type Wattmeter, induction-type Energy Meter, Two-wattmeter method for the measurement of power in three phase circuits, Introduction to digital voltmeter, digital Multimeter and Electronic Energy Meter. [T1],[T2],[R2] **[No. of Hrs. 11]**

UNIT–IV Transformer and Rotating Machines

Fundamentals of Magnetic Circuits, Hysteresis and Eddy current losses, working principle, equivalent circuit, efficiency and voltage regulation of single phase transformer and its applications. Introduction to DC and Induction motors (both three phase and single phase), Stepper Motor and Permanent Magnet Brushless DC Motor. [T1],[T2],[R2]

[No. of Hrs. 12]

FIRST/SECOND SEMESTER
ELECTRICAL SCIENCE [ES-107/108]

UNIT-I: DC CIRCUITS

Introduction

The interconnection of various electric elements in a prescribed manner comprises as an electric circuit in order to perform a desired function. The electric elements include controlled and uncontrolled source of energy, resistors, capacitors, inductors, etc.

Analysis of electric circuits refers to computations required to determine the unknown quantities such as voltage, current and power associated with one or more elements in the circuit. To contribute to the solution of engineering problems, one must acquire the basic knowledge of electric circuit analysis and laws.

Basic Elements

Electrical Network: A combination of various electric elements (such as R, L, C, voltage & current sources) connected in any manner whatsoever is called an electric network.

Circuit Elements

(a) **Active Element:** The elements which supply energy to the network are known as active elements. For example, Voltage sources, dc & ac generators, current sources, transistors.

(b) **Passive Elements:** The components which dissipate or store energy are known as Passive elements. For example, Resistors (dissipate energy), inductors (store energy) and capacitors (store energy).

Difference between Active and Passive Elements:

Refer to Q.1(b), Page: 1 2017.

Bilateral Element: Conduction of current in both direction in an element with same magnitude is termed as bilateral element. For ex. R, L, C

Unilateral Element: Conduction of current in one direction is termed as unilateral element. For ex. Diode, Transistor.

Terminology

Linear Circuits: A circuit whose parameters do not change with voltage or current (Fig. 1). The electric circuits containing only linear resistances are called linear circuits.

Non-linear Circuits: A circuit whose parameters change with voltage or current (Fig. 2). The electric circuits containing resistive elements for which volt-ampere characteristics is other than a straight line are called non-linear circuits. For eg. Tungsten lamps, vacuum tubes, transistors, etc.

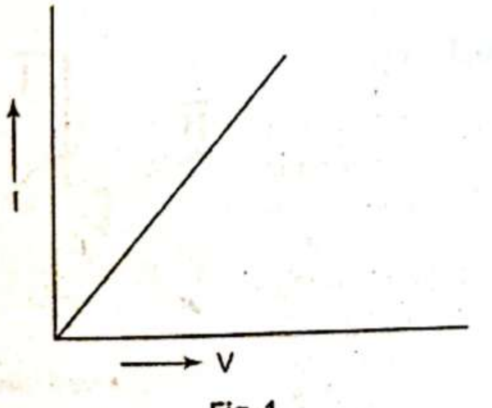


Fig. 1

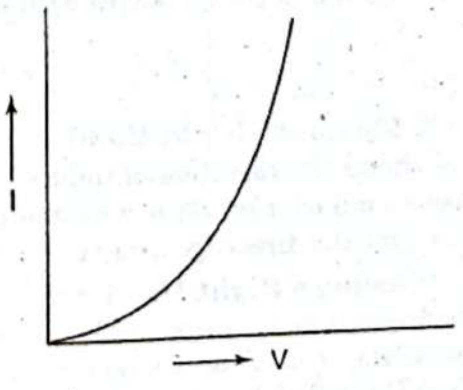


Fig. 2

Potential Energy Difference: The voltage or potential difference between two points in an electric circuit is the amount of energy required to move a unit charge between two points.

Electric Current: It is defined as the time rate of net motion of an electric charge across a cross-sectional boundary. Its unit is **ampere (A)**.

$$i = \text{Rate of transfer of electric charge}$$

$$= \frac{\text{Quantity of electric charge transferred during a given time duration}}{\text{Time duration}}$$

$$= \frac{dQ}{dt}$$

Electromotive Force (EMF): It is the force that causes an electric current to flow in an electric circuit. Its unit is Volt.

Potential Difference: Potential difference between two points in an electric circuit is that difference in their electrical state which tends to cause flow of electric current between them. Its unit is Volt.

Resistance: It may be defined as that property of a substance which opposes the flow of an electric current / electrons through it. Its unit is **ohm** (Ω).

Basic Laws of Electrical Engineering

1. Ohm's Law: The ratio of potential difference applied across a conductor and current flowing through it remains constant provided physical state i.e. temperature etc. of the conductor remains unchanged.

According to ohm's law,

$$\frac{V}{I} = \text{constant} = R$$

where, R is the resistance of the conductor

V is the potential difference across the conductor

I is the current flowing through the conductor

Limitations of Ohm's Law ***(Refer to Q.1(a), Page: 1–2017)***

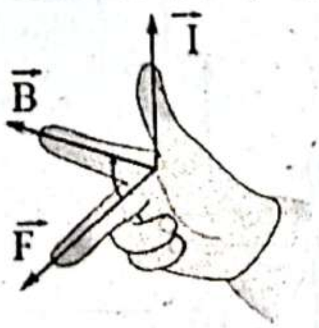
2. Faraday's Law of Electromagnetic Induction: Michael Faraday formulated the two laws of electromagnetic Induction. It is commonly referred as Faraday's Law.

First law states that when a conductor is forcefully moved or rotated in an electromagnetic field, the conductor cuts the magnetic flux, which induces an emf across the conductor.

Second law states that the magnitude of emf induced in a coil is equal to the rate of change of flux that linkages with the coil.

$$e = \frac{d\phi}{dt} \text{ and } \lambda = N\phi$$

3. Flemings' Right Hand rule: Leming's Right-hand Rule shows the direction of induced current in a generator when a conductor moves in a magnetic field. It can be used to determine the direction of current in a generator's windings.



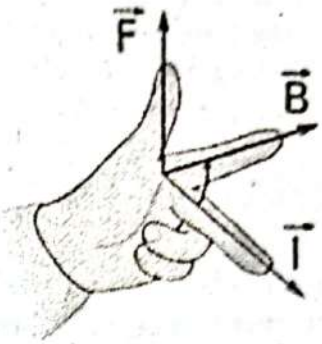
Fleming's Right Hand Rule

Fig. 3

Fleming's Right Hand rule states: "Stretch out the fore finger, middle finger and thumb of your right hand in such a way that they are mutually perpendicular to each other. If the fore finger represents the direction of field (F), the thumb points in the direction of motion or applied force (B), then middle finger points in the direction of the induced current (I)".

4. Flemings' Left Hand rule: Fleming's left-hand Rule shows the direction of motion of motor.

Fleming's Left Hand rule states: "Stretch out the fore finger, middle finger and thumb of your left hand in such a way that they are mutually perpendicular to each other. If the fore finger represents the direction of the field (B) and the middle finger represents that of the current (I), then thumb gives the direction of the force (F)".



Fleming's Left Hand Rule

Fig. 4

5. Lenz's Law: Lenz's law states that "The current flowing in a conductor due to the induced emf always opposes the cause producing it".

According to lenz's law,

$$e = -\frac{d\phi}{dt}$$

6. Laws of Resistance: The resistance of a wire depends upon its length, area of cross-section, type of material, purity & hardness of material of which it is made of and the operating temperature.

Therefore, Resistance of a wire is

(*i*) Directly proportional to its length, L i.e. $R \propto L$

(*ii*) Inversely proportional to its cross-sectional area, A i.e. $R \propto \frac{1}{A}$

Combining the two factors, we have

$$R \propto \frac{L}{A} \text{ or } R = p\frac{L}{A}$$

where, ρ is known as Specific resistance or resistivity of the material of the wire. It is named as Rho and is a constant quantity, Its unit is ohm-meters (Ω-m).

SOLVED EXAMPLE

Q.1. ***Refer to Q.1(b), Page: 1–2016***

Temperature Resistance Coefficient: The resistance of all pure metallic conductors increases with the increase in temperature but the resistance of the insulators and non-metallic materials generally decrease with the increase in temperature.

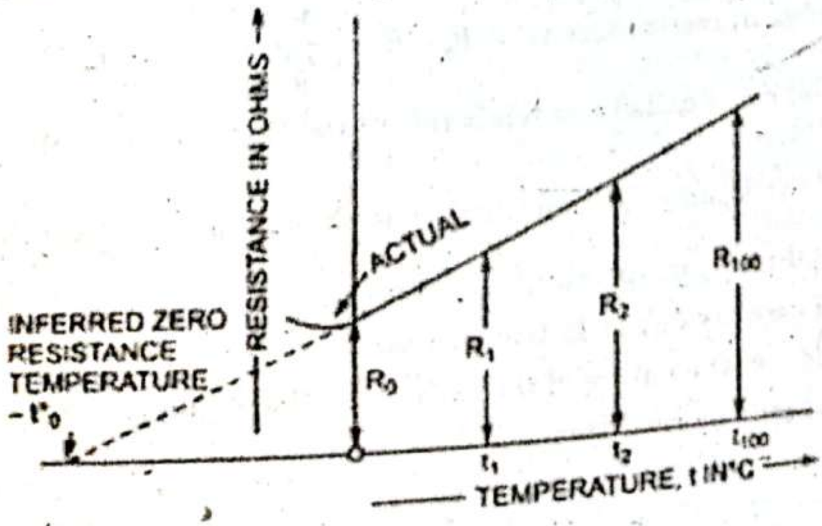


Fig. 5

If the resistance of any pure metal is plotted on a temperature base, it is found that over the range of temperature from 0 to 100 °C the graph is practically a straight line, as illustrate in Fig. 5. If this straight line is extended, it cuts the temperature axis at some temperature, $-t_0$ °C, known as *inferred zero resistance temperature*. This does not mean that the resistance of the metal is actually zero at that temperature, but $-t_0$ °C is the temperature at which the resistance would be zero if the rate of decrease between 100 and 0°C were maintained constant at all temperatures. From the similarity of the triangles in Fig. 5.

$$\frac{R_2}{R_1} = \frac{t_0 + t_2}{t_0 + t_1} \qquad \text{...(1)}$$

where R_1 and R_2 are the resistances at temperatures t_1°C and t_2°C respectively. Thus, if the resistance R_1 for any temperature t_1°C is known, then resistance for any other temperature t_2 can be computed from above equation provided that t_0 for that particular material is known.

The variation of resistance with temperature is often utilized in determining temperature variations. For example, in testing of an electric machine, the resistance of the coil is measured both before and after the test run, and the increase in resistance is a measure of the rise in temperature. For computation of temperature rise Eq. 1 may be transposed to the following form

$$t_2 - t_1 = \frac{R_2 - R_1}{R_1}(t_0 + t_1) \qquad \text{...(2)}$$

A temperature of 20°C has been adopted as the *standard reference temperature* for measurement of resistance, and the handbooks give the resistance of the various material at that temperature. Consequently, when a designer is computing the resistance of any conductor from its dimensions, the initial temperature t, at which the resistance is known, is generally 20°C.

Temperature Coefficient of Resistance: Let a metallic conductor having a resistance of R_0 at 0°C be heated to t°C and let its resistance at this temperature be R_t, From Eq. (1)

$$\frac{R_t}{R_0} = \frac{t_0 + t}{t_0 + 0}$$

$$\text{or } R_t = R_0 + \frac{1}{t_0} R_0 t$$

or change in resistance, $\Delta R = R_t - R_0 = \frac{1}{t_0} R_0 t = \alpha_0 R_0 t$

where $\alpha_0 = \frac{1}{t_0}$ and is called the temperature coefficient of resistance of the material at 0°C ...(3)

From Eq. (3) it may be concluded that change in resistance due to change in temperature

(a) varies directly as its initial resistance,

(b) varies directly as rise in temperature and

(c) depends on the nature of the material of the conductor.

The Eq. (3) may be rewritten as

$$\alpha_0 = \frac{\Delta R}{R_0 t} \qquad \text{...(4)}$$

So that temperature coefficient of resistance may be defined as the ratio of increase in resistance per degree rise of temperature to the original resistance.

If R_0 is the resistance of any conductor at 0°C and α_0 is the temperature coefficient of resistance at 0°C, the resistance at t°C is given as

R_t = Original resistance + increase in resistance $= R_0 + R_0\alpha_0 t = R_0(1 + \alpha_0 t)$ ...(5)

The above expression holds goods for both increase as well as decrease in temperature.

It is to be noted that

(*i*) temperature coefficient of resistance for all pure metallic conductors is positive *i.e.*, the resistance of all pure metallic conductors increases with the increase in temperature, that of non-metallic materials such as of carbon is negative *i.e.*, the resistance of non-metallic materials such as of carbon decrease with the increase in temperature. The temperature coefficient of resistance of alloys like constantan and manganin is negligible.

(*ii*) temperature coefficient of resistance is not constant but depends on the initial temperature on which the increment in resistance is based. When the increment is based on the resistance measured at 0°C, then the temperature coefficient of resistance has the value of α_0. At any other temperature t°C, value of temperature coefficient of resistance is α_1 and so on. For any material the temperature coefficient of resistance at 0°C *i.e.*, α_0 has the maximum value.

The temperature coefficient of resistance at any temperature t_1 is given as

$$\alpha_1 = \frac{1}{\frac{1}{\alpha} + t_1} \qquad ...(6)$$

The temperature coefficient of resistance at temperature t_2 in term of temperature coefficient of resistance at temperature t_1 is given as

$$\alpha_2 = \frac{1}{\frac{1}{\alpha_1} + (t_2 - t_1)} \qquad ...(7)$$

If R_1 is the resistance of any conductor at t_1°C and α_1 is the temperature coefficient of resistance at t_1°C, then resistance of the conductor at t_2°C is given

$$R_2 = R_1[1 + \alpha_1 (t_2 - t_1)] \qquad ...(8)$$

(*iii*) As the resistance of the materials change with the change in temperature so it is obvious that resistivity of the material depends on temperature.

Conductance and Conductivity

Conductance is the reciprocal of the resistance and denoted by 'G'. It is defined as the inducement offered by the conductor to the flow of current. Its unit is Siemen (S) or mho (℧).

$$\therefore \quad G = \frac{1}{R} \text{ and } R = \rho\frac{L}{A} \; ... \rightarrow \; G = \frac{1}{\rho}.\frac{A}{L} \; ... \rightarrow \; G = \sigma\frac{A}{L}$$

Where, σ is known as Specific Conductance or Conductivity of the material. It is the reciprocal of the resistivity and defined as the conductance between two opposite forces of a unit cube. Its unit is Siemen/metre.

Voltage and Current Sources (Energy Sources)

Independent Sources and Sependent Sources *(Refer to Q.1(b), Page: 2–2018)*

Ideal and Practical Voltage Source

A Voltage sources is a two-terminal device whose voltage any instant of time is constant and is independent of the current drawn from it. Such a voltage source is called an **Ideal Voltage Source** and have zero internal resistance.

Practically an ideal voltage source cannot be obtained.

Sources having some amount of internal resistances are known as **practical voltage source.** Due to this internal resistance; voltage drop takes place, and it causes the terminal voltage to reduce. The smaller is the internal resistance (r) of a voltage source, the more closer it is to an Ideal Source.

The symbolic representation of the ideal and practical voltage source is shown below.

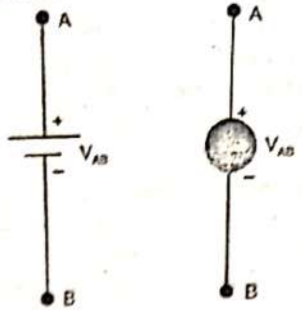


Fig. 6

Figure 7 shown shows the circuit diagram and characteristics of an ideal voltage source and Figure 8 shown gives the circuit diagram and characteristics of Practical Voltage Source. **The example of voltage sources is batteries and alternators.**

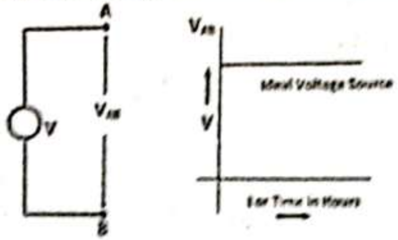


Fig. 7

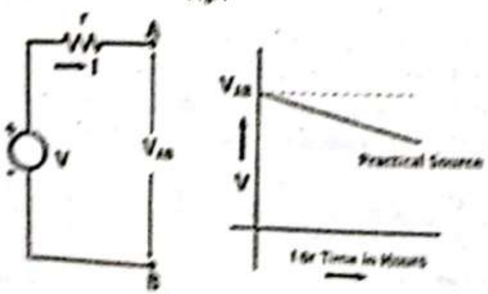


Fig. 8

Ideal and practical current source: The current source are further categorised as Ideal and Practical current source.

An **ideal current source** is a two-terminal circuit element which supplies the same current to any load resistance connected across its terminals. It is important to keep in mind that the current supplied by the current source is independent of the coltage of source terminals. It has infinite resistance.

A practical current source is represented as an ideal current source connected with the resistance in parallel.

The symbolic representation is shown:

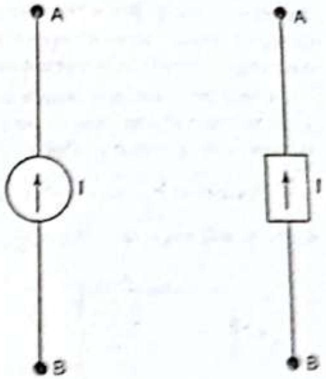


Fig. 9

Figure 10 shows its characteristics and Figure 11 shown the characteristics of Practical Current Source. **The example of current sources is photoelectric cells, collectors currents of transistors.**

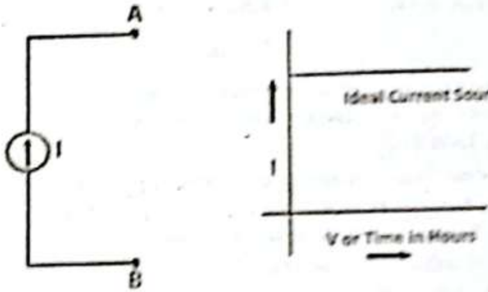


Fig. 10

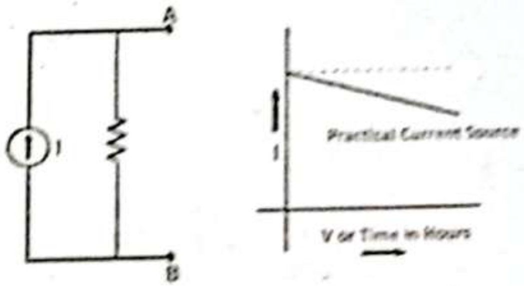
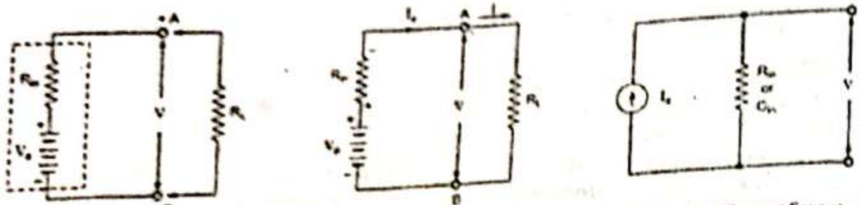


Fig. 11

Source transformation: Practically, a voltage sources is not different from a current source. In fact, a source can either operate as a current source or as a voltage source. It merely depends upon its operating conditions. If load impedance is very large in comparison to internal impedance of the source, it will be advantageous to treat the source as a voltage source. On the other hand, if the load impedance is very small in comparison to the internal impedance of the source, it is better represent the source as a current source. From the circuit point of view it does not matter at all whether the source is treated as a voltage source or a current source. In fact, it is possible to convert a voltage source into a current source and vice versa.

Consider a voltage source of voltage V_1 and internal resistance R_{in} shown in Fig 12(a) for conversion into an equivalent current source. The current supplied by this voltage source, when a short circuit is put across terminals A and B will be equal to $\frac{V_S}{R_{in}}$. A current source supplying this current $I_s = \frac{V_S}{R_{in}}$ and having the same resistance across it will represent the equivalent current source [Fig. 10 (c)].



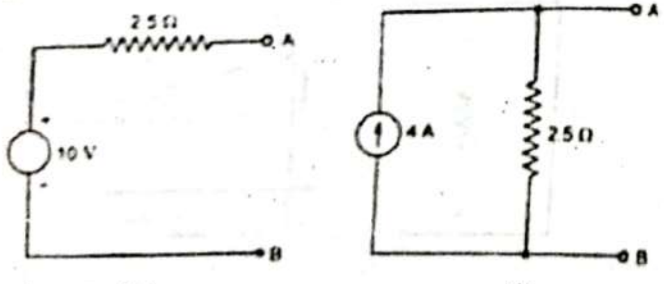
(a) A Practical Voltage Source (b) Voltage Drop in R_{in} (c) Practical Current Source

Fig. 12

Similarly a current source of output current I_s in parallel with resistance R_{in} can be converted into an equivalent voltage source of voltage $V_s = I_s R_{in}$ and a resistance R_{in} in series with it [Fig. 12 (a)].

It should be noted that a voltage source series resistance combination is equivalent to a current source-parallel resistance combination if and only if their respective open-circuit voltage are equal, and their respective short-circuit currents are equal.

For example, a voltage source branch consisting of a 10V source in series with a resistance of 2.5 Ω may be replaced by a current source branch consisting of a 4 A source in parallel with a 2.5Ω resistance and vice versa as shown in fig. 13(a) and 13(b) respectively.



(a) (b)

Fig. 13

SOLVED EXAMPLE

Q.1. *Refer to Q.1(a), Page: 1–2015*

Q.2. *Refer to Q.1(b), Page: 1–2015*

Q.3. *Refer to Q.3(a), Page: 3–2016*

Series and Parallel Circuits

Series Circuits: *When the resistors are connected end to end, so that they form only one path for the flow of current, then resistor are said to be connected in series and such circuits are known as series circuit.*

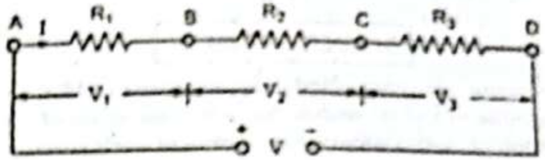


Fig. 14 Series Circuit

Let resistors R_1, R_2 and R_3 be connected in series, as shown in Fig.1, and the potential difference of V volts be applied between extreme ends A and D to cause flow of current of 1 amperes through all the resistors R_1, R_2 and R_3.

Now according to Ohm's law

Voltage drop across resistor R_1, $V_1 = I R_1$

Voltage drop across resistor R_2, $V_2 = I R_2$

Voltage drop acros resistor R_3, $V_3 = I R_3$

Voltage drop across whole circuit,

V = Voltage drop across resistor R_1 +voltage drop across resistor R_2 + voltage drop across resistor R_3

$$\text{i.e., } V = I R_1 + I R_2 + I R_3 = I(R_1 + R_2 + R_3)$$

$$\text{or} \quad \frac{V}{I} = R_1 + R_2 + R_3 \qquad ...(9)$$

and according to Ohm's law $\frac{V}{I}$ gives the whole circuit resistance, say R

∴ Effective resistance of the series circuit,

$$R = R_1 + R_2 + R_3 \qquad ...(10)$$

Thus, when a number of resistor are connected in series, the equivalent resistance is given by the arithmetic sum of their individual resistances.

i.e.,

$$R = R_1 + R_2 + R_3 + ...R_n \qquad ...(11)$$

From the above discussions for a series circuit we conculde that

1. same current flows through all parts of the circuit,
2. applied voltage is equal to the sum of voltage drops across the different parts of the circuit,
3. different resistors have their individual voltage drops,
4. voltage drop across individual resistor is directly proportional to its resistance, current being the same in each resistor,
5. voltage drops are additive,
6. resistance are additive,
7. powers are additive.

Series circuit are common in electrical equipment. The tube filaments in small radios are usually in series. Current controlling devices are wired in series with the controlled equipment. Fuses are in series with the equipment they protect. A thermostat switch is in series with the heating element in an electric iron. Automatic house-heating equipment has a thermostat, electromagnet coils, and safety cut-outs in series with voltage source. Rheostats are placed in series with the coils in large motors for motor current control.

SOLVED EXAMPLE

Q.1. *Three resistors are connected in series across a 12 V battery. The first resistor has the value of 1 ohm, second has a voltage drop of 4 V and third has a power dissipation of 12 W. Calculate the value of each resistance and circuit current.*

Solution: Let the three resistors be of R_1 (= 1Ω), R_2 and R_3 ohms, current flowing through the three resistors R_1, R_2 and R_3 be of I amperes and voltage drops across resistors R_1, R_2 and R_3 be of V_1, V_2 and V_3 volts respectively. The circuit is show in Fig 15.

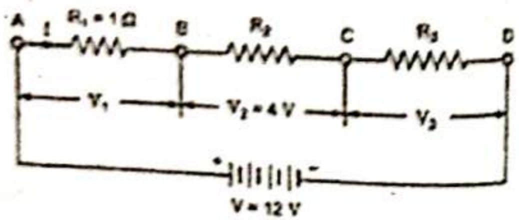


Fig. 15

Now $\quad V_1 = IR_1 = I$ volts

$V_2 = IR_2 = 4$ volts

$V_3 = \dfrac{\text{Power dissipation}}{I} = \dfrac{12}{I}$ volts

since $\quad V = V_1 + V_2 + V_3$

so $\quad 12 = I + 4 + \dfrac{12}{I}$

or $\quad I^2 - 8I + 12 = 0$

or $\quad (I-6)(I-2) = 0$

or $\quad I = 6$ or $2A$ **Ans.**

When $I = 6A$; $\quad R_2 = \dfrac{V_2}{I} = \dfrac{4}{6} = \dfrac{2}{3}\Omega$

and $\quad R_3 = \dfrac{P}{I^2} = \dfrac{12}{6^2} = \dfrac{1}{3}\Omega$

i.e., $\quad R_1 = 1\Omega; R_2 = \dfrac{2}{3}\Omega$ and $R_3 = \dfrac{1}{3}\Omega$ **Ans.**

When $I = 2A$; $\quad R_2 = \dfrac{V_2}{I} = \dfrac{4}{2} = 2\Omega$

and $\quad R_3 = \dfrac{P}{I^2} = \dfrac{12}{2^2} = 3\Omega$

i.e., $\quad R_1 = 1\Omega; R_2 = 2\Omega$ and $R_3 = 3\Omega$ **Ans.**

Q.2. *A 100 V, 60 watt bulb is to be operated from 220V supply. What is the resistance to be connected in series with the bulb to glow normally?*

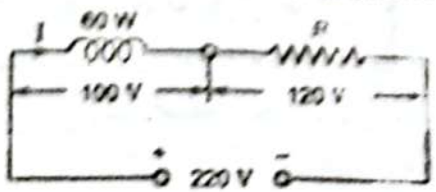


Fig. 16

Solution: Rated power of lamp, P = 60 W

Rated voltage of lamp, V = 100 V

Current drawn by the lamp, when operated on rated voltage, *i.e.*,

rated current, $I = \dfrac{P}{V} = \dfrac{60}{100} = 0.6\,A$

Lamp will operate normally on 220V also if the current flowing through the lamp remains the rated current i.e., 0.6 A.

Let the resistance connected in series with the lamp to make it glow normally on 220 V be of R ohms, as shown in Fig. 16.

Now since the resistance R is in series with the lamp, the same current will flow through the resistance R, as in the lamp *i.e.*, 0.6 A and voltage drop across series resistance R will be equal to supply voltage less voltage drop across the lamp (*i.e.*, rated voltage of the lamp) or Voltage drop across the series resistance, IR = supply voltage – rated voltage of the lamp

$= 220 - 100 = 120$ V

or $\quad R = \dfrac{120}{I} = \dfrac{120}{0.6} = 200\Omega$ **Ans.**

Parallel Circuits

When a number of resistors are connected in such a way that one end of each of them is joined to a common point and the other ends being joined to another common point, as shown in Fig. 17, then resistors are said to be connected in parallel and such circuit are known as *parallel circuits*. In these circuit current is divided into as many paths as the number of resistances.

Let the resistors R_1, R_2 and R_3 be connected in parallel, as shown in Fig. 17, and the potential difference of V volts be applied across the circuit.

Since potential difference across each resistor is same and equal to potential difference applied to the circuit *i.e.*, V

∴ According to Ohm's law

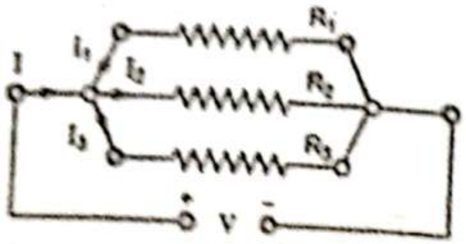


Fig. 17 Parallel Circuit

Current in resistor $R_1, I_1 = \dfrac{V}{R_1}$ ...(1)

Current in resistor $R_2, I_2 = \dfrac{V}{R_2}$ ...(2)

Current in resistor $R_3, I_3 = \dfrac{V}{R_3}$ ...(3)

Adding Eqs. (1), (2) and (3), we have

$$I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \quad ...(4)$$

and since $I_1 + I_2 + I_3 = I$, the total current flowing through the circuit

so
$$I = I_1 + I_2 + I_3 = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

or
$$\frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

and since $\dfrac{I}{V} = \dfrac{1}{R}$ where R is the equivalent resistance of the whole circuit,

$$\therefore \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad ...(5)$$

Thus, when a number of resistors are connected in parallel, the reciprocal of the equivalent resistance is given by the arithmetic sum of the reciprocals of their individuals resistances.

In general if n resistors of resistance $R_1, R_2, R_3, ... R_n$ are connected in parallel, then equivalent resistance R of the circuit is given by the expression

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n} \quad ...(6)$$

Also
$$G = G_1 + G_2 + G_3 + ... + G_n \quad ...(7)$$

where $G = \dfrac{1}{R}, G_1 = \dfrac{1}{R_1}, G_2 = \dfrac{1}{R_2}, G_3 = \dfrac{1}{R_3}$ and so on.

From the above discussion for a parallel circuit we conclude that

1. same voltage acts across all branches of the circuit,
2. different resistors (or branches) have their individual currents,
3. total circuit current is equal to the sum of individual currents through the various resistors (or branches),

4. branch current are additive,
5. conductances are additive,
6. power are additive
7. the reciprocol of the equivalent or combined resistance is equal to the sum of the sum of the reciprocals of the resistance of the individual branches.

Parallel circuit are very comon in use. Various lamps and appliances in a house are connected in parallel, so that each one can be operated independently. A series circuit is an "all or none" circuit, in which either every thing operates or nothing operates. For individuals control, devices are wired in parallel.

Series-Parallel Circuits: So far, only simple series and simple series and simple parallel circuit have been considered. Practical electric circuit very often consist of combinations of series and parallel resistance. Such circuits may be solved by the proper application of Ohm's law and the rules for series and parallel circuit to the various parts of the complex circuit. There is not definite procedure to be followed in solving complex circuits, the solution depends on the known facts concerning the circuit and the quantities which one desires to find. One simple rule may usually be followed, however–reduce the parallel branches to an equivalent series branch and then solve the circuit as a simple series circuit.

For example, consider a series-parallel circuit shown 18 for solution.

First of all equivalent resistance of all parallel branches are determined separately *e.g.*, of branches AB and CD by the law of parallel circuits.

Equivalent resistance of parallel branches AB,

$$R_{AB} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 + R_2}{R_1 + R_2}$$

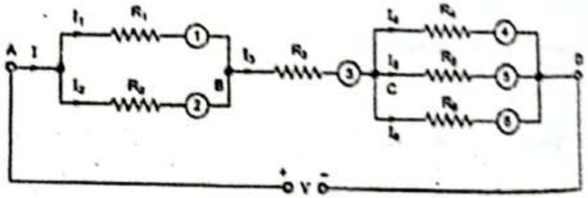


Fig. 18

and equivalent resistance of parallel branch CD

$$R_{CD} = \frac{1}{\frac{1}{\frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6}}} = \frac{R_4R_5R_6}{R_5R_6 + R_4R_6 + R_4R_5}$$

Now the circuit shown in Fig. 18 gets reduced to a simple series circuit shown in Fig. 19 consisting of three resistance,

$$R_{AB} = \frac{R_1R_2}{R_1 + R_2}, R_{BC} = R_3 \quad \text{and} \quad R_{CD} = \frac{R_4R_5R_6}{R_5R_6 + R_4R_6 + R_4R_5}$$

Total resistance of circuit, $R_T = R_{AB} + R_{BC} + R_{CD}$

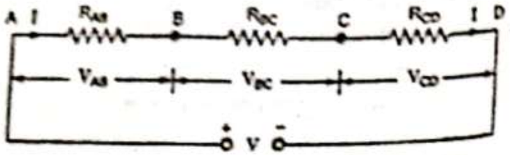


Fig. 19

Now circuit may be determined from the relation

$$I = \frac{V}{R_T}$$

After knowing I, potential difference across branches AB, BC and CD are determined from the relations

PD across branch AB, $\quad V_{AB} = I.R_{AB} = \frac{V}{R_T} R_{AB}$

PD across branch BC, $\quad V_{BC} = I.R_{BC} = \frac{V}{R_T} R_{BC}$

and PD across branch CD, $V_{CD} = IR_{CD} = \frac{V}{R_T} R_{CD}$

After determine of potential difference across each prallel branch, the current in the various resistance are determined from the relations

Current in resistance $R_1 = I_1 = \frac{V_{AB}}{R_1}$

Current in resistance $R_2 = I_2 = \frac{V_{AB}}{R_2}$

Current in resistance $R_3 = I_3 = I$

Current in resistance $R_4 = I_4 = \frac{V_{CD}}{R_4}$

Current in resistance $R_5 = I_5 = \frac{V_{CD}}{R_5}$

Current in resistance $R_6 = I_6 = \frac{V_{CD}}{R_6}$

Thus, equivalent resistance of the whole circuit, voltage drop across each branch and current in the various resistors may be determined.

SOLVED EXAMPLE

Q.1. Two resistance of 20 Ω and 30 Ω respectively are connected in parallel. These two parallel resistances are further connected in series with a resistance of 15 Ω. If the current through the 15 Ω resistance is 3 A find (a) the current through the 20 Ω and 30 Ω resistances respectively (b) the voltage across the whole circuit (c) the total power consumed.

Solution: Equivalent resistance of branch AB, $R_{AB} = \frac{1}{\frac{1}{20}+\frac{1}{30}} = 12\Omega$

Effective resistance of the circuit, Reff = $R_{AB} + R_{BC} = 12 + 15 = 27\Omega$

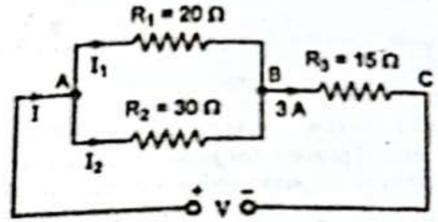


Fig. 20

Circuit current, I = Current through 15 Ω resistance = 3A

(b) Voltage across the whole circuit, $V = I\,R_{eff} = 3 \times 27 = 81\ V$ Ans.

(c) Total power consumed, $P = VI = 81 \times 3 = 243$ watts Ans.

(a) Voltage drop across branch AB, $V_{AB} = I\,R_{AB} = 3 \times 12 = 36\ V$

Current through 20 Ω resistance, $I_1 = \frac{V_{AB}}{R_1} = \frac{36}{20} = 1.84$ Ans.

Current through 30 Ω resistance, $I_2 = \frac{V_{AB}}{R_2} = \frac{36}{30} = 1.24$ Ans.

Q.2. For the circuit shown in Fig. 21, using the method of series-parallel combination, find V_1 and I_2

Solution: Total resistance of the circuit,

Req = 25 + 2.5 + equivalent resistance of parallel combination of resistors of 10.50 and 20 Ω

$$= 25 + 2.5 + \frac{1}{\frac{1}{10}+\frac{1}{50}+\frac{1}{20}}$$

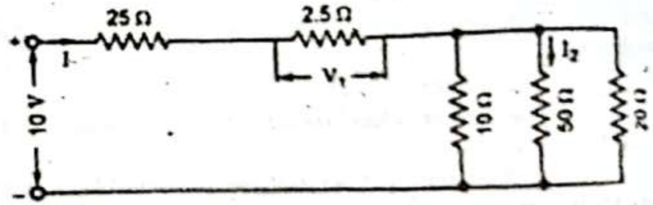


Fig. 21

$$= 25 + 2.5 + \frac{100}{10+2+5} = \frac{1.135}{34}\Omega$$

Applied voltage, $V = 10V$

Current drawn from the supply, $I = \frac{V}{R_{eq}} = \frac{10}{\frac{1,135}{34}} = \frac{10 \times 34}{1,135} = \frac{68}{227}A$

Voltage drop across resistor of 2.5 Ω $V_1 = I \times 2.5 = \frac{68}{227} \times 2.5 = \frac{170}{227} V$ **Ans.**

Voltage drop across parallel combination, $V_2 = \frac{68}{227} \times \frac{100}{17} = \frac{400}{227} V$

Current through 50 Ω resistor, $I_2 = \frac{V_2}{50} = \frac{400}{227 \times 50} = \frac{8}{227} A$ **Ans.**

Power and Energy

Power is defined as the rate of doing work or the amount of work done in unit time.

The MKS or SI unit of power is the joule/second or watt. In practice, the watt is often found to be inconveniently small and so a bigger unit, the kilowatt is *frequently* used.

$$1 \text{ kilowatt} = 1{,}000 \text{ watts}$$

The bigger unit of power most commonly used in engineering practice (not at all SI system) is horse power defined as below:

Metric Horse Power: It is the practical unit of power in MKs system (not in SI system) which according to ISI specifications is equal to 75 kgf-m of work done per second.

Energy is defined as the capacity of doing work. Its units are same as those of work, mentioned above. If a body having mass m, in kg, is moving with velocity v, in meters/second,

$$\text{Kinetic energy} = \frac{1}{2}mv^2 \text{ joules}$$

If a body having mass m, in kg, is lifted vetically through height h, in meters, and if g is the gravitational acceleration, in meters/second² in that region, potential energy acquired by the body

= work done in lifting the body = mgh joules = $9.81\ mh$ joules

As already stated, in SI system the unit of energy of all forms is joule. Bigger unit of energy is mega joules (MJ) where 1 MJ = 10^6 J

The thermal units of energy, calorie (gm calorie) and kilocalorie (kilogram calorie), are defined below:

Calorie: It is the amount of heat required to raise the temperature of one gram of water through 1°C.

$$\therefore 1 \text{ calorie} = 4.18 \text{ J} = 4.2 \text{ J}$$

Kilocalorie: It is the amount of heat required to arise the temperature of 1 kg of water through 1°C.

$$1 \text{ k. calorie} = 1{,}000 \text{ calories} = 4{,}180 \text{ joules} = 4{,}200 \text{ J}$$

Electric Unit of Power and Energy

The unit of work done and of energy expended is joule. It is equal to the energy expended in passing 1 coulomb of charge through a resistance of 1 ohm i.e., the energy expended in passing one ampere current for 1 second through a resistance of one ohm is taken as one joule. It may also be expressed as 1 watt-second i.e., one watt of power consumed for one second.

i.e.,

$$1 \text{ joule} = 1 \text{ watt-second}$$

The unit of energy, joule or watt-second is too small for pratical purposes, so a bigger unit Mega joule (MJ) or kilowatt-hour (kWh) is used in electrical engineering.

$$1\text{kWh} = 1{,}000 \text{ watt-hour} = 1{,}000 \times 3{,}600 \text{ watt-second or joules} = 3.6 \text{ MJ}$$

The kWh, also called the *Board of Trade* (BOT) *unit*, is the energy absorbed by supplying a load of 1 KW or 1,000 watts for the period of one hour. This is legal unit on which charges for electrical energy are made, and, therefore, it is called the Board of Trade (BOT) unit.

Watt: It is defined as the power expended when there is an unvarying current of one ampere between two points having a potential difference of one volt. As already stated the bigger unit of power is kW or Megawatt.

$$1 \text{ kW} = 1{,}000 \text{ watts}$$

$$1 \text{ MW} = 1{,}000 \text{ kW} = 1 \times 10^6 \text{ watts}$$

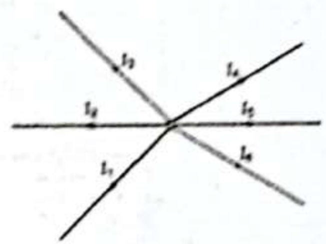
Kirecoff's Laws

- They are used for the systmatic analysis of electric circuits.
- They describe the relationship among circuit voltage and circuit current that must be satisfied.
- they are helpful in determining the equivalent resistance / impedance of a complex network and the current flowing in the various branches of the network.

1. **Kirchhoff's Current Law (KCL) / or Kirchhoff's Point Law:** According to KCL, in any network of wires carrying currents, the algebraic sum of all currents meeting at a point (or junction) is zero.

[OR]

According to KCL, in any network of wires carrying currents, the sum of incoming currents towards any points is equal to the sum of outgoing currents away from that point.



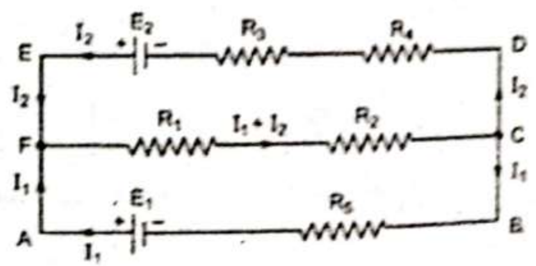
If $I_1, I_2, I_3, I_4, I_5, I_6$ are the currents meeting at junction O as shown, then according to KCL, we get

$$I_1 - I_2 - I_3 + I_4 + I_5 - I_6 = 0$$

OR $$I_1 + I_4 + I_5 = -I_2 - I_3 - I_6$$

2. **Kirchhoff's Voltage Law (KVL) / or Kirchhoff's Second Law / or Kirchhoff's Mesh Law:** According to KVL, in any closed circuit or mesh, the algebraic sum of emfs in that circuit or mesh is equal to the algebraic sum of the products of the currents & resistances of each part of the circuit.

Considering the circuit as shown below,



According to KVL in mesh AFCBA,

$$E_1 - (I_1 + {}_2)R_1 - (I_1 + I_2)R_2 - I_1R_5 = 0$$

According to KVL in mesh EFCDE,

$$E_2 - (I_1 + I_2)R_1 - (I_1 + I_2)R_2 - I_2R_4 - I_2R_3 = 0$$

According to KVL in mesh AEDBA,

$$E_1 - E_2 - I_1R_5 + I_2R_4 + I_2R_3 = 0$$

SOLVED EXAMPLE

Q.1. ***Refer to Q.1 (a), Page: 13-2018***

Q.2. ***Refer to Q.2 (a), Page: 3-2015***

Q.3. ***Refer to Q.2 (b), Page: 5-2018***

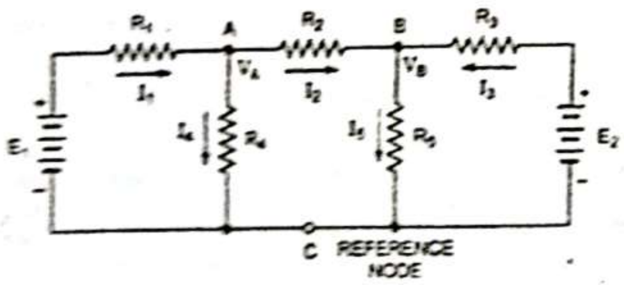
Nodal analysis (Node-Voltage Theorem): According to Nodal Analysis, one of the nodes is taken as refernce node (or zero potential of datum node) and the potential difference between each of the other nodes & the reference node is expressed in terms of an unkonwn voltage and at every node KCL is applied assuing the possible directions of branch currents.

- For 'n' number of nodes, the total number of nodal equation will be $(n - 1)$ in terms $(n - 1)$ number of unkonwn variable of nodal voltages.

Illustration: Considering a two node network as shown. Node C has taken as refernce node. Let V_A and V_B be the voltages at nodes A and B respectively w.r.t node C. Marking the currents arbitrarily, we get

$$I_1 = I_2 + I_4 \dashrightarrow \frac{E_1 - V_A}{R_1} = \frac{V_A - V_B}{R_2} + \frac{V_A}{R_4}$$

$$V_A\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4}\right) - \frac{V_B}{R_2} = \frac{E_1}{R_1} \dots \rightarrow \quad \text{(i)}$$



Applying KCL at node B, we get

$$I_5 = I_2 + I_3 \dashrightarrow \frac{V_B}{R_5} = \frac{V_A - V_B}{R_2} + \frac{E_2 - V_B}{R_3}$$

$$-\frac{V_A}{R_2} + V_B\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_5}\right) = \frac{E_2}{R_3} \dots \rightarrow \quad \text{(ii)}$$

Now, the eq. (i) and (ii) will be solved to find V_A and V_B, and then the values of I_1, I_2, I_3, I_4 & I_5 can be computed easily.

SOLVED EXAMPLE

Q.1. ***Refer to Q.3(a), Page: 19-2017***

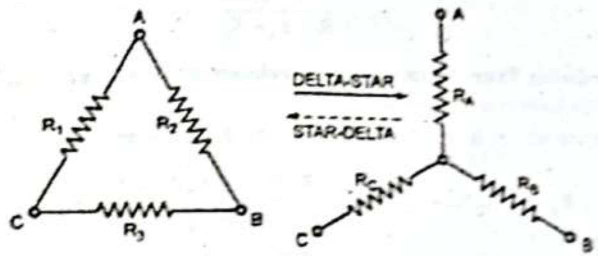
Q.2. ***Refer to Q.2, Page: 8-2016***

Q.3. ***Refer to Q.2(b), Page: 5-2018***

Q.4. ***Refer to Q.2(a), Page: 15-2018***

Network Reduction by Star-Delta

1. Delta-Star Transformation: The replacemnt of delta or mesh by equivalent star system is know as delta-star system.



The two system will be equivalent if the resistance measured between any pair of lines is same in both of the system, when the third line is open.

For terminal B & C,

$$R_{BC} = (R_1 + R_2) \| R_3 \quad \text{(From Delta System)}$$

$$R_{BC} = \frac{(R_1 + R_2) \times R_3}{R_1 + R_2 + R_3}$$

Also, $$R_{BC} = R_B + R_C \quad \text{(From Star System)}$$

Since, two system are idential,

$$R_B + R_C = \frac{(R_1 + R_2) \times R_3}{R_1 + R_2 + R_3} \quad \text{...(i)}$$

Similarly, $$R_{CA} = (R_2 + R_3) \| R_1 \quad \text{(From Delta System)}$$

$$R_{CA} = \frac{(R_2 + R_3) \times R_1}{R_1 + R_2 + R_3}$$

Also, $$R_{CA} = R_C + R_A \quad \text{(From Star System)}$$

Since, two system are identical,

$$\therefore \quad R_C + R_A = \frac{(R_2 + R_3) \times R_1}{R_1 + R_2 + R_3} \quad \text{...(ii)}$$

similarly, $$R_A + R_B = \frac{(R_1 + R_3) \times R_2}{R_1 + R_2 + R_3} \quad \text{...(iii)}$$

Adding eq. (i), (ii) & (iii), we get,

$$2(R_A + R_B + R_C) = \frac{2(R_1R_3 + R_2R_3 + R_1R_2)}{R_1 + R_2 + R_3}$$

$$R_A + R_B + R_C = \frac{R_1R_3 + R_2R_3 + R_1R_2}{R_1 + R_2 + R_3} \quad ...(iv)$$

Subtracting eq. (i), (ii), & (iii) from eq. (iv), we get respectively,

$$R_A = \frac{R_1R_2}{R_1 + R_2 + R_3} \quad ...(v)$$

$$R_B = \frac{R_2R_3}{R_1 + R_2 + R_3} \quad ...(vi)$$

$$R_C = \frac{R_3R_1}{R_1 + R_2 + R_3} \quad ...(vii)$$

2. Star-Delta Transformation: the replacement of star network by equivalent delta systemis known as delta-star system.

Multiplying eq. (v) & (vi), (vi)& (vii) and (vii) & (v), we get,

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R^2{}_2R_3 + R_1R_2R^2{}_3 + R^2{}_1R_2R_3}{(R_1 + R_2 + R_3)^2}$$

$$= \frac{R_1R_2R_3(R_1 + R_2 + R_3)}{(R_1 + R_2 + R_3)^2}$$

$$= \frac{R_1R_2R_3}{R_1 + R_2 + R_3} \quad ...(viii)$$

Solving eq. (v), (vi), (vii) with eq. (viii), we get

$$R_3 = R_B + R_C + \frac{R_BR_C}{R_A}$$

$$R_1 = R_A + R_C + \frac{R_AR_C}{R_B}$$

$$R_2 = R_A + R_B + \frac{R_AR_B}{R_C}$$

SOLVED EXAMPLE

Q.1. ***Refer to Q.3(b), Page: 20–2017***
Q.2. ***Refer to Q.1(c), Page: 3–2018***
Q.3. ***Refer to Q.3(a), Page: 18–2018***
Q.4. ***Refer to Q.4(b), Page: 6–2016***
Q.5. ***Refer to Q.1(a), Page: 6–2016***
Q.7. ***Refer to Q.1(d), Page: 1–2017***
Q.7. ***Refer to Q.3(b), Page: 29–2015***
Q.8. ***Refer to Q.1(b), Page: 10–2015***

Superposition Theorem ***(Refer to Q.3(b), Page: 22–2014)***

Limitation of Superposition Theorem ***(Refer to Q.1(a), Page: 10–2015)***

SOLVED EXAMPLES

Q.1. ***Refer to Q.3(b), Page: 12–2016***
Q.2. ***Refer to Q.4(b), Page: 11–2018***
Q.3. ***Refer to Q.2(b), Page: 3–2017***

Thevenin's Theorem

(Refer to Q.2(a), Page: 26–2015 and Refer to Q.1(d), Page: 3–2018)

SOLVED EXAMPLES

Q.1. ***Refer to Q.2(a), Page: 14–2017***
Q.2. ***Refer to Q.3(b), Page: 12–2016***
Q.3. ***Refer to Q.4(a), Page: 9–2018***
Q.4. ***Refer to Q.1(c), Page: 1–2015***

Norton's Theorem ***(Refer to Q.1(d), Page: 3–2018)***

SOLVED EXAMPLES

Q.1. ***Refer to Q.4(a), Page: 9–2018***
Q.2. ***Refer to Q.3(b), Page: 19–2018***
Q.3. ***Refer to Q.2(a), Page: 2–2017***
Q.4. ***Refer to Q.3(a), Page: 5–2015***

Maximum Power Transfer Theorem ***(Q.2(a), Page: 13–2015)***

• **PLEASE NOTE**

In case of Dependent Source, R_{Th} will be calculated as-

$$R_{Th} = \frac{V_{OC}}{I_{SC}}$$

SOLVED EXAMPLES

Q.1. ***Refer to Q.2(b), Page: 16–2018***
Q.2. ***Refer to Q.3(a), Page: 4–2017***
Q.3. ***Refer to Q.2(b), Page: 27–2015***
Q.4. ***Refer to Q.2(b), Page: 2–2016***

Time Domain Analysis of First Order RC & LC Circuits

Inductance and Capacitance Behaviour at $t = 0^+$

Inductance

$$i_L = \int_0^t v_L dt + i(0)$$

Inductance current, therefore, cannot change suddenly because it would require infinite voltage. Thus at $t = 0^+$, inductance acts as an ideal current source of strength $i_L(0^+) = i_L(0^-)$. If $i_L(0^-) = 0$, the inductance acts as an open-circuit.

This is illustrated in Fig. 1

Capacitance

$$V_C = \int_0^t i dt + v_c(0)$$

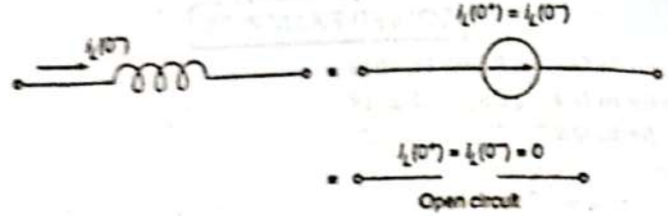


Fig. 1 Inductance behaviour at $t = 0^+$

Capacitance voltage, therefore, cannot change suddenly because of which it acts as an ideal voltage source of strength $v_C(0^+) = v_C(0^-)$. If $v_C(0^-) = 0$ it would act as a short circuit. This is illustrate in Fig. 2.

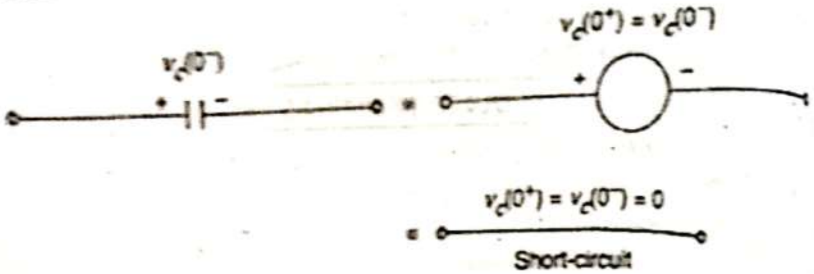


Fig. 2

Inductance and Capacitance Behaviour at $t = \infty$ (Steady State) for dc Excitation

Induction Under steady state the inductance current reaches a constant value I.

The inductance voltage is then

$$v_L = \frac{dI_L}{dt} = 0$$

Therefore, the inductance acts as short-circuit.

Capacitance Under steady-state, capacitance voltage reaches a constant value V.

The capacitance current is then

$$i_C = C\frac{dV_C}{dt} = 0$$

Therefore, the capacitance acts as an open-circuit.

It is immediately concluded that steady state inductance current and capacitance voltage are determined by the resistive circuit after all inductance have been short-circuit and capacitances open-circuited.

Step Voltage Response of *RL* Series Circuit: Consider the *RL* series circuit of Fig. 3. Just before the application of voltage (step) the circuit history is represented by the inductor current $i_L(0^-)$ which in this circuit is zero because

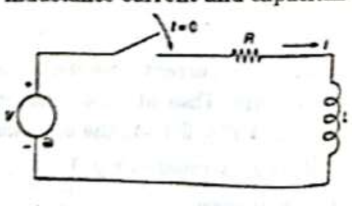


Fig. 3

the circuit is open before the switching-on operation.

The KVL equation of the circuit is

$$R_i + L\frac{di}{dt} = V; \quad t > 0 \tag{1}$$

This is a *nonhomogeneous linear* differential (of first order) with the excitation term appearing on its right hand side. The solution to eq. (1) will have two component, viz. *complimentary function* (natural response, i_n) which should satisfy the equation

$$\frac{di}{dt} + \frac{R}{L}i = 0 \tag{2}$$

and the particular integral (forced response, i_f) which shoul satisfy Eq. (1).

Thus, the complete solution (response) is

$$i = i_n + i_f \tag{3}$$

We already know that the natural response is

$$i_n = Ae^{-(R/L)t} = Ae^{-t/\tau} \tag{4}$$

Let us now discover the forced response (particular integral of eq. (1)). Since the excitation is constant it is intuitively expected that $i_f = I$(a constant) would satisfy Eq. (1). It leads to

$$RI + L\frac{dI}{dt} = V$$

But

$$L\frac{dI}{dt} = 0$$

$\therefore$

$$I = \frac{V}{R} = i_f \tag{5}$$

The complete response is then

$$i(t) = Ae^{-(R/L)t} + \frac{V}{R}\ ; t > 0 \tag{6}$$

in which we must determine the arbitrary constant A such that it satisfies the initial condition on inductance current. As already state above

$$i(0^+) = i(0^-) = 0$$

Substituting in Eq. (3.30)

$$0 = A + \frac{V}{R}$$

or

$$A = -\frac{V}{R}$$

Hence

$$i(t) = \frac{V}{R}(1 - e^{-(R/L)t});\ t > 0 \tag{7a}$$

$$= \frac{V}{R}(1 - e^{-t/\tau});\ t > 0 \tag{7b}$$

From the response, the current rise exponentially from 0 to $I = V/R$ in accordance with the time constant (or natural frequency). It is noticed that the intial (at $t = 0^+$) rate of rise of current is I/τ and the current reaches a vlaue of 63.2% of final value $(I = V/R)$ in time of one time constant.

behaviour at $t = 0^+$ and $t = \infty$ stated earlier is confirmed by the response of Eq. (7) from which it follows that

$$i(0^+) = 0$$

i.e., the inductance acts as an open-circuit at $t = 0^+$,

and
$$i(\infty) = \frac{V}{R}$$

i.e., inductance acts as a short-circuit at $t = \infty$ (for de excitation).

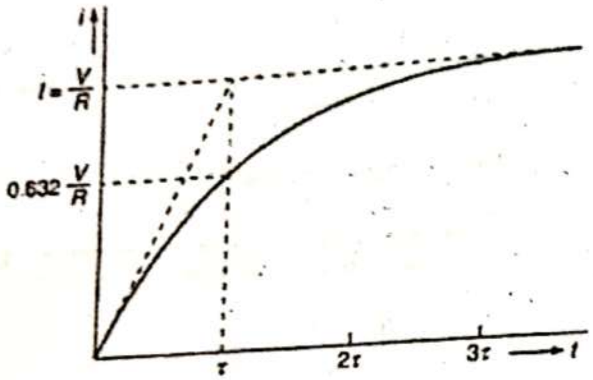


Fig. 4

Consider now the general case with **non-zero initial condition**. then

$$i(0^+) = i(0^-), \text{ non-zero}$$

From Eq. (6) at $t = 0^+$, we find

$$i(0^+) = A + \frac{V}{R} \text{ or } A = i(0^+) - \frac{V}{R}$$

Substituting in Eq. (6), we have the solution

$$i(t) = \left[i(0^+) - \frac{V}{R}\right]e^{-t/\tau} + \frac{V}{R};\ t > 0 \qquad (8)$$

We have already shown that

$$i(\infty) = \frac{V}{R}$$

Then eq. (8) is written in the **general form**

$$i(t) = i(\infty) + [i(0^+) - i(\infty)]e^{-t/\tau}, t > 0 \qquad (9)$$

In the **general functional form**, we replace $i(t)$ by $f(t)$. The complete response is

$$f(t) = f(\infty) + [f(0^+) - f(\infty)]e^{-t/\tau}, t > 0 \qquad (10)$$

From Eq. at $\quad t = 0^+$

$$i(t = 0^+) = i(0^+)$$

Which mean that inductance act as a current source

At $\quad t = \infty$

$$i(t = \infty) = \frac{V}{R}$$

which mean that inductance acts as short-circuit in steady-state.

SOLVED EXAMPLES

Q.1. For the circuit shown in Fig. 5, find $i(t)$ after the switch is closed at $t = 0$.

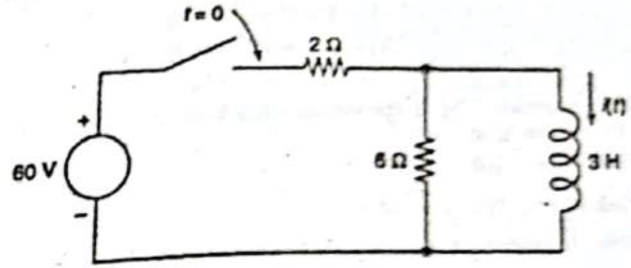


Fig. 5

Solution: Natural Response: After the switch is closed, short-circuiting the voltage source yields the circuit of Fig. 6 from which

$$\tau = L/R_{eq} = 3/1.5 = 2s$$

$$i_n = Ae^{-t/2} \qquad \text{–(i)}$$

Forced Responses: With switch closed and $t \to \infty$, the inductance behaves as a short-circuit. The resultant circuit is shown in Fig. 7 from which it follows that

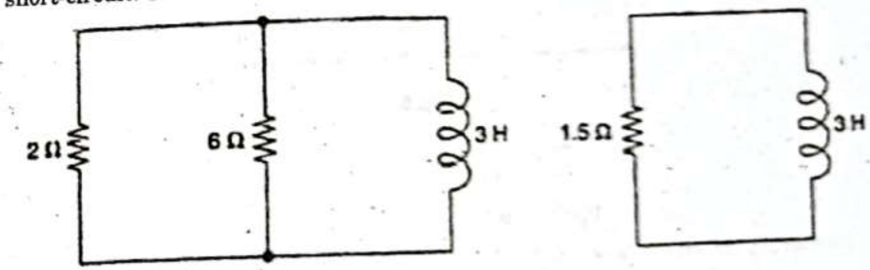


Fig. 6

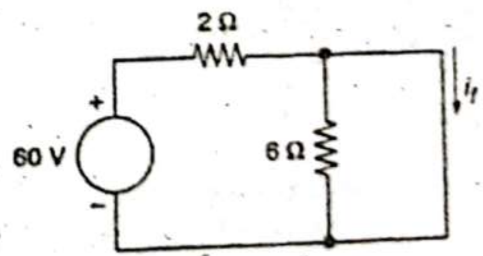


Fig. 7

$$i_f = \frac{60}{2} = 30A \qquad \text{...(ii)}$$

Combining

$$i = i_n + i_f$$

$$i(t) = Ae^{-t/2} + 30;\ t > 0 \qquad \text{...(iii)}$$

Initial Condition before closing the switch $i(0^-) = 0$

$$i(0^+) = i(0^-) = 0$$

$\therefore$

Substituting in Eq. (iii)

$$0 = A + 30 \text{ or } A = -30$$

$$i(t) = 30(1 - e^{-t/2});\ t > 0 \quad \text{...(iv)}$$

$$= 30(1 - e^{-t/2})\ u(t) \quad \text{...(v)}$$

Q.2. In the circuit of Fig. 2, the switch S has been in position '1' for a long time. It is thrown to position '2' at $t = 0$

(a) Find $i(t)$ for $t > 0$

(b) Find $V_L(0^-)$, $V_L(0^+)$ d $\frac{di}{dt}(0^+)$.

Solution: In position '1', steady state has been reached; inductance acts as a short

Then

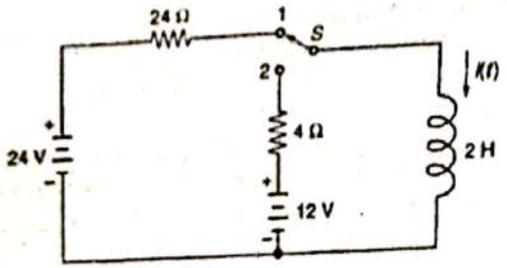


Fig. 8

$$i(0^-) = \frac{24}{24} = 1A$$

$$V_L(0^-) = 0\ V$$

(a) Switch thrown to position '2'

$$\tau = \frac{L}{R} = \frac{2}{4} = 0.5s \quad \text{(i)}$$

$$i_n(t) = Ae^{-2t}$$

$$i_f = \frac{12}{4} = 3A$$

Hence

$$i(t) = Ae^{-2t} + 3 \quad \text{(ii)}$$

$$i(0^+) = i(0^-) = 1\ A$$

Substituting in Eq. (ii)

$$1 = A + 3 \text{ or } A = -2$$

Hence

$$i(t) = (3 - 2e^{-2t});\ t > 0$$

$$= (3 - 2e^{-2t})\ u(t) \quad \text{(iii)}$$

Which is plotted in Fig. 9,

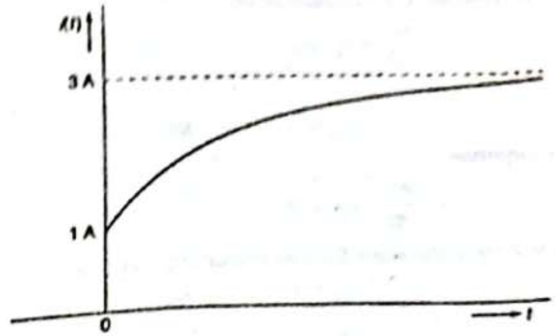


Fig. 9

(b) $v_L(0^-) = 0$, under steady-state inductance acts as a short-circuit. Applying KVL at $t = 0^+$

$$v_L(0^+) + 4i(0^+) = 12$$

$$v_L(0^+) + 4 \times 1 = 12$$

$$v_L(0^+) = 8\ V$$

or

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

As

$$v_L(0^+) = L\frac{di}{dt}(0^+)$$

$\therefore$

$$\frac{di}{dt}(0^+) = \frac{v_L(0^+)}{L}$$

$$= \frac{8}{2} = 4A/s$$

Step Voltage Response of RC Series Circuit: Consider the RC series circuit of Fig. 10. Just before the switch is closed, the capacitance is charged to a voltage of V_0. After the switch is closed, the differential equation governing the capacitance voltage is

$$Ri + v_C = V;\ t > 0$$

but

$$i = C\frac{dv_C}{dt}$$

$\therefore$

$$RC\frac{dv_C}{dt} + v_C = V;\ t > 0 \quad (1)$$

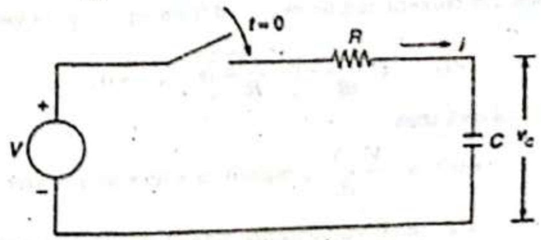


Fig. 10

Natural Response: It is the solution of

$$RC\frac{dv_C}{dt} + v_C = 0$$

which gives

$$V_{Cn} = Ae^{-t/\tau};\ \tau = RC \qquad ...(2)$$

Forced Response

$$RC\frac{dv_C}{dt} + v_C = V$$

Response will have the same form as excitation. Let it be

$$v_{Cf} = V_{Cf}\text{(constant)}$$

substituting in Eq. (1)

$$V_{Cf} = V \qquad ...(3)$$

Combining Eqs. (2) and (3), the complete response is

$$V_C(t) = Ae^{-t/\tau} + V \qquad ...(4)$$

Substituting the initial condition $v_C(0^+) = V_0$

$$V_0 = A + V \text{ or } A = V_0 - V$$

Hence

$$v_C(t) = (V_0 - V)e^{-t/\tau} + V$$
$$= V_0e^{-t/\tau} + V(1 - e^{-t/\tau});\ t > 0 \qquad ...(5)$$

The plot $V_C(t)$ is shown in Fig. 11.

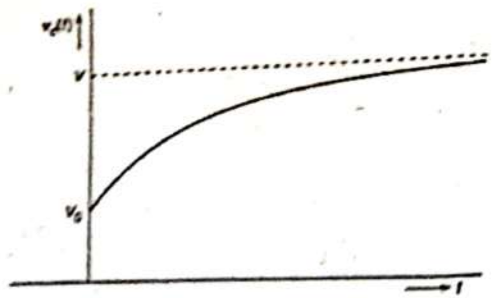


Fig. 11

Observe that $v_C(t)$ of Eq. (5) has the general form

$$f(t) = f(\infty) + [f(0^+) - f(\infty)]e^{-t/\tau};\ t > 0 \qquad ...(6)$$

The expression for current can be obtained from eq. (5) as below

$$i(t) = C\frac{dv_C}{dt} = \left(\frac{V - V_0}{R}\right)e^{-t/\tau};\ t > 0 \qquad ...(7)$$

from which it follows that

$$i(0^+) = \frac{V - V_0}{R};\ \text{capacitance acts as a source of voltage} \qquad ...(8a)$$

$$i(\infty) = 0;\ \text{capacitance acts as an open-circuit} \qquad ...(8b)$$

SOLVED EXAMPLES

Q.1. In the circuit of Fig. the switch has been closed for a long time.

Find the expression for v_C as the switch is thrown open. What is the rate of energy consumption in the 400 Ω resistance at $t = 0^+$?

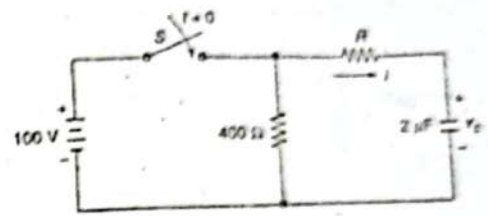


Fig. 12

Solution: It is obvious that $v_C(0^+) = v_C(0^-) = 100V$

After the switch is opened

$$\tau = RC = (400 + 100) \times 2 \times 10^{-6} = 10^{-3}\ s$$

$\therefore$

$$v_C(t) = Ae^{-10^{3}t}$$
$$v_C(0^+) = A = 100V$$

Hence

$$v_C(t) = 100e^{-10^{3}t}$$
$$i(0^+) = \frac{100}{500} = 0.2\ A\ \text{(capacitance acts as a source of 100 V)}$$

$$p(0^+) \text{ in } 400\ \Omega \text{ resistance} = (0.2)^2 \times 400 = 16\ W$$

Step Current Response of *RL* Parallel Circuit: Consider the circuit of Fig. 13.

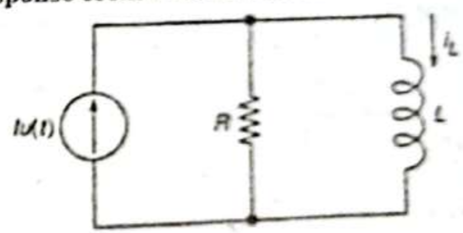


Fig. 13

τ(with current source open-circuited) $= L/R$.

$\therefore$

$$i_{Lf} = Ae^{-t/\tau}$$

i_{Lf} (inductance acts as short-circuit) $= I$

Hence

$$i_L = Ae^{-t/\tau} + I;\ t > 0$$

But

$$i_L(0^+) = 0$$

$\therefore$

$$A = -I$$

Finally

$$i_L(t) = I(1 - e^{-t/\tau});\ t > 0 \qquad (9)$$

Step Current Response of RC Parallel Circuit: Consider the circuit of Fig. 14

τ(with current source open-circuited) = RC

$\therefore$ $$v_{C_n} = Ae^{-t/\tau}$$

Under steady state, capacitance acts as an open-circuit so that all the current passes through R. Therefore

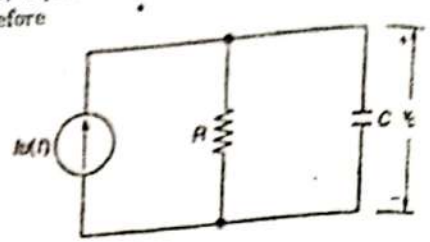


Fig. 14

$$v_{Cf} = RI$$

Hence $$v_C(t) = Ae^{-t/\tau} + RI;\ t > 0$$

But $$v_C(0^+) = V_0 \text{ (say)}$$
$$V_0 = A + RI \text{ or } A = V_0 - RI$$

$\therefore$

Hence $$v_C(t) = (V_0 - RI)e^{-t/\tau} + RI$$
$$= v_0 e^{-t/\tau} + RI\,(1 - e^{-t/\tau});\ t > 0 \quad (10)$$

SOLVED EXAMPLES

Q.1. In the circuit of Fig. 15, the switch S_1 has been closed for a long time. At $t = 0$, the switch S_2 is closed.

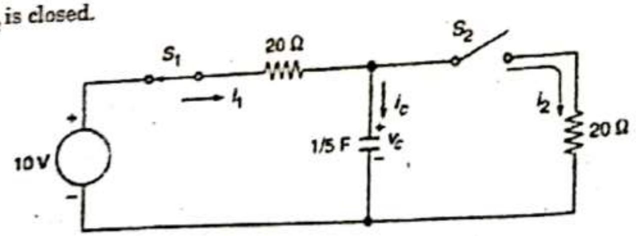


Fig. 15

(a) Without solving for $v_C(t)$, find $v_C(0^+)$, $i_C(0^+)$, $v_C(\infty)$ and $i_C(\infty)$

(b) Derive an expression for $v_C(t)$ and check the result of part (a)

Solution:

(a) Before S_2 is closed, the capacitance is fully charged.

$\therefore$ $$v_C(0^+) = v_C(0^-) = 10\text{ V}$$

Applying KVL and KCL at $t = 0+$,

KVL (left loop): $-10 + 20\,i_1(0^+) + v_C(0^+) = 0$

or $$i_1(0^+) = 0$$

KVL (right loop): $-v_C(0^+) + 20\,i_2(0^+) = 0$

or $$i_2(0^+) = \frac{10}{20} = 0.5\,A$$

Using KCL at the node

$\therefore$ $$i_C(0^+) + i_2(0^+) = i_1(0^+) \Rightarrow i_C(0^+) = 0 - 0.5 = -0.5\,A$$

At $t = \infty$, capacitance acts as open-circuit, therefore

$$i_C(\infty) = 0$$
$$v_C(\infty) = 10 \times \frac{20}{40} = 5V$$

(b) After closure S_2

To find τ, Short-circuit voltage source. The circuit is shown in Fig. 16.

Then $$\tau = RC = 10 \times \frac{1}{5} = 2s$$

$\therefore$ $$v_{C_n} = Ae^{-t/2}$$

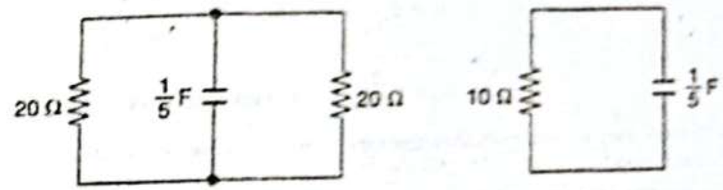


Fig. 16

To find forced response, assume capacitance as open-circuit.

$$v_{Cf} = 10 \times \frac{20}{40} = 5V$$

Hence $$v_C(t) = Ae^{-t/2} + 5;\ t > 0$$

But $$v_C(0^+) = 10V$$
$$10 = A + 5$$

or $$A = 5$$

$\therefore$ $$v_C(t) = 5(1 + e^{-t/2});\ t > 0 \quad (i)$$

Also $$i_C(t) = \frac{1}{5} \times 5 \frac{d}{dt}(1 + e^{-t/2}) = 0.5e^{-t/2};\ t > 0 \quad (ii)$$

All the result of part (a) are borne out by Eqs. (i) and (ii).

LC Circuit: If R is assumed infinite in the parallel circuit of RLC or R is assumed zero in the series circuit of RLC, the describing equation of the resulting LC circuit (Fig. 17) is a second order differential equation in which the first order derivative term is absent (case of zero damping). It immediately follows (with $R = \infty$) that

$$\frac{d^2v(t)}{dt^2} + \frac{1}{LC}v(t) = 0 \quad ...(1)$$

Let $$v(t) = Ae^{st}$$

Which gives

$$Ae^{st}\left(s \quad \overline{LC}\right) = 0 \qquad ...(2)$$

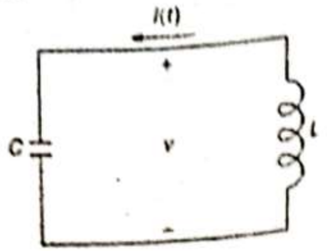


Fig. 17

Non-trivial solution is given by

$$s^2 + \frac{1}{LC} = 0 \qquad ...(3)$$

From which

$$S = \pm j\frac{1}{\sqrt{LC}} = \pm j\omega_0 \qquad ...(4)$$

where

$$\omega_0 = \frac{1}{\sqrt{LC}} = \text{resonant frequency}$$

It is seen that in contrast that the term α which causes exponential decay of the response is absent.

The natural response is now given by

$$v(t) = A_1e^{j\omega_0 t} + A_2e^{-j\omega_0 t}$$
$$= (B_1 \cos \omega_0 t + B_2 \sin \omega_0 t) \qquad ...(5)$$

Thus $v(t)$ (and so also $i(t)$) is a continuous (non-decaying) sinusoidal oscillation.

In practical circuit, R is never zero so that dissipation occurs and the oscillation cannot be sustained but decays slowly. First few cycles would correspond to nearly sinusoidal oscillation.

Assume LC combination such that

$$\omega_0 = \frac{1}{\sqrt{LC}} = \sqrt{13} \qquad (i)$$

Then

$$v(t) = B_1 \cos\sqrt{13}t + B_2 \sin\sqrt{13}t \qquad (ii)$$

Let the capacitor be initially charged so that

$$v_C(0^+) = V_C \qquad (iii)$$

Because the inductance acts as an open-circuit

$$i(0^+) = 0 \qquad (iv)$$

Substituting Eq. (iii) in Eq. (i)

$$V_C = B_1 \qquad (v)$$

From Eq. (ii)

$$i(t) = C\frac{dv(t)}{dt} = C(-\sqrt{13}B_1 \sin\sqrt{13}t + \sqrt{13}\, B_2 \cos\sqrt{13}t) \qquad (vi)$$

By use of Eq. (iv) it follws that

$$B_2 = 0 \qquad (vii)$$

Hence

$$v(t) = V_C \cos\sqrt{13}\, t \qquad (viii)$$

Then

$$i(t) = C\frac{d}{dt}(V_C \cos\sqrt{13}\, t)$$
$$= -\sqrt{13}\, CV_C \sin\sqrt{13}\, t, \sqrt{13} = \frac{1}{\sqrt{LC}}$$
$$= -\frac{V_C}{\sqrt{L/C}} \sin\sqrt{13}\, t \qquad (ix)$$

Step Response: This will be illustrated by means of examples.

Q.1. Solve for $v_C(t)$ in the circuit of Fig. 18. The circuit is initially quiescent (zero initial conditions).

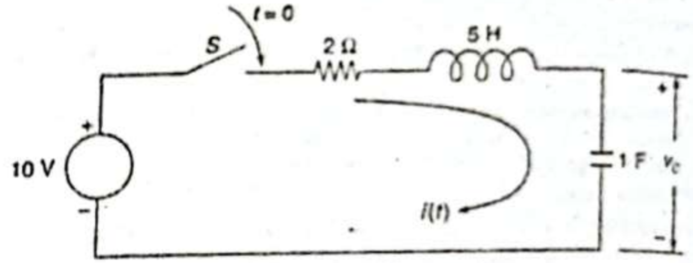


Fig. 18

Solution The describing differential equation of the circuit is

$$2i + 5\frac{di}{dt} + v_c = 10;\ t > 0 \qquad (i)$$

But

$$i = 1 \times \frac{dv_C}{dt}$$

and

$$\frac{di}{dt} = \frac{d^2v_C}{dt}$$

Substituting in Eq. (i)

$$2\frac{dv_C}{dt} + 5\frac{d^2v_C}{dt^2} + v_C = 10$$

or

$$\frac{d^2v_C}{dt} + \frac{2}{5}\frac{dv_C}{dt} + \frac{1}{5}v_C = 2 \qquad (ii)$$

$$\frac{d^2v_C}{dt^2} + \frac{2}{5}\frac{dv_C}{dt} + \frac{1}{5}v_C = 0$$

UNIT - II: AC CIRCUITS

AC Fundamentals

Alternating Quantity: An alternating quantity (V or I) is one which changes continuously in magnitude and alternates in direction at regular intervals of time, it rises from zero to maximum positive value, falls to zero increase to maximum value in the reverse direction and falls back to zero again.

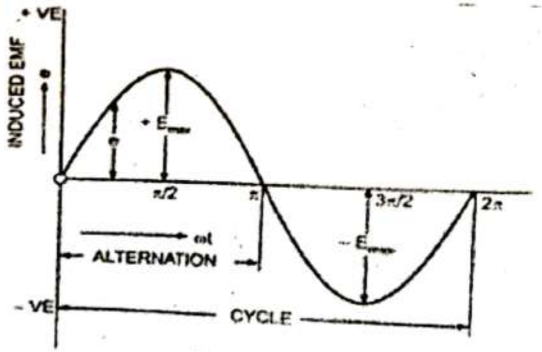
Sinusoidal Quantities (EMF, Voltage or Current): Reasons or advantages of using sinusoidal voltage and current are as follows:

1. The sinusoidal waveform from generation to utilization remains the same.
2. There are no oscillations in develop torque in 3-phase machines and absence of noise in operation.
3. According to Fourier analysis, non-sinusoidal voltages are harmful to the system in term of increased losses in generators, motors, transformers, transmission & distribution system. So, using sinusoidal voltages, the losses can be reduced.
4. Non-sinusoidal voltages provide more interference (or noise) to nearby communication circuits.

Terminology

1. **Waveform:** The shape of the curve of the voltage or current when plotted against time as abscissa is called the waveform.
2. **Instantaneous Value:** The value of alternating quantity at any particular instant is called the instantaneous value. It is denoted by small italic letter such as *e* for emf, *v* for voltage, *i* for current.
3. **Alternation and Cycle**

Alternation: It is a periodic wave with one complete set of positive values or negative values. One alternation corresponds to π radians.



Cycle: It is a periodic wave with one complete set of positive values and negative values. One cycle corresponds to 2π radians.

3. **Time Period and Frequency**

Time period: Time taken in second by an alternating quantity to complete one cycle is known as Time Period or Periodic Time, denoted by 'T'

Frequency: Number of cycle complete per second by an alternating quantity is known as Frequency, denoted by 'f'. Its unit is Hertz (Hz).

5. **Angular Velocity:** Each cycle spans 2π radians and if this quantity is divided by time period, angular velocity of sine wave is obtained.

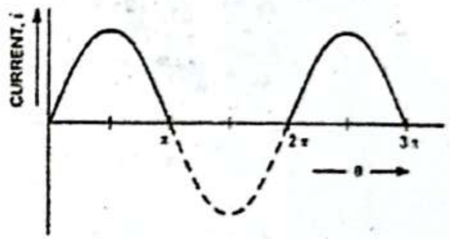
$$\therefore \quad \omega = \frac{2\pi}{T} = 2\pi f \text{ radians / sec}$$

6. **Electric Time Degrees and Mechanical Degrees**

Electrical Time Degrees: In circuit network, one complete cycle of voltage or current is termed as 360 electrical degrees or 2π electrical radians.

Mechanical Degrees: The arc through which a coil of dynamo must rotate in order to generate one cycle of emf is called mechanical degree.

7. **Amplitude:** The maximu, value, positive or negative, which an alternating quantity attains during one cycle, is called the amplitude of the alternating quantity. The amplitude of an alternating emf is designated by E_{max} or E_m, amplitude of an alternating voltage is designated by V_{max} or V_m, amplitude of an alternating current is designated by I_{max} or I_m.



SOLVED EXAMPLES

Q.1. ***Refers to Q.3(b), Page: 4–2016***

Average and RMS (or Effective) Values of Sinusoidal Quantity:

Refer to Q.4(a), Page- 30, 2015

Form Factor and Peak factor: ***Refer to Q.1(c), Page- 1, 2017***

Significance of From Factor: From factor is a means of relating the mean value with the rms value of alternating quantity. It is useful in determination of rms values of the alternating quantities whose average values over half a period can be determined conveniently.

Significance of Peak Factor: Peak factor of an alternating quantity is very essential in connection with determining the dielectric strength since the dielectric stress developed in an insulating material is proportional to the peak value of the voltage applied to it.

Average and RMS (or Effective) Values of Half-Wave Rectified Alternating Quantity

Average value of Alternating Current or Voltage: Instantaneous values of sinusoidal current is given by

$$i = I_m \sin \omega t$$

Considering the complete cycle, we have

$$I_{avg} = \frac{\textit{Area of complete cycle}}{2\pi}$$

$$= \frac{1}{2\pi}\int_0^{\pi} i \, d(\omega t) = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t)$$

$$= \frac{I_m}{2\pi}[-\cos\omega t]_0^\pi = \frac{I_m}{\pi}$$

$\therefore$ $$I_{avg} = 0.318 I_m$$

Similarly $$E_{avg} = 0.318\, E_m$$

RMS Value of Sinusoidal Current or Voltage: Instantaneous value of sinusoidal current is given by

$$i = I_m \sin\omega t$$

$$I^2_{rms} = \frac{\textit{Area of complete cycle of } i^2}{\pi}$$

$$= \frac{1}{2\pi}\int_0^\pi i^2\, d(\omega t) = \frac{1}{2\pi}\int_0^\pi I^2_m \sin^2\omega t\, d(\omega t)$$

$$= \frac{I^2_m}{4\pi}\int_0^\pi (1-\cos 2\omega t)\, d(\omega t) = \frac{I^2_m}{4\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^\pi$$

$$= \frac{I^2_m}{4\pi}\times\pi = \frac{I^2_m}{4},$$

$\therefore$ $$I_{rms} = \frac{I_m}{2}$$

Similarly $$E_{rms} = \frac{E_m}{2}$$

Form factor, $$K_f = \frac{E_{rms}}{E_{avg}} = \frac{E_m/2}{E_m/\pi} = \frac{\pi}{2} = 1.57$$

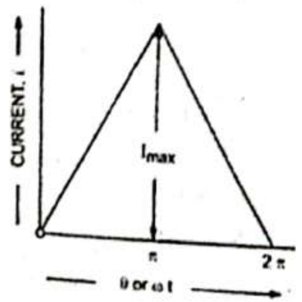
Peak factor, $$K_p = \frac{E_{max}}{E_{rms}} = \frac{E_m}{E_m/2} = 2$$

Average and RMS (or Effective) Values of a Triangular Waveform

Average Value of Alternating Current or Voltage: Let the maximum value of the current be Imax amperes.

The expression for the instantaneous current can be written as

$$i = \frac{I_{max}}{\pi}\theta \qquad \textit{for } 0 < \theta < \pi$$



Considering the half-cycle, we have

$$I_{avg} = \frac{1}{\pi}\int_0^\pi i\, d\theta = \frac{1}{\pi}\int_0^\pi \frac{I_{max}}{\pi}\theta\, d\theta = \frac{I_{max}}{\pi^2}\left[\frac{\theta^2}{2}\right]_0^\pi = \frac{I_{max}}{2}$$

$\therefore$ $$I_{avg} = \frac{I_{max}}{2}$$

RMS Value of Sinusoidal Current or Voltage

$$I^2_{rms} = \frac{1}{\pi}\int_0^\pi i^2\, d\theta = \frac{1}{\pi}\int_0^\pi\left(\frac{I_{max}}{\pi}\theta\right) d\theta = \frac{I^2_{max}}{\pi^3}\int_0^\pi \theta^2\, d\theta = \frac{I^2_{max}}{\pi^3}\left[\frac{\theta^3}{3}\right]_0^\pi = \frac{I^2_{max}}{3}$$

$\therefore$ $$I_{rms} = \frac{I_{max}}{\sqrt{3}}$$

Form factor, $$K_f = \frac{E_{rms}}{E_{avg}} = \frac{E_m/\sqrt{3}}{E_m/2} = \frac{2}{\sqrt{3}} = 1.155$$

Peak factor, $$K_p = \frac{E_{max}}{E_{rms}} = \frac{E_m}{E_m/\sqrt{3}} = \sqrt{3} = 1.732$$

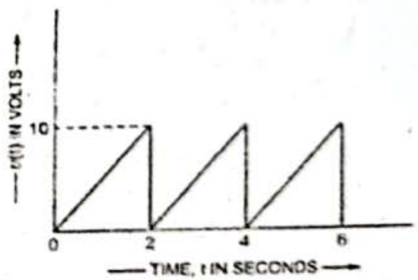
SOLVED EXAMPLE

Q.1. Find average and rms values of the waveform $v(t)$ in Fig

Sol. The given wave is triangular wave of peak value of 10 V.

$$V_{avg} = \frac{V_{max}}{2} = \frac{10}{2} = 5V$$

$$V_{rms} = \frac{V_{max}}{\sqrt{3}} = \frac{10}{\sqrt{3}} = 5.77V$$



Q.2. ***Refer to Q.4(a), Page: 20–2018***

Q.3. ***Refer to Q.4(a), Page: 30–2015***

Q.4. ***Refer to Q.4(a), Page: 4–2016***

Q.5. ***Refer to Q.3(b), Page: 6–2015***

Phase or Graphical Representation of Alternating Quantities

Phasor: For solution of ac problem, it is advantageous to represent a sinusoidal quantity by a line of definite length rotating in counter-clockwise direction with the same angular velocity as that of the sinusoida; quantity.

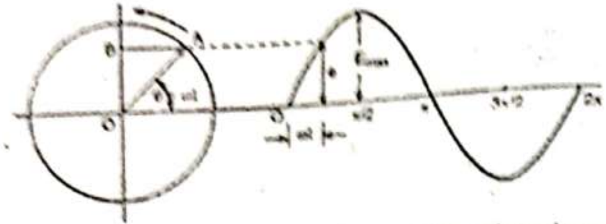
Such a rotating line is called the phasor.

Let $e = E_{max} \sin \omega t$

In Fig., $OA = E_{max}$

OB = *Projection of OA on y – axis*

= *inatananeous value of e*



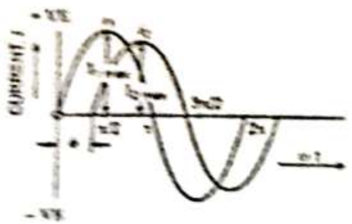
If length of the phasor is taken equal to the rms value, then the projection of th rotating phasor on the vertical axis will not give the instantaneous value.

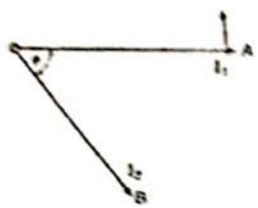
Phase: It is the fraction of the time period of that alternating current that h elapsed since the current last passed through the zero position of reference.

Phase Angle: The angle made by the phasor representing the quantity makes wi the reference line.

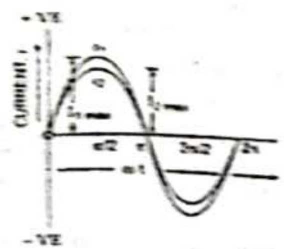
Phase Difference: It is measured by the angular distance between the poin where two curves cross the base or reference line in the same direction.

Case1: $i_1 = I_1 \sin \omega t, \quad i_2 = I_2 \sin(\omega t - \phi)$

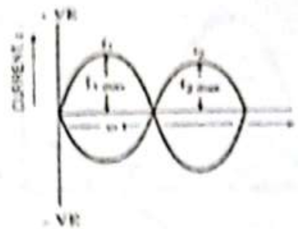




Case 2: $i_1 = I_1 \sin \omega t \quad , i_2 = I_2 \sin \omega t$



Case 3: $i_1 = I_1 \sin \omega t, \quad i_2 = I_2 \sin(\omega t - 180)$



Apparent, Active, Reactive Power Factor ***(Refer to Q.1(c), Page- 10, 2017)***

Power factor: Power factor may be defined as

(i) Cosine of the phase angle between voltage and current, or

(ii) the ratio of the resistance to impedance, or

(iii) The ratio of true power to apparent power.

Physical significance of power factor in AC system

(Refer to Q.1(b), Page: 7-2016)

SOLVED EXAMPLE

Q.1. ***Refer to Q.1(b), Page: 14-2018***

Q.2. ***Refer to Q.3(b), Page: 5-2017***

ANALYSIS OF SINGLE-PHASE AC CIRCUITS

1. Purely resistive Circuits: If the circuit is purely resistive or non-inductive, no reactance emf (self-induced or back emf) is set-up and therefore, whole of the applied voltage is utilized in overcoming the ohmic resistance of the circuit.

Consider an ac circuit containing a resistance R ohms connected across a sinusoidal voltage $v = V_m \sin \omega t$

$$\therefore \quad v = iR$$

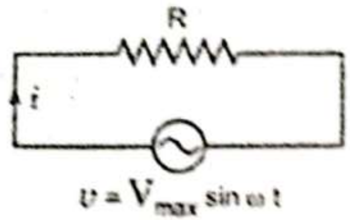


Fig. 1 Circuit Diagram

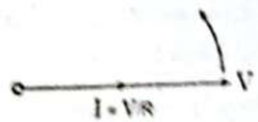


Fig. 2 Phasor Diagram

$$i = \frac{v}{R} = \frac{V_m \sin \omega t}{R} \quad ... \rightarrow i = I_m \sin \omega t$$

where, $I_m = \frac{V_m}{R}$

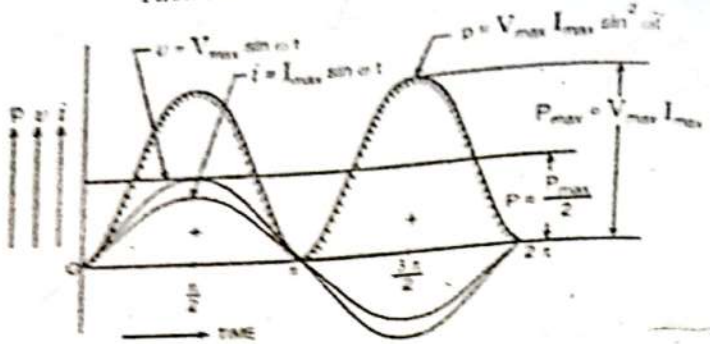


Fig. 3 Wave Diagram

Power in purely Resistive Circuit: Instantaneous Power delivered to the circuit is given as

$$p = v.i = V_m \sin \omega t \,.\, I_m \sin \omega t$$

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

$$= \frac{V_m I_m}{2} - \frac{V_m I_m}{2}\cos 2\omega t$$

Average power, $P = Avg. of \frac{V_m I_m}{2} - Avg. of \frac{V_m I_m}{2}\cos 2\omega t$

$$= \frac{V_m I_m}{2} - 0 = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}$$

$$p = V.I$$

where, V and I are the rms values of applied voltage and current respectively.

2. Purely Inductive Circuits: An inductive is a coil with or without iron core having negligible resistance (practically small resistance). However, a coil of thick copper wire wound on a laminated iron core has negligible resistance is known as choke coil.

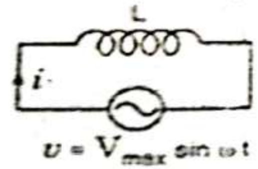


Fig. 1

Let the applied voltage be $v = V_m \sin \omega t$ and

Self-induced of coil = L Henry

Self-induced emf in the coil, $e = -L\frac{di}{dt}$

Since, applied voltage at every instant is equal and opposite to the self-induced emf i.e., $v = -e$

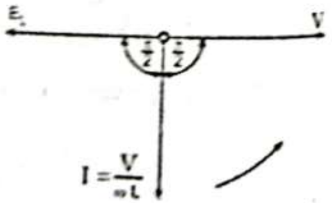


Fig. 2

$$\therefore \quad V_m \sin \omega t = -\left(-L\frac{di}{dt}\right)$$

$$di = \frac{V_m}{L}\sin \omega t \, dt$$

$$i = \frac{V_m}{\omega L}(-\cos \omega t) + A,$$

where A is constant of integration

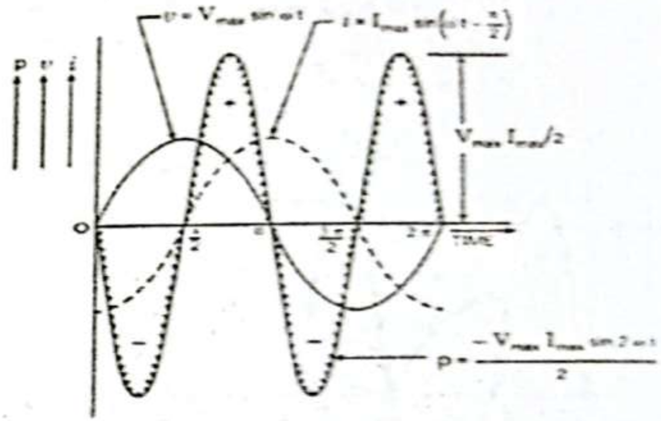
From initial conditions, $A = 0$

$$\therefore \quad i = -\frac{V_m}{\omega L}\cos \omega t = \frac{V_m}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

At $\omega t = \frac{\pi}{2}$, $i = 0$ *and at* $\omega t = \pi, i = \frac{V_m}{\omega L} = I_m$ (maximum value)

$$i = I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

where, $I_m = \frac{V_m}{\omega L} = \frac{V_m}{X_L}$, *$X_L$ is inductive resistance in Ω*



Power in Purely Inductive Circuit

Instanttaneous power, $p = v.i = V_m \sin \omega t \,.\, I_m \sin\left(\omega t - \frac{\pi}{2}\right)$

$$= -V_m I_m \sin \omega t \cos \omega t = -\frac{V_m I_m}{2}\sin 2\omega t$$

The power measured by wattmeter is the average value of 'p' which is zero since average of a sinusoidal quantity of double frequency over a complete cycle is zero. Hence, in a purely inductive circuit, power absorbed is zero

$P_{avg=0}$, Energy stored, $W_L = \frac{1}{2}LI_m^2$

3. Purely Capacitive Circuits: Let the applied voltage be $v = V_m \sin \omega t$ and Capacitance of a capacitor = C

Farad

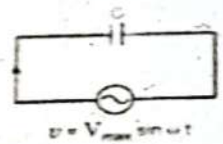


Fig. 1 Circuit Diagram

The instantaneous charge is –

$$q = C \,.\, v = C\,V_m \sin \omega t$$

As current is rate of change of charge, we have

$$i = \frac{dq}{dt}$$

$$i = \frac{d[CV_m \sin \omega t]}{dt} = \omega C V_m \cos \omega t$$

$$i = \frac{V_m}{1/\omega C}\sin\left(\omega t + \frac{\pi}{2}\right) \qquad \ldots \rightarrow i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

where, $I_m = \frac{V_m}{1/\omega C} = \frac{V_m}{X_C}$

where, X_C is a Capacitive Reactance in Ω

Power in purely Capacitive Circuit

Instantaneous power,

$$p = v.i = V_m \sin\omega t \, .I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$= V_m I_m \sin\omega t \cos\omega t = \frac{V_m I_m}{2}\sin 2\omega t$$

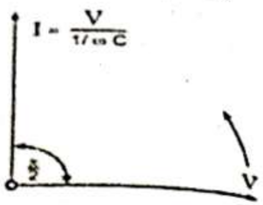


Fig. 2 Phasor Diagram

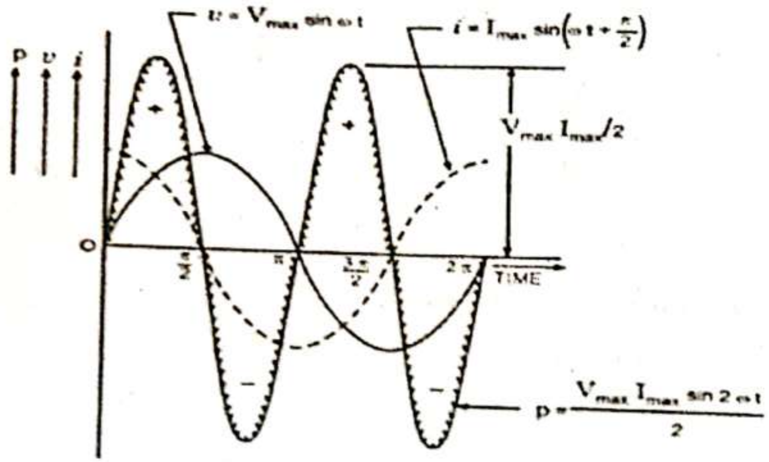


Fig. 3 Wave Diagram

the power measured by wattmeter is the average value of 'p' which is zero since average of a sinusoidal quantity of double frequency over a complete cycle is zero. Hence, in a purely capacitive circuit, power absorbed is zero

$$P_{avg} = 0 \;, \textit{Energy stored}, W_C = \frac{1}{2}CV^2_m$$

SOLVED EXAMPLE

Q.1. ***Refer to Q.4(a), Page: 21-2017***

4. Resistance-Inductance (R-L) Series Circuit

Consider an ac circuit consisting of resistance of R ohms and inductance of L henrys connected in series.

Let the supply frequency be 'f' and current flowing through the circuit be of 'I' amperes (rms value).

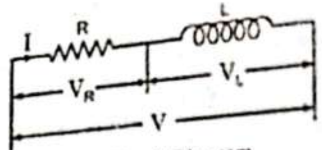


Fig. 1 Circuit Diagram

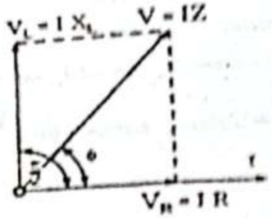


Fig. 2 Phasor Diagram

Voltage drop across resistance, $V_R = I\,R$ in phase with current.

Voltage drop across inductance, $V_L = I\,X_L = I\omega L$ leading current I by $\pi/2$ radians

From the phasor diagrams, the applied voltage is give as-

$$V = \sqrt{V^2_R + V^2_L} = \sqrt{(IR)^2 + (IX_L)^2}$$

$$= I\sqrt{R^2 + X^2_L} = I.Z$$

where, $Z = Z = \sqrt{R^2 + X^2_L}$ and Z is know as impedance

Also, $\tan\phi = \frac{V_L}{R_L} = \frac{IX_L}{IR} = \frac{X_L}{R} = \frac{\omega L}{R} \qquad \ldots \rightarrow \qquad \phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

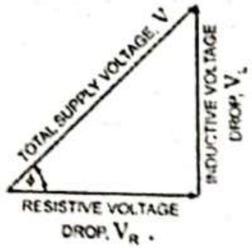


Fig. 3 Voltage Triangle

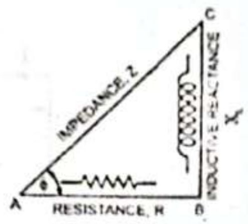


Fig. 4 Impedance Triangle

Let applied voltage voltage be $v = V_m \sin\omega t$,then

$i = I_m \sin(\omega t - \phi)$, *where* $I_m = \frac{V_m}{Z}$ *and* $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

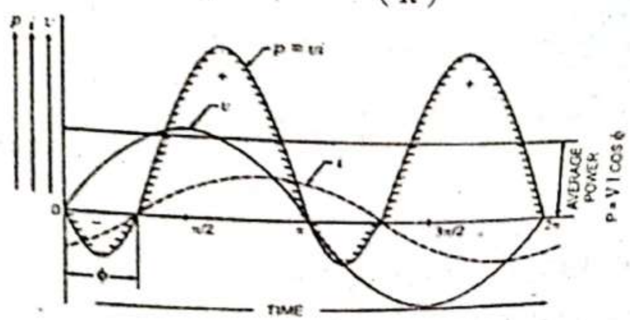


Fig. 5 Wave Diagram

Power in R-L Circuit

instantaneous power,

$p = v.i = v = V_m \sin \omega t . I_m \sin(\omega t - \phi)$

$$\frac{V_m I_m}{2}[2\sin\omega t . \sin(\omega t - \phi)] = \frac{V_m I_m}{2}[\cos\phi - \cos(2\omega t - \phi)]$$

$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t - \phi)$$

Average Power, $P = \frac{V_m I_m}{2}\cos\phi - 0 = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\phi$

$$P = VI\cos\phi$$

So, the power in an ac circuit is the product of rms values of voltage and current and cosine of the phase angle between voltage and current.

5. Resistance-Capacitance (R-C) Series Circuit: Consider an ac circuit consisting of resistance of R ohms and capacitance of C farads connected in series.

Let the supply frequency be 'f' and current flowing through the circuit be of 'I' amperes (rms value).

Voltage drop across resistance, $V_R = IR$ in phase with current.

Voltage drop across capacitance, $V_L = IX_C = \frac{I}{\omega C}$ lagging current I by $\frac{\pi}{2}$ radians

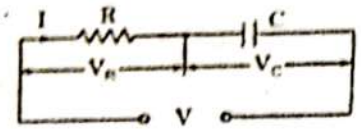


Fig. 1 Circuit Diagram

From the phasor diagram, the applied voltage is give as-

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{(IR)^2 + (IX_C)^2}$$

$$= I\sqrt{R^2 + X_C^2} = I.Z$$

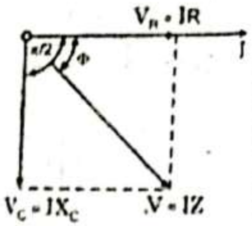


Fig. 2 Phasor Diagram

where, $Z = \sqrt{R^2 + X_C^2}$ and Z is know as impedance

Also, $\tan\phi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R} = \frac{1}{\omega CR}$

$$\phi = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

Let applied voltage be $v = V_m \sin t$, then

$i = I_m \sin(\omega t + \phi)$, *where* $I_m = \frac{V_m}{Z}$ *and* $\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$

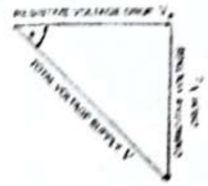


Fig. 3 Voltage Triangle

Fig. 4 Impedance Triangle

Power in R-C Circuit

Instantaneous Power, $p = v.i = v = V_m \sin\omega t . I_m \sin(\omega t + \phi)$

$$= \frac{V_m I_m}{2}[2\sin\omega t . \sin(\omega t + \phi)] = \frac{V_m I_m}{2}[\cos\phi - \cos(2\omega t + \phi)]$$

$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}(2\omega t + \phi)$$

Average power,

$$p = \frac{V_m I_m}{2}\cos\phi - 0 = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\phi$$

$$P = VI\cos\phi$$

So, the power in an ac circuit is the product of rms values of voltage and current and cosine of the phase angle between voltage and current.

6. Resistance-Inductance-Capacitance (R-L-C) Series Circuit: Consider an ac circuit consisting of resistance of R ohms, inductance of L henry and capacitance of C farads connected in series.

Let the supply frequency be 'f' and current flowing through the circuit be of 'I' amperes (rms value)

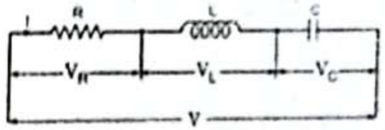


Fig. 1 Circuit Diagram

Voltage drop across resistance, $V_R = IR$ in phase with current.

Voltage drop across inductance, $V_L = I\,XL = I\omega L$ leading current I by $\frac{\pi}{2}$ radians

Voltage drop across capacitance, $V_L = I\,XC = \frac{1}{\omega C}$ lagging current I by $\frac{\pi}{2}$ radians

From the phasor diagram, the applied voltage is give as-

(Assuming $V_L > V_C$)

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

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

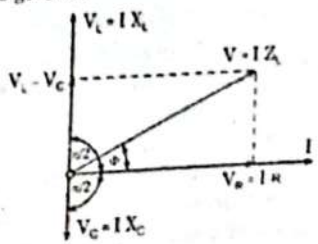


Fig. 2 Phasor Diagram

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

and Z is known as impedance of the circuit.

Also, $\tan\phi = \dfrac{V_L - V_C}{V_R} = \dfrac{IX_L - IX_C}{IR}$

$$= \frac{X_L - X_C}{R} = \frac{X}{R}$$

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

ϕ will be positive if $X_L > X_C$ and ϕ will be nagative if $X_L < X_C$

Let applied voltage be $v = V_m \sin \omega t$, then

$i = I_m \sin(\omega t \pm \phi)$, where $I_m = \dfrac{V_m}{Z}$ and $\phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$

Power in R-L-C Circuit

instantaneous power, $p = v.i = V_m \sin \omega t \,.\, I_m \sin(\omega t \pm \phi)$

$$= \frac{V_m I_m}{2}[2\sin\omega t.\sin(\omega t + \phi)] = \frac{V_m I_m}{2}[\cos\phi - \cos(2\omega t \pm \phi)]$$

$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t \pm \phi)$$

Average Power, $p = \dfrac{V_m I_m}{2}\cos\phi - 0 = \dfrac{V_m}{\sqrt{2}}\dfrac{I_m}{\sqrt{2}}\cos\phi$

$$P = VI\cos\phi$$

So, the power in an ac circuit is the product of rms values of voltage and current and cosine of the phase angle between voltage and current.

SOLVED EXAMPLE

Q.1. *Refer to Q.4(b), Page: 21–2018*

Q.2. *Refer to Q.5(a), Page: 22–2018*

Q.3. *Refer to Q.4(b), Page: 22–2017*

Q.4. *Refer to Q.5(b), Page: 23–2017*

Q.5. *Refer to Q.5(b), Page: 33–2015*

Q.6. *Refer to Q.3(b), Page: 16–2015*

Q.7. *Refer to Q.3(b), Page: 14–2015*

Q.8. *Refer to Q.1(d), page: 2–2015*

Q.9. *Refer to Q.4(b), Page: 6–2017*

Resonance in R-L-C Circuits

- Resonance is the term employed for describing the steady-state operation of a circuit at that frequency for which the resultant response is in the time phase with source function despite the presence of energy storing elements.
- For resonance, there must be two types of independent energy-storing elements capable of intercharging energy between them. For L & C.
- Under the condition of resonance, a network becomes purely resistive in its effects, and the voltage & current in the network are in phase.

1. Series or Voltage Resonance: Under the condition of resonance, a network becomes purely resistive in its effects, and the voltage and current in the network are in phase. For the resonance condition to occur, X_L and X_C should be made equal.

Consider an ac circuit containing a resistance R, an inductance L and a capacitance C connected in series.

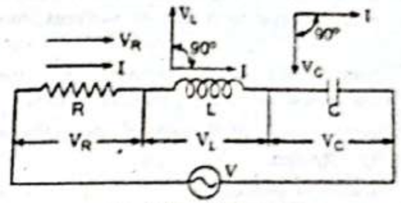


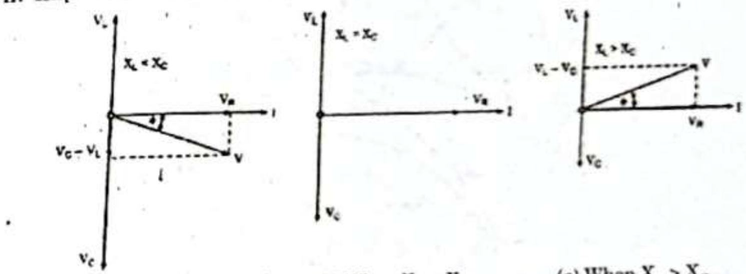
Fig. 1 Circuit Diagram

Impedance of the circuit, $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2}$

If for some frequency of applied voltage, $X_L = X_C$ in magnitude, then

i. Net reactance is zero i.e. $X = 0$

ii. Impedance of the circuit, $Z = R$.



(a) When $X_L < X_C$ (b) When $X_L = X_C$ (c) When $X_L > X_C$

Fig. 2. Phasor Diagram

iii. The current flowing through the circuit is maximum and in phase with applied voltage. The magnitude of the current will be equal to $\dfrac{V}{R}$.

iv. The voltage drop across the inductance is equal to the voltage drop across capacitance and is maximum.

v. The power factor is unity.

vi. The power expended = VI watts.

When this condition exists, the circuit is said to be in resonance and the frequency at which it occurs is known as *resonant frequency*.

Let the resonant frequency be f_r, then

$X_L = \omega L = 2\pi f_r L$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi f_r C}$

$X_L = X_C$ (Condition for resonance)

$$2\pi f_r L = \frac{1}{2\pi f_r C} \quad \ldots \rightarrow \quad f_r = \frac{1}{2\pi\sqrt{LC}} \text{ or } \omega_r = \frac{1}{\sqrt{LC}}$$

Therefore, the value of resonance frequency depends on the parameters of the two energy-storing elements i.e. L and C.

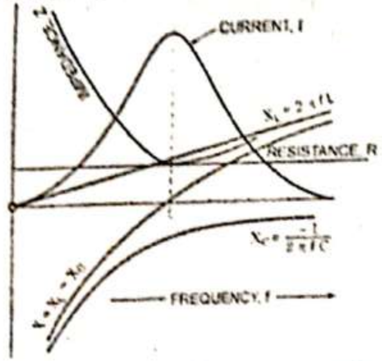
Reason of Voltage Resonance

- When the circuit in resonance, the current is too large and will produce large voltage drop across inductance & capacitance, which will be equal in magnitude but opposite in phase, and each may be several times greater than applied voltage.
- If resistance R would have not been present in the circuit, such a circuit would act like a short-circuit to currents of frequency to which it resonates.
- Since the voltage is maximum, it is called the Voltage Resonance.

Reason of Acceptor Circuit

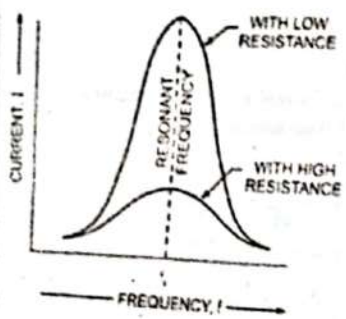
- The series resonance is also called an Acceptor Circuit because such a circuit accepts currents at one particular frequency but rejects currents of other frequencies.
- Such circuits are used in Radio Receivers.

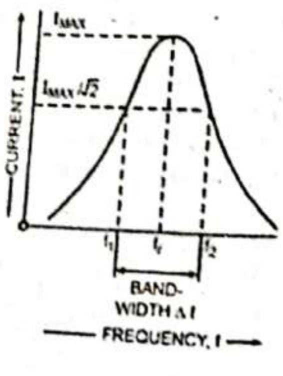
Graphical Representation of Series Resonance



Derivation of bandwidth and quality factor for a series RLC circuit

Bandwidth: The half-wave bandwidth of a circuit is given by the band of frequencies which lies between two points on either side of f_0 where current falls to $\frac{I_0}{\sqrt{2}}$. Narrower the bandwidth, higher the selectivity of the circuit and vice-versa. As shown in Fig., the half power bandwidth is given by





$$\Delta f = f_2 - f_1$$

where, f_1 and f_2 are the corner frequencies.

Actual power input at f_1 and f_2,

$$p = I^2R = \left(\frac{I_{max}}{\sqrt{2}}\right)^2 .R = \frac{I^2_{max}R}{2} = \frac{1}{2}P_{max}$$

$$P = \frac{1}{2} \times \textit{power input at resonance}$$

Therefore, f_1 and f_2 at the limits of bandwidth are called half-power points on the frequency scale, and the corresponding value of the bandwidth is termed as half-power bandwidth (B_{hp}) or – 3 dB Bandwidth.

Derivation: The impedance of the turned circuit must be $\sqrt{2}$ times its impedance at resonance so that the current is $\frac{I_{max}}{\sqrt{2}}$. But the impedance at resonance, $X = R$ so at half-power points, the impedance is $\sqrt{2}R$.

$$Z = \sqrt{R^2 + X^2} \quad \ldots\rightarrow \quad \sqrt{2}R = \sqrt{R^2 + X^2} \ \ldots\rightarrow \quad X = R$$

The reactance at the lower half-power frequency is given as–

$$X_1 = \omega_1 L - \frac{1}{\omega_1 C} = -R$$

Here, minus sign signifies that below resonance, the capacitive reactance exceeds the inductive reactance. The above equation may also be re-written as–

$$\omega^2_1 + \frac{R}{L}\omega_1 - \frac{1}{LC} = 0$$

$$\omega 1 = \frac{-R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} = -\alpha \pm \sqrt{\alpha^2 + \omega^2_r}$$

where, $\alpha = \frac{R}{2L}$, $\omega_r = \sqrt{\frac{1}{LC}}$

The equation for the lower half-power frequency is

$$\omega_1 = -\alpha + \sqrt{\alpha^2 + \omega^2_r}$$

(negative frequency is meaingless, so discarded)

The reactance at the upper half-power frequency is given as–

$$X_2 = \omega_2 L - \frac{1}{\omega_2 C} = R$$

Here, minus sign signifies that below resonance, the capacitive reactance exceeds the inductive reactance. the above equation may also be re-written as –

$$\omega^2_2 - \frac{R}{L}\omega_2 - \frac{1}{LC} = 0$$

$$\omega_2 = \frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} = \alpha \pm \sqrt{\alpha^2 + \omega^2_r}$$

where, $\alpha = \frac{R}{2L}$, $\omega_r = \sqrt{\frac{1}{LC}}$

The equation for the upper half-power frequency is

$$\omega_2 = \alpha + \sqrt{\alpha^2 + \omega_r^2}$$

(*negative frequency is meaningless, so discarded*)

Now, the equation for the bandwidth becomes

$$\omega_{BW} = \omega_2 - \omega_1 = \left[\alpha + \sqrt{\alpha + \omega_r^2}\right] - \alpha\sqrt{\alpha^2 + \omega_r^2} = 2\alpha$$

$$\omega_{BW} = \frac{R}{L}$$

and Bandwidth, $\Delta f = f_2 - f_1 = \frac{\omega_2 - \omega_1}{2\pi} = \frac{R}{2\pi L} HZ$

Lower half-power frequency, $f_1 = f_r - \frac{\Delta f}{2} = f_r - \frac{R}{4\pi L} HZ$

Upper half-power frequency, $f_2 = f_r + \frac{\Delta f}{2} = f_r + \frac{R}{4\pi L} HZ$

Also, $f_1 f_2 = f_r^2$

Quality Factor: It is the voltage magnification that the circuit produces at resonance.

$$Q_r = \frac{Reactive\ Power}{Active\ Power} = \frac{I_{max} X_L}{I_{max} R} = \frac{X_L}{R}$$

$$= \frac{\omega_r L}{R} = \frac{2\pi f_r L}{R} = \frac{2\pi L}{R} \times \frac{1}{2\pi\sqrt{LC}} \qquad \left(f_r = \frac{1}{2\pi\sqrt{LC}}\right)$$

$$Q_r = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$Q_r = \frac{\text{Reactive Power}}{\text{Active Power}} = \frac{I_{max} X_C}{I_{max} R} = \frac{X_C}{R}$$

$$= \frac{1}{w_r CR} = \frac{1}{2\pi f_r CR} = \frac{2\pi\sqrt{LC}}{2\pi CR} \qquad \left(f_r = \frac{1}{2\pi\sqrt{LC}}\right)$$

$$Q_r = \frac{1}{R}\sqrt{\frac{L}{C}}$$

The Q-factor may also be defined as–

$$Q-factor = 2\pi \times \frac{\text{Maximum stored energy}}{\text{Energy disspated per cycle}}$$

$$= 2\pi \times \frac{\frac{1}{2} \times L(I_{max})^2}{\left(\frac{I_{max}}{\sqrt{2}}\right)^2 R.T_r} = \frac{2\pi L}{R} f_r = \frac{2\pi f_r L}{R}$$

$$Q-factor = \frac{w_r L}{R}$$

If Q-factor is high, voltage magnification is high and selectivity of tuning coil is also higher.

Q-factor may also be defined as the ratio of resonant frequency to Bandwidth.

i.e.

$$Q_r = \frac{f_r}{\Delta f} = \frac{f_r}{f_2 - f_1}$$

$$= \frac{\frac{1}{2\pi\sqrt{LC}}}{\frac{R}{2\pi L}} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

2. Parallel or Current Resonance *(Refer to Q.5(b), Page: 22-2018)*

Important Points

(*i*) Net Susceptance is zero i.e. $\frac{1}{X_C} = \frac{X_L}{Z^2} \ldots \rightarrow \quad Z = \sqrt{\frac{L}{C}}$

(*ii*) Admittance = Conductance

(*iii*) Reactive component of line current is zero.

(*iv*) Impedance is purely resistive, maximum in magnitude and equal to L/CR_1

(*v*) Line current is minimum and equal to *** and is in phase with the applied voltage.

(*vi*) $$f_r = \frac{1}{2\pi\sqrt{LC}}\sqrt{1 - \frac{CR_1^2}{L}}$$

Reason of Current Resonance

- Since in parallel resonant circuit, circulating current between the branches is many times the line current.

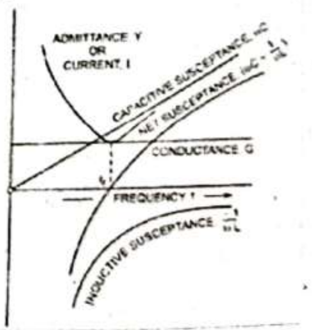
Such type of resonance is sometimes known as Current Resonance.

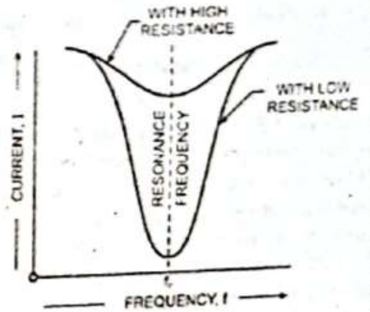
Reason for Rejector Circuit

- Parallel Resonant Circuit is sometimes called the Rejector Circuit because at resonant frequency, the line current is minimum or it almost rejects it.

Tank Circuit: An inductive coil of Inductance L connected in parallel with a Capacitance C is called Tank Circuit.

Graphical Representation of Parallel Resonance





Resonant frequency, Damped resonant frequency and Quality Factor for parallel RLC Circuit

Resonant Frequency: A parallel RLC circuit is said to be in electrical resonance when the reactive component of line current becomes zero. The frequency at which this happens is known as resonant frequency.

Damped Resonant Frequency: The peak resonance frequency depends on value of the resistor and is described as the damped resonant frequency.

Q-factor: ***Refer to Q.5, Page: 16-2016***

Bandwidth:

$$\omega_{BW} = \frac{1}{RC}$$

Bandwidth, $\Delta f = f_2 - f_1 = \frac{\omega_2 - \omega_1}{2\pi} = \frac{1}{2\pi RC}\text{Hz}$

Lower half-power frequency, $f_1 = f_r - \frac{\Delta f}{2} = f_r - \frac{1}{4\pi RC}\text{ Hz}$

Upper half-power frequency, $f_2 = f_r + \frac{\Delta f}{2} = f_r + \frac{1}{4\pi RC}\text{ Hz}$

Also $f_1 f_2 = f^2_r$

SOLVED EXAMPLE

Q.1. ***Refer to Q.5(a), Page: 23-2017***

Q.2. ***Refer to Q.4(a), Page: 14-2016***

Q.3. ***Refer to Q.3(a), Page: 15-2015***

Three-phase Balanced Circuits

- **Single-phase systems involve single-phase currents and voltages and they are applicable for domestic applications. For eg, Motors for mixers, fans, air conditioners, refrigerators, etc. However, 1-ϕ system has its own limitation and, therefore, has been replaced by polyphase system.**
- **For general supply, three-phase (3-ϕ) supply has been universally used. For generation, transmission and distribution of electric power, 3-ϕ system has been universally adopted.**
- The 2-ϕ supply and 6-ϕ supply are obtained from 2-ϕsupply.
- A polyphase system is essentially a combination of several 1-ϕ voltage having same magnitude and frequency but displaced from one another by equal angle (electrical), which depends upon the number of phases.

$$\text{Electrical displacement} = \frac{360\text{ electrical degree}}{\text{Number of Phases}}$$

and Number of phase > 2.

Balanced / Symmetrical System: A supply system is said to be symmetrical when several voltages of the same frequency have equal magnitude and are displaced from one another by equal time. For eg. 3-phase 3-wire or 3-phase 4-wire systems.

Unbalanced System: A 3-phase supply will be unbalanced when either of the 3 phase voltage are unequal in magnitude or the phase angle between these phase is not equal to 120°.

Balanced Load: A load circuit is said to be balanced when the loads (impedances) connected in various phase are same in magnitude as well as in phase.

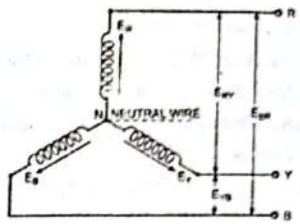
Unbalanced Load: Any 3-phase load in which the impedances in one more phase differ from the impedances of other phases is called unbalanced 3-phase load.

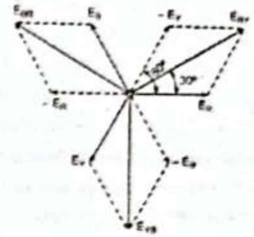
Advantage of 3-phase System over Single Phase System

Refer to Q.5(a), Page: 32-2015

Voltage and Current Relations in Star and Delta Connections

1. STAR / WYE (Y) Connected System





Phase Voltage: Voltage between any line and the neutral point i.e. voltage across the phase winding.

Line Voltage: It is phasor difference of phase emfs of the two phases concerned.

In above Fig.,

- $E_R, E_Y, E_B \rightarrow$ *Phases of induced emf*
- $E_{RN}, E_{YN}, E_{BN} \rightarrow$ *Phase Voltages*
- $E_{RY}, E_{YB}, E_{BR} \rightarrow$ *Line Voltageesn*

(potential differences between two outers)

Now, $E_{RY} = E_R - E_Y = E_R + (-E_Y)$

$$E_{RY} = \sqrt{|E_R|^2 + |-E_Y|^2 + 2|E_R||E_Y|\cos 60^\circ}$$

Assuming balanced system, i.e.

$$E_R = E_Y = E_B = E_P$$

$$\therefore \quad E_{RY} = \sqrt{E_P^2 + E_P^2 + 2E_P^2 \times \frac{1}{2}} = \sqrt{3}E_P$$

$$\Rightarrow \quad E_{RY} = E_{YB} = E_{YR} = E_L = \sqrt{3}E_P \quad \text{and } I_L = I_P$$

Three Phase Power

Instantaneous Phase Voltages are given by –

$$E_R = \sqrt{2}E_P \sin\omega t$$

$$E_Y = \sqrt{2}E_P \sin(\omega t - 120^\circ)$$

$$E_B = \sqrt{2}E_P \sin(\omega t - 240^\circ) = \sqrt{2}E_P \sin(\omega t + 120^\circ)$$

Instantaneous Phase Current are given by –

$$I_R = \sqrt{2}I_P \sin(\omega t - \varnothing)$$

$$I_Y = \sqrt{2}I_P \sin(\omega t - \varnothing - 120^\circ)$$

$$i_B = \sqrt{2}I_P \sin(\omega t - \varnothing - 240^\circ) = \sqrt{2}I_P(\omega t - \varnothing + 120^\circ)$$

where, ∅ is the phase angle between E_P and I_P

Total instantaneous power, P is given as –

$$P = E_R I_R + E_Y I_Y + E_B R_B$$

$$= \left[\sqrt{2}E_P \sin\omega t\right]\left[\sqrt{2}I_P \sin(\omega t - \varnothing)\right] + \left[\sqrt{2}E_P \sin(\omega t - 120^\circ)\right]$$
$$\left[\sqrt{2}I_P \sin(\omega t - \varnothing - 120^\circ)\right] + \left[\sqrt{2}E_P \sin(\omega t + 120^\circ)\right]\left[\sqrt{2}I_P \sin(\omega t - \varnothing + 120^\circ)\right]$$

$= E_p I_p [2\sin(\omega t).\sin(\omega t - \varnothing) + 2\sin(\omega t - 120°).\sin(\omega t - \varnothing - 120°) +$
$2\sin(\omega t + 120°).\sin(\omega t - \varnothing + 120°)]$
$= E_p I_p [\cos\varnothing - \cos(2\omega t - \varnothing) + \cos\varnothing - \cos(2\omega t - \varnothing - 240°) +$
$\cos\varnothing - \cos(2\omega t - \varnothing + 240°)]$ $[\because 2\sin A \sin B = \cos(A-B) - \cos(A+B)]$
$P = E_p I_p [3\cos\varnothing - \cos(2\omega t - \varnothing) + \cos(2\omega t - \varnothing - 240°) + \cos(2\omega t - \varnothing + 240°)]$
$= E_p I_p [3\cos\varnothing - 0]$ ($\because$ Sum of the three second harmonic oscillating terms which have a progressive phase difference of 120° is zero.)

Thus, the instantaneous power in a 3-$\varnothing$ balanced system is constant and equal to 3 times the average power per phase.

- Total Circuit Power, $P = 3E_pI_p\cos\varnothing = \sqrt{3}E_LI_L\cos\varnothing$
- Reactive Power, $Q = 3E_pI_p\sin\varnothing = \sqrt{3}E_LI_L\sin\varnothing$
- Apparent Power, $S = 3 \times$ Apparent power per phase $= 3E_pI_p = \sqrt{3}E_LI_L$

Key Points in a Balanced Star-Connected System

1. Line Voltages are 120° apart.
2. Line Voltages are 30° ahead of the respective phase voltages.
3. Line voltages are $\sqrt{3}$ times of the phase voltages.
4. Line currents are equal to phase currents.
5. The angle between line currents and the corresponding line voltages is $(30 \pm \varnothing)$; *+ve for lagging currents and – ve for leading currents.*
6. True Power output $= \sqrt{3}E_LI_L\cos\varnothing$, where $\varnothing$ is the angle between the respective phase current and phase voltage.
7. Apparent Power $= \sqrt{3}E_LI_L$.
8. In balanced system, the potential of neutral or star point is zero as

$$E_{NR} + E_{NY} + E_{NB} = 0$$

2. DELTA / MESH (A) Connected System: From the fig., it is obvious that line current is phasor difference of phase currents of two phases concerned.

Line Current, $I_R = I_{YR} - I_{RB} = I_{YR} + (-I_{RB})$

Since, phase angle between phase current phasors I_{YR} and $-I_{RB}$ is 60°.

$$I_R = \sqrt{I_{YR}^2 + I_{RB}^2 + 2I_{YR}I_{RB}\cos 60°}$$

Assuming balanced load, the phase current in each winding is equal. Let the phase current in each winding be I_P

$\therefore$ $$I_R = \sqrt{I_P^2 + I_P^2 + 2I_PI_P \times \frac{1}{2}} = \sqrt{3}I_P$$

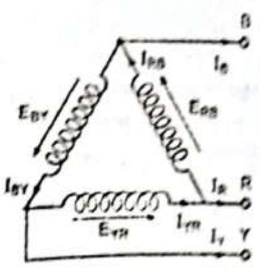
Similarly, Line Current, $I_Y = I_{BY} - I_{YR} = I_{BY} + (-I_{YR})$

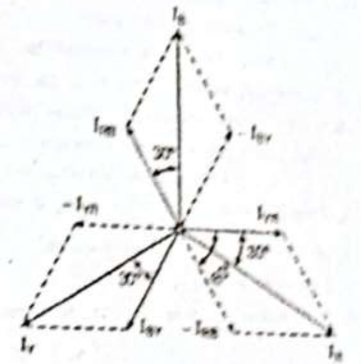
$$I_Y = \sqrt{I_P^2 + I_P^2 + 2I_PI_P \times \frac{1}{2}} = \sqrt{3}I_P$$

And Line Current, $I_B = I_{RB} - I_{BY} = I_{RB} + (-I_{BY})$

$$I_B = \sqrt{I_P^2 + I_P^2 + 2I_PI_P \times \frac{1}{2}} = \sqrt{3}I_P$$

$\Rightarrow$ $I_R = I_Y = I_B = I_L = \sqrt{3}I_P$ and $E_L = E_P$





Three phase power

Instantaneous Phase Voltage are given by –

$$E_R = \sqrt{2}E_p\sin\omega t$$
$$E_Y = \sqrt{2}E_p\sin(\omega t - 120°)$$
$$E_B = \sqrt{2}E_p\sin(\omega t - 240°) = \sqrt{2}E_p\sin(\omega t + 120°)$$

Instantaneous Phase Current are given by –

$$I_R = \sqrt{2}I_p\sin(\omega t - \varnothing)$$
$$I_Y = \sqrt{2}I_p\sin(\omega t - \varnothing - 120°)$$
$$i_B = \sqrt{2}I_p\sin(\omega t - \varnothing - 240°) = \sqrt{2}I_p\sin(\omega t - \varnothing + 120°)$$

where, $\varnothing$ is the phase angle between E_p and I_p

Total instantaneous power, P is given as –

$$P = E_RI_R + E_YI_Y + E_BR_B$$

$$= \begin{matrix}\left[\sqrt{2}E_p\sin\omega t\right]\left[\sqrt{2}I_p\sin(\omega t - \varnothing)\right] + \left[\sqrt{2}E_p\sin(\omega t - 120°)\right] \\ \left[\sqrt{2}I_p\sin(\omega t - \varnothing - 120°)\right] + \left[\sqrt{2}E_p\sin(\omega t + 120°)\right]\left[\sqrt{2}I_p\sin(\omega t - \varnothing + 120°)\right]\end{matrix}$$

$= E_pI_p[2\sin(\omega t).\sin(\omega t - \varnothing) + 2\sin(\omega t - 120°).\sin(\omega t - \varnothing - 120°) +$
$2\sin(\omega t + 120°).\sin(\omega t - \varnothing + 120°)]$
$= E_pI_p[\cos\varnothing - \cos(2\omega t - \varnothing) + \cos\varnothing - \cos(2\omega t - \varnothing - 240°) +$
$\cos\varnothing - \cos(2\omega t - \varnothing + 240°)]$ $[2\sin A\sin B = \cos(A-B) - \cos(A+B)]$
$P = E_pI_p[3\cos\varnothing - \cos(2\omega t - \varnothing) + \cos(2\omega t - \varnothing - 240°) + \cos(2\omega t - \varnothing + 240°)]$
$= E_pI_p[3\cos\varnothing - 0]$ ($\because$ Sum of the three second harmonic oscillating terms which have a progressive phase difference of 120° is zero.)

$\therefore P = 3E_pI_p\cos\phi$

Thus, the instantaneous power in a 3-$\varnothing$ balanced system is constant and equal to 3 times the average power per phase.

- Total Circuit Power, $P - 3E_pI_p\cos\varnothing = \sqrt{3}E_LI_L\cos\varnothing$
- Reactive Power, $Q = 3E_pI_p\sin\varnothing = \sqrt{3}E_LI_L\sin\varnothing$
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5. The angle between line currents and the corresponding line voltages is $(30 \pm \varnothing)$; *+ve for lagging currents and – ve for leading currents.*
6. True Power output = $\sqrt{3}\, E_L I_L \cos \varnothing$, where $\varnothing$ is the angle between the respective phase current and phase voltage.
7. Apparent Power = $\sqrt{3}\, E_L I_L$.
8. In balanced system, the resultant emf in the closed circuit will be zero.

$$E_{RY} + E_{YB} + E_{BR} = 0$$

Hence, there will be no circulating current in the mesh if no load is connected to the lines.

SOLVED EXAMPLES

Q.1. ***Refer to Q.4(a), Page: 17–2015.***

UNIT-III

D. C. GENERATORS & MOTORS: Principle of operation of Generators & Motors

Working of DC generator: ***Refer to Q.8(a), Page: 29-2017***

Types of DC generators: ***Refer to Q.8(b), Page: 28-2018***

Working of DC motor: ***Refer to Q.8(a), Page: 22-2015***

Back EMF in DC motor: ***Refer to Q.1(b), Page: 25-2015***

Types of DC Motors: ***Refer to Q.9(a), Page: 22-2016***

Speed Control of shunt motors

The expression of speed for a dc motor is given as –

$$N = K\frac{V - I_a(R + R_a)}{\varnothing}$$

Form the above expression, it is revealed that the speed can be controlled by adjusting an one of the three factors:

(i) Applied voltage to the armature terminals, V

(ii) External resistance in the armature circuit, R and

(iii) Flux per pole, Ø

The speed control methods are broadly classified as:

1. Field Control Methods

2. Armature Resistance Control Methods

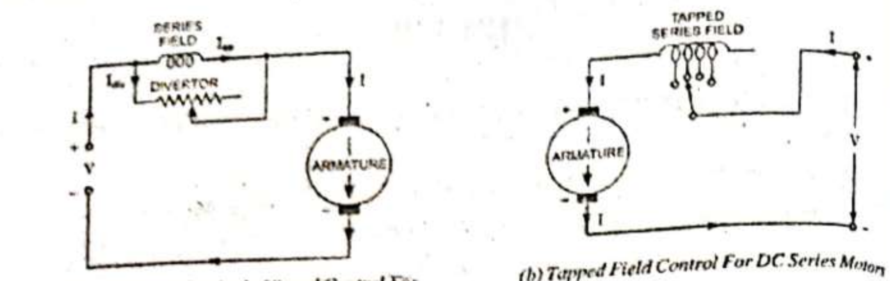
3. Armature Voltage Control Methods

I. Field Control Methods: In case of dc series motors, the flux can be varied by any one of the following methods.

(a) Field Divertor Method: The field flux can be reduced by shunting a portion of motor current around the series field, thus reducing the excitation mmf and weakening of field. This method is illustrated in Fig. 1 (a). This method provides speeds above normal because flux is reduced. Lesser the divertor resistance, less the field current, less flux, and therefore, more the speed. This method is used in electric drives.

(b) Tapped Field Control: This is another method of increasing the speed by reducing the flux and it is accomplished by reducing the number of turns of the field winding through which the current flows. This method is illustrated in Fig. 1 (b). A number of series field turns can be short-circuited according to the requirement. When all field turns are in circuit, the motor runs at the lowest speed and speed increases with cutting out some of the series field turns. This method is employed in electric traction.

(c) Paralleling Field Coils Method: In this method, several speeds can be obtained by re-grouping of field coils, as illustrated in Fig. 1 (c). This method is used in fan motors.



(a) Field Divertor Method of Speed Control For DC Series Motors

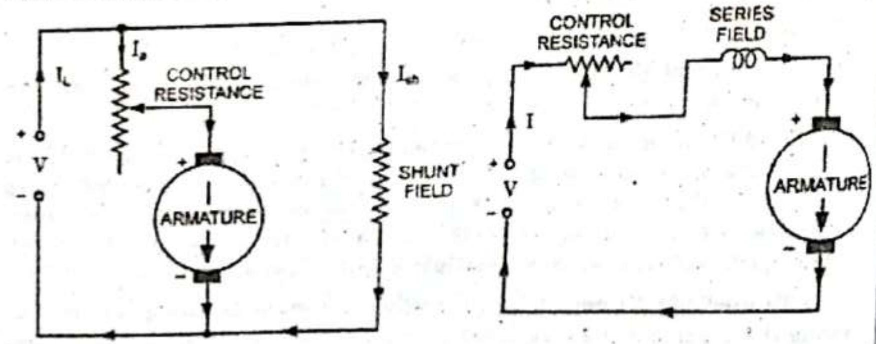
(b) Tapped Field Control For DC Series Motors

(i) (ii)

(c)

Fig. 1 Field Control Methods

2. Armature Resistance Control Methods: In this method, reduced speeds are obtained by inserting resistance in the armature circuit. In case of a dc shunt and dc series motor, an increase in armature circuit resistance will cause more voltage drop in the armature circuit, so the speed will be reduced. This method is illustrated in Fig. 2. This method is most economical for constant torque drives and is employed for driving cranes, hoists, trains, etc.



(a) For DC Shunt Motor (b) For DC Series Control

Fig. 2 Armature Resistance Control

3. Armature Voltage Control Methods: This method of speed control requires a source of variable voltage separate from the source supplying the field current. This method avoids the disadvantages of poor speed regulation and low efficiency which are the characteristics of the armature resistance control method but it is more expensive in initial cost. The adjustable voltage for the armature is obtained from an adjustable voltage generator or from an adjustable electronic rectifier.

Speed control of series motors: ***Refer to Q.8(b), Page: 32–2014***

Factors affecting speed of DC motor: ***Refer to Q.8(a), Page: 37–2015***

A. C. GENERATORS & MOTORS: Principle of operation

AC Generator: A machine that transforms mechanical energy into electrical energy is known as an AC generator. Mechanical energy is supplied to the AC Generator through steam turbines, gas turbines, and combustion engines. Alternating electrical power in the form of alternating voltage and current is the output.

Principle of AC Generator: AC generators function on Faraday's law of electromagnetic induction states that electromotive force (EMF or voltage) is created in a current-carrying wire that cuts a uniform magnetic field. Rotating a conducting coil in a static magnetic field or rotating the magnetic field enclosing the stationary conductor can both be used to accomplish this. Because it is easier to extract induced alternating current from a stationary armature coil than from a revolving coil.

Note: The EMF generated is determined by the number of armature coil turns, magnetic field intensity, and rotating field speed.

Working of an AC Generator: The flux linkage of the armature varies continually as it revolves between the poles of the magnet on an axis perpendicular to the magnetic field. An electric current travels through the galvanometer, slip rings and brushes as a consequence. The galvanometer changes its value from positive to negative. This implies that the galvanometer is receiving an alternating current. Fleming's Right-Hand Rule can be used to determine the direction of the induced current.

AC Motor (Induction Motor): The motor that converts the alternating current into mechanical power by using an electromagnetic induction phenomenon is called an AC Motor. The stator and the rotor are the two most important parts of the AC motors. The stator is the stationary part of the motor. And the rotor is the rotating part of the motor. An AC motor may be single phase or three phase.

Working Principle of an AC Motor

The fundamental operation of an AC Motor depends on the principle of magnetism. The simple AC Motor contains a coil of wire and two fixed magnets surrounding a shaft. When an electric (AC) charge applies to the coil of wire, it becomes an electromagnet. This electromagnet generates a magnetic field.

Inside the stator, there is a solid metal axle, a loop of wire, a coil, a squirrel cage made of metal bars and some other freely rotating metal part that can conduct electricity. In an AC motor you send power to the outer coils that make up the stator. The coils energized in pairs, in sequence, producing a magnetic field that rotates around the outside of the motor.

The rotor suspended inside the magnetic field. The magnetic field is constantly changing due to rotation so, according to the law of electromagnetism, the magnetic field produces an electric current inside the rotor.

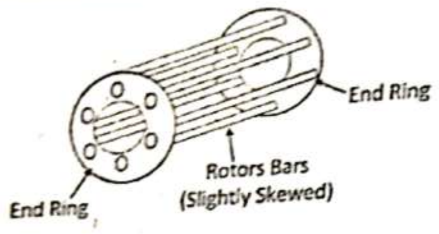
If the conductor is a ring or a wire, the current flows around it in a loop. If the conductor is simply a solid piece of metal, eddy currents flows around it instead. The induced current produces its own magnetic field and according to another law of electromagnetism, the rotating magnetic field by rotating as well. Simply described, When the magnets interact, the shaft and the coil of wires begin to rotate, which operates the motor.

Revolving Magnetic field: Refer to Q.8(a), Page- 20, 2016

Squirrel cage and phase wound rotor

Definition of Squirrel Cage Motor

The motor which employing squirrel cage type rotor is known as the squirrel cage motor. The construction of the rotor is rugged and simple. The rotor of the motor consists the cylindrical laminated core having semi-closed circular slots and short circuit at each end by copper or aluminium ring, called short circuiting ring. It is not possible to add any external resistance in the rotor of the circuit.



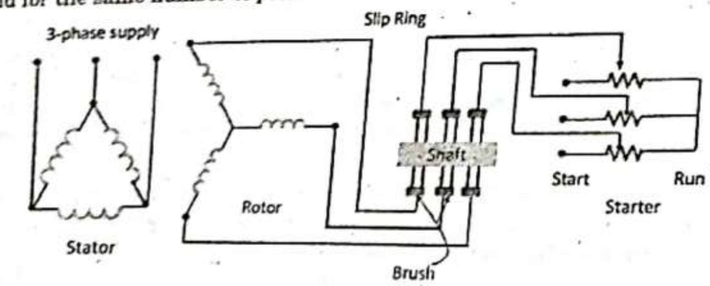
Squirrel Cage Motor

The rotor slots are not parallel but are skewed. The skewing of the rotor has the following advantages.

1. Its reduces humming and thus ensuring the quiet running of a motor.
2. The skewed rotor gives smooth torque curves for different positions of the rotor.
3. It reduces the magnetic locking of the stator and rotor.
4. It increases the rotor resistance due to the increased length of the rotor bar conductors.

Definition of Slip Ring Motor (Phase Wound Rotor)

The motor which employing the wound rotor is known as a slip ring induction motor or phase wound motor. It consists laminated cylindrical core which has a semi-closed slot at the outer periphery and carries three-phase insulated winding. The rotor is wound for the same number of poles as that of the stator.



Slip Ring Induction Motor

The three finish terminals are connected forming star point, and the three start terminals are connected to three copper slip rings fixed on the shaft. The mild steel shaft is passed through the centre of the rotor and fixed to the key. The purpose of the shaft is to send mechanical power.

Key Difference: The overloading capacity of the slip ring motor is high as compared to squirrel cage motor and it is smoothly running under heavy loads. It is less sensitive and also has no abnormal heating during the starting.

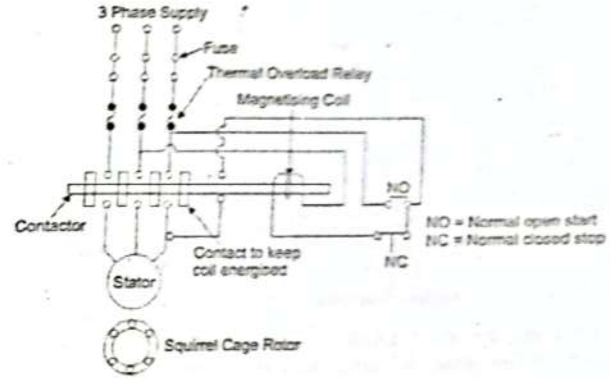
Starting of Induction motors: Direct on line and Star Delta starters

Slip: Refer to Q.9(a), Page- 33, 2014 or Refer to Q.1(e), Page- 26, 2015

DOL Starter

A DOL starter (also known as a direct on line starter or across the line starter) is a method of starting a 3 phase induction motor. In a DOL Starter, an induction motoris connected directly across its 3-phase supply, and the DOL starter applies the full line voltage to the motor terminals.

Despite this direct connection, no harm is done to the motor. A DOL motor starter contains protection devices, and in some cases, condition monitoring. A wiring diagram of a DOL starter is shown below:



Since the DOL starter connects the motor directly to the main supply line, the motor draws a very high inrush current compared to the full load current of the motor (up to 5-8 times higher). The value of this large current decreases as the motor reaches its rated speed.

A direct on line starter can only be used in circumstances when the high inrush current of the motor does not cause an excessive voltage drop in the supply circuit. If a high voltage drop needs to be avoided, a star delta starter should be used instead. Direct on line starters are commonly used to start small motors, especially 3 phase squirrel cage induction motors.

As we know, the equation for armature current in the motor.

$$I_a = \frac{V-E}{R_a}$$

The value of back emf (E) depends upon speed (N), i.e. E is directly proportional to N.

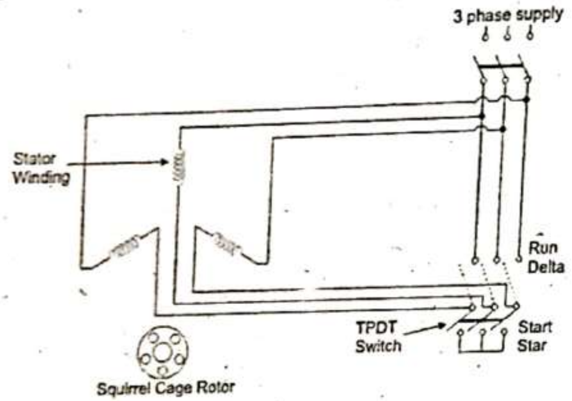
At starting, the value of E is zero. So starting current is very high. In a small rating motor, the rotor has a more considerable axial length and small diameter. So it gets accelerated fastly. Hence, speed increases and thus the value of armature current decreases rapidly. Therefore, small rating motors smoothly run when it is connected directly to a 3-phase supply.

If we connect a large motor directly across 3-phase line, it would not run smoothly and will be damaged, because it does not get accelerated as fast as a smaller motor since it has short axial length and larger diameter more massive rotor. However, for large rated motors, we can use an oil-immersed DOL starter.

Star Delta Starter

A star delta starter is the most commonly used method for the starting of a 3 phase induction motor. In star delta starting an induction motor is connected in through a star connection throughout the starting period. Then once the motor reaches the required speed, the motor is connected in through a delta connection.

A star delta starter will start a motor with a star connected stator winding. When motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding.



A star delta starter is a type of reduced voltage starter. We use it to reduce the starting current of the motor without using any external device or apparatus. This is a big advantage of a star delta starter, as it typically has around 1/3 of the inrush current compared to a DOL starter.

The starter mainly consists of a TPDP switch which stands for Tripple Pole Double Throw switch. This switch changes stator winding from star to delta. During starting condition stator winding is connected in the form of a star.

Advantages of Star Delta Starter

The advantages of star delta starters include:

1. Inexpensive
2. No heat is produced, or tap changing device needs to be used, hence efficiency increases.
3. Starting current reduced to 1/3 of direct online starting current.
4. Produce high torque per ampere of line current.

Disadvantages of Star Delta Starter

The disadvantages of star delta starters include:

1. Starting torque is reduced to 1/3 of full load torque.
2. A particular set of motors required.

Application of Star Delta Starter

As discussed in the above advantages and disadvantages, a star delta starter is most suited to applications where the required starting current is low and where the line current draw must be at a minimum value.

The star delta starter is not suitable for applications where high starting torque delivery is required. For these applications, a DOL starter should be used instead.

If the motor is too heavily loaded, there will not be enough torque to accelerate the *motor upto speed* before switching over to the delta position. Example application for a *star delta starter is* a Centrifugal compressor.

SOLVED EXAMPLES

Q.1. Refer to Q.1(f), Page: 13–2017

Q.2. Refer to Q.9(c), Page: 32–2018

Synchronous machines

Synchronous Machine constitutes of both synchronous motors as well as synchronous generators. An AC system has some advantages over a DC system. Therefore, the AC system is exclusively used for the generation, transmission, and distribution of electric power. The machine which converts mechanical power into AC electrical power is called a **Synchronous Generator** or Alternator. However, if the same machine can be operated as a motor is known as **Synchronous Motor**.

Synchronous machine is an AC machine whose satisfactory operation depends upon the maintenance of the following relationship.

$$N_s = \frac{120f}{P} \quad ...(1) \text{ or}$$

$$f = \frac{PN_s}{120}$$

Where,

- N_s is the synchronous speed in revolution per minute (r.p.m)
- f is the supply frequency
- P is the number of poles of the machine.

When connected to an electric power system, a synchronous machine always maintains the above relationship shown in equation (1).

If the synchronous machine working as a motor fails to maintain the average speed (Ns) the machine will not develop sufficient torque to maintain its rotation and will stop. Then the motor is said to be **Pulled Out of Step**.

In case, when the synchronous machine is operating as a generator, it has to run at a fixed speed called Synchronous speed to generate the power at a particular frequency. As all the appliances or machines are designed to operate at this frequency. In some countries, the value of the frequency is **50 hertz**.

Basic Principles of Synchronous Machine

A synchronous machine is just an electromechanical transducer that converts mechanical energy into electrical energy or vice versa. The fundamental phenomenon or law which makes these conversions possible is known as the **Law of Electromagnetic Induction and Law of interaction.**

Three-Phase Synchronous Machine

- The machine which is used in the household appliance such as the small machine used in air coolers, refrigeration, fans, air conditioners, etc.

• However, large AC machines are three-phase type synchronous machines because of the following reasons.

• For the same size of the frame, three-phase machines have nearly 1.5 times the output than that of the single-phase machine.

• Three-phase power is transmitted and distributed more economical than single-phase power.

• Three-phase motors are self-starting (except synchronous motors).

• Three-phase motors have an absolute uniform continuous torque, whereas, single-phase motors have pulsating torque.

In a small synchronous machine, the fielding winding is placed on the stator, and the armature winding is placed on the rotor whereas for the large synchronous machine the field winding is placed on the rotor, and the armature winding is placed on the stator.

UNIT-IV

TRANSFORMERS:

Construction: The transformer is a **static device** in its construction and the principle behind the working of transformer is Faraday's law of Electromagnetic Induction. The transformer **transfers the electrical power** from one circuit to the other circuit **without the change in frequency**. The transfer happens based on the mutual induction between the two circuits that are linked by a magnetic flux.

A transformer has two inductive coils that are electrically separated from each other but are magnetically linked through a path for the flow of magnetic flux.

Transformers vary in different sizes and ranges. It ranges from small transformers used in the communication system to giant transformers used in the High voltage transmission system.

The output voltage of a transformer can be increased or decreased, with a proportional change in the current ratings. Accordingly, there are two types of transformers: **Step up transformer and step down transformer**.

In a step-up transformer, the input voltage is stepped up to a high output voltage. The number of turns in the primary coil is less than the secondary coil in the step-up transformer. When the output voltage is lower than the input side, it is called a step-down transformer. It has more turns in the primary coil than the secondary coil.

The construction of transformer is very simple for the small-sized transformer. It consists of a transformer core, primary and secondary windings. For a high range of power transformers, the core and windings are placed in a transformer tank with additional accessories.

Transformer Core: The transformer core is mainly used for two purposes: Provide mechanical support for the entire transformer and provide a path for the flow of magnetic flux.

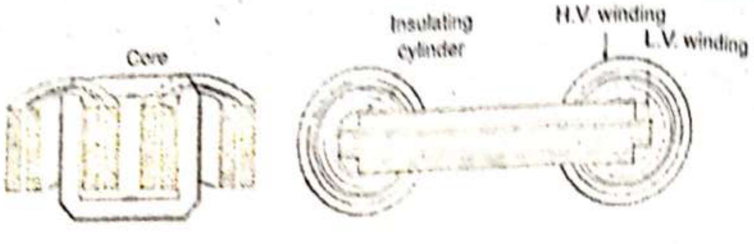
The core is built up of soft iron or silicon steel laminations to provide a low reluctance path to the magnetic flux. The steel used should have high silicon content and be treated with heat to have better permeability and low hysteresis loss.

The laminations are insulated from each other by a coat of varnish or by an oxide layer. These laminations reduce the eddy current loss. The thickness of the laminations varies from 0.35 mm to 0.5 mm.

The laminations in the form of strips called stampings are joined together and pivoted to avoid any air gaps between the core. Various types of stampings like 'E' shaped, 'I' shaped, 'L' shaped and 'U' shaped stampings are used for the construction of transformer.

Based on the type of core used there are two types: core type transformer, and shell-type transformer.

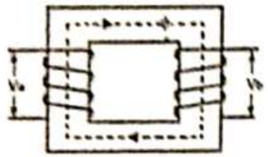
1. Core- Type Transformer: In core-type transformer, the windings are given to a considerable part of the core. The coils used for this transformer are form-wound and are of cylindrical type. Such a type of transformer can be applicable for small sized and large sized transformers. In the small sized type, the core will be rectangular in shape and the coils used are cylindrical. The figure below shows the large sized type. You can see that the round or cylindrical coils are wound in such a way as to fit over a cruciform core section. In the case of circular cylindrical coils, they have a fair advantage of having good mechanical strength. The cylindrical coils will have different layers and each layer will be insulated from the other with the help of materials like paper, cloth, micarta board and so on. The general arrangement of the core-type transformer with respect to the core is shown below. Both low-voltage (LV) and high voltage (HV) windings are shown.

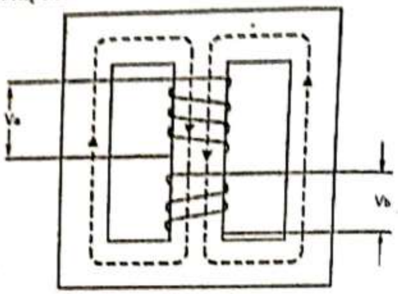


Core Type Transformers

The low voltage windings are placed nearer to the core as it is the easiest to insulate. The effective core area of the transformer can be reduced with the use of laminations and insulation.

2. Shell-Type Transformer: In shell-type transformers, the core surrounds a considerable portion of the windings. The comparison is shown in the figure below.

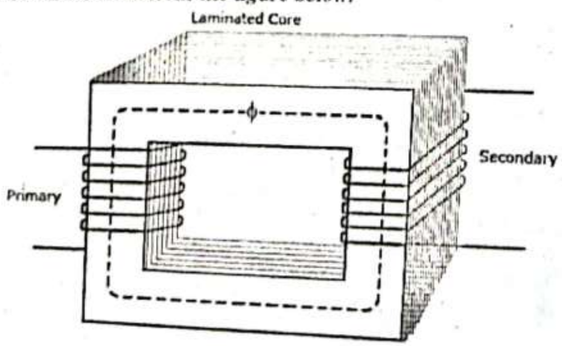




Core Type and Shell Type Transformer Winding

The coils are form-wound but are multi layer disc type usually wound in the form of pancakes. Paper is used to insulate the different layers of the multi-layer discs. The whole winding consists of discs stacked with insulation spaces between the coils. These insulation spaces form the horizontal cooling and insulating ducts. Such a transformer may have the shape of a simple rectangle or may also have a distributed form.

Principle of operation: The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance. The working principle of the transformer can be understood from the figure below.



Transformer Working

As shown above the electrical transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core. These staggered joints are said to be 'imbricated'. Both the coils have high mutual inductance. A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faraday's laws of Electromagnetic Induction as

$$e = M\frac{dI}{dt}$$

If the second coil circuit is closed, a current flows in it and thus electrical energy is transferred magnetically from the first to the second coil.

The alternating current supply is given to the first coil and hence it can be called as the primary winding. The energy is drawn out from the second coil and thus can be called as the secondary winding.

In short, a transformer carries the operations shown below:

1. Transfor of electric power from one circuit to another.
2. Transfer of electric power without any change in frequency.
3. Transfer with the principle of electromagnetic induction.
4. The two electrical circuits are linked by mutual induction.

Ideal Transformer: ***Refer to Q.1(e), Page: 19–2014 or Refer to Q.7(b), Page: 21–2015***

EMF Equation: ***Refer to Q.7(a), Page: 21–2015 or Refer to Q.9(a), Page: 39–2015***

Phasor Diagram: ***Refer to Q.8(b), Page: 20–2016***

Equivalent circuit: ***Refer to Q.8(a), Page: 27–2018***

Losses in transformers: ***Refer to Q.9(b), Page: 32–2017***

SOLVED EXAMPLES

Q.1 ***Refer to Q.9(b), Page: 40–2015***

Q.2 ***Refer to Q.1(h), Page: 13–2015***

Q.3 ***Refer to Q.1(e), Page: 8–2016***

Q.4 ***Refer to Q.9(a), Page: 30–2018***

Q.5 ***Refer to Q.9(b), Page: 31–2018***

Regulation and efficiency: ***Refer to Q.8(a), Page: 30–2014 or Refer to Q.9(b), Page: 23–2016***

Auto-transformer: An **Auto Transformer** is a transformer with only one winding wound on a laminated core. An auto transformer is similar to a two winding transformer but differ in the way the primary and secondary winding are interrelated. A part of the winding is common to primary and secondary sides.

On load condition, a part of the load current is obtained directly from the supply and the remaining part is obtained by transformer action. An Auto transformer works as a **voltage regulator.**

Explanation of Auto Transformer with Circuit Diagram: In an ordinary transformer, the primary and the secondary windings are electrically insulated from each other but connected magnetically as shown in the figure below. While in auto transformer the primary and the secondary windings are connected magnetically as well as electrically. In fact, a part of the single continuous winding is common to both primary and secondary.

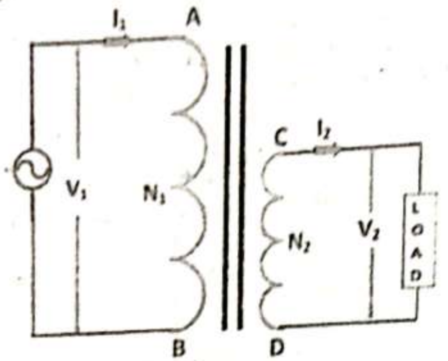


Figure A: Ordinary Two Winding Transformer

There are two types of auto transformer based on the construction. In one type of transformer, there is continuous winding with the taps brought out at convenient points determined by the desired secondary voltage. However, in another type of auto transformer, there are two or more distinct coils which are electrically connected to form a continuous winding. The construction of Auto transformer is shown in the figure below.

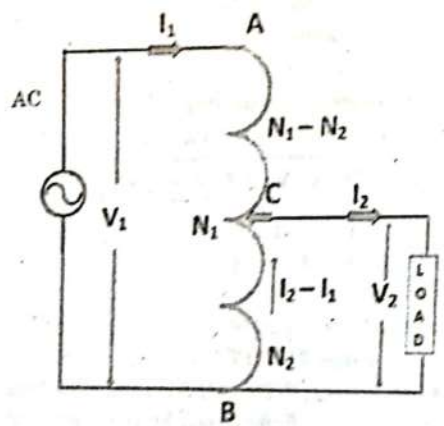


Figure B: Auto - Transformer

The primary winding AB from which a tapping at C is taken, such that CB acts as a secondary winding. The supply voltage is applied across AB, and the load is connected across CB. The tapping may be fixed or variable. When an AC voltage V_1 is applied across AB, an alternating flux is set up in the core, as a result, an emf E_1 is induced in the winding AB. A part of this induced emf is taken in the secondary circuit.

Let,

- V_1 – primary applied voltage
- V_2 – secondary voltage across the load
- I_1 – primary current
- I_2 – load current
- N_1 – number of turns between A and B
- N_2 – number of turns between C and B

Neglecting no-load current leakage reactance and losses,

$V_1 = E_1$ and $V_2 = E_2$

Therefore, the transformation ratio:

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

As the secondary ampere-turns are opposite to primary ampere-turns, so the current I_2 is in phase opposition to I_1. The secondary voltage is less than the primary. Therefore current I_2 is more than the current I_1. Therefore, the resulting current flowing through section BC is $(I_2 - I_1)$.

The ampere-turns due to section BC = current × turns

$$\text{Ampere turns due to section BC} = (I_2 - I_1) N_2 = \left(\frac{I_1}{K} - I_1\right) \times N_1 K = I_1 N_1 (1 - K) \quad ...(1)$$

$$\text{Ampere turns due to section AC} = I_1(N_1 - N_2) = I_1 N_1 \left(1 - \frac{N_2}{N_1}\right) = I_1 N_1 (1 - K) \quad ...(2)$$

Equation (1) and (2) shows that the ampere-turns due to section BC and AC balance each other which is characteristic of the transformer action.

Three-phase transformer connections.

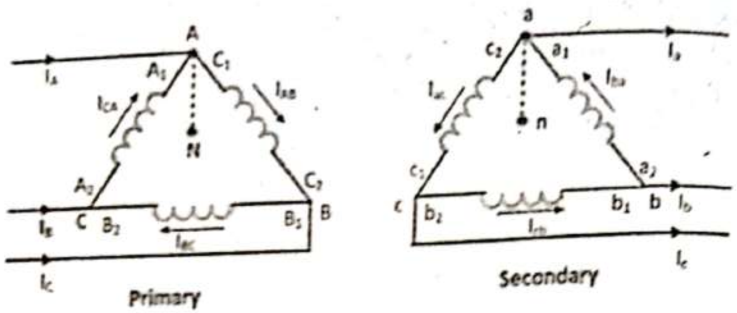
The three phase transformer consists three transformers either separate or combined with one core. The primary and secondary of the transformer can be independently connected either in star or delta. There are four possible connections for a 3-phase transformer bank.

1. Δ - Δ (Delta - Delta) Connection
2. Y - Y (Star - Star) Connection
3. Δ - Y (Delta - Star) Connection
4. Y - Δ (Star - Delta) Connection

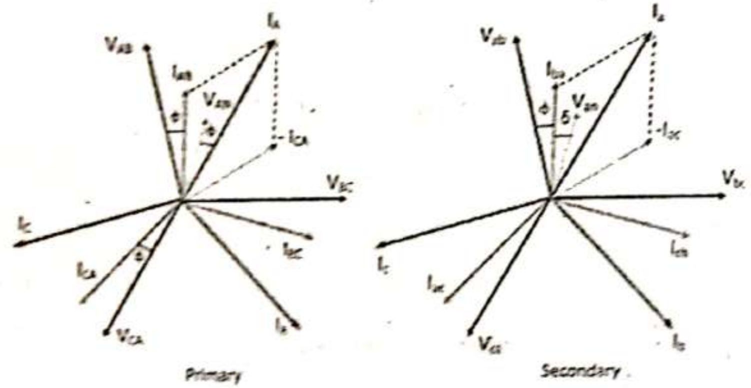
The choice of connection of three phase transformer depends on the various factors likes the availability of a neutral connection for grounding protection or load connections, insulation to ground and voltage stress, availability of a path for the flow of third harmonics, etc. The various types of connections are explained below in details.

1. Delta-Delta (Δ-Δ) Connection

The delta-delta connection of three identical single phase transformer is shown in the figure below. The secondary winding a_1a_2 is corresponding to the primary winding A_1A_2, and they have the same polarity. The polarity of the terminal a connecting a_1 and c_2 is same as that connecting A_1 and C_2. The figure below shows the phasor diagram for lagging power factor cos ϕ.



Delta-Delta Connection of Transformer



Phasor Diagram of Delta-Delta Connection of Transformer

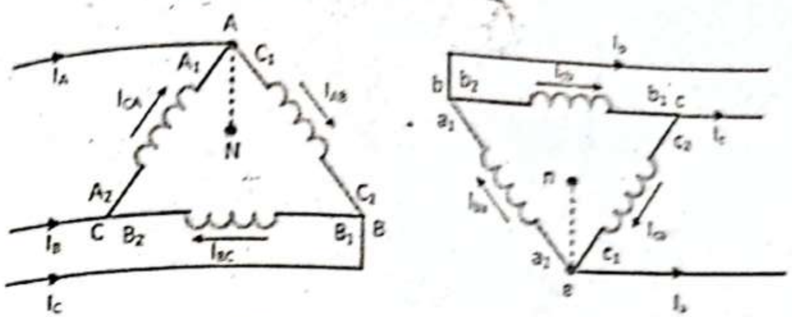
The magnetising current and voltage drops in impedances have been neglected. Under the balanced condition, the line current is √3 times the phase winding current. In this configuration, the corresponding line and phase voltage are identical in magnitude on both primary and secondary sides.

The secondary Line-to-Line voltage is in phase with the primary Line-to-Line voltage with a voltage ratio equal to the turns ratio.

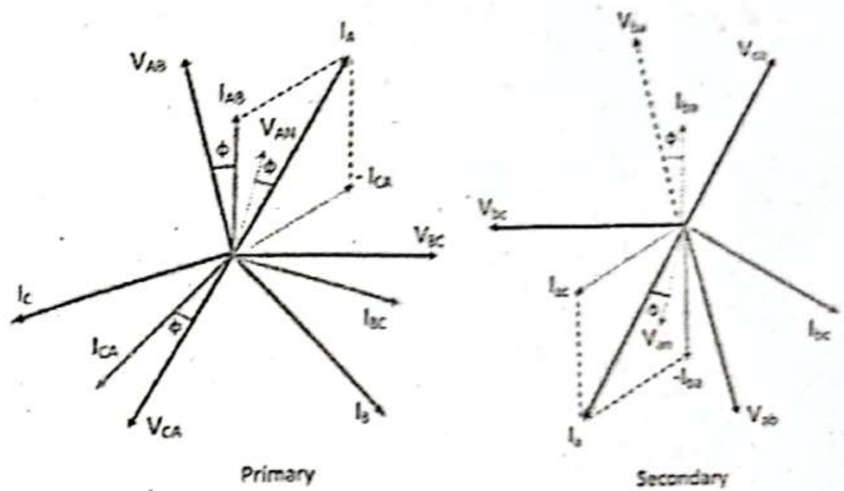
If the connection of the phase windings is reversed on either side, the phase difference of 180° is obtained between the primary and the secondary system. Such a connection is known as an 180° connection.

The delta-delta connection with 180° phase shift is shown in the figure below. The phasor diagram of a three phase transformer shown that the secondary voltage is in phase opposition with the primary voltage.

The delta-delta transformer has no phase shift associated with it and problems with unbalanced loads or harmonics.



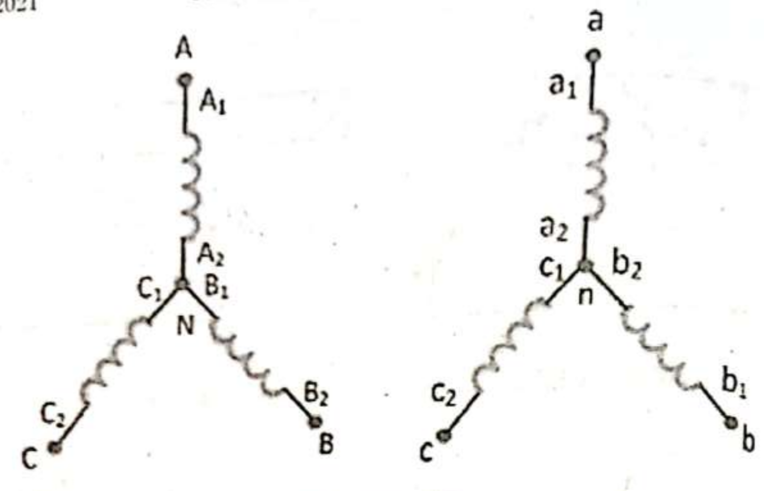
180° Phase Shift of Delta-Delta Connection of Transformer



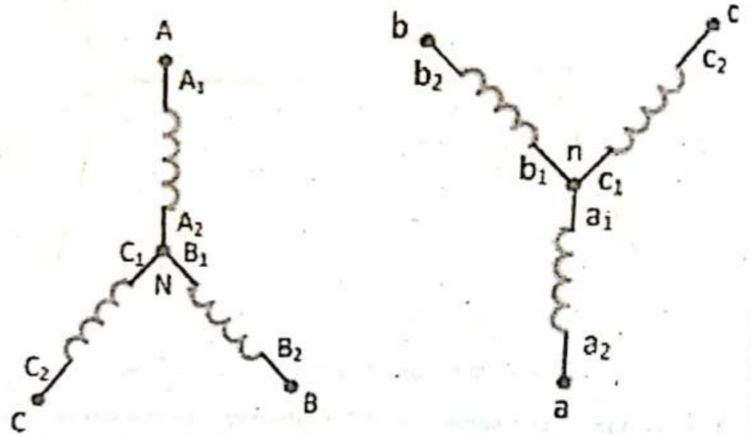
180° Phase Shift of Delta Delta Connection of Transformer

2. Star-Star (Y-Y) Connection of Transformer: The star-star connection of three identical single phase transformer on each of the primary and secondary of the transformer is shown in the figure below. The phasor diagram is similar as in delta-delta connection.

The phase current is equal to the line current and they are in phase. The line voltage is three times the phase voltage. There is a phase separation of 30° between the line and phase voltage. The 180° phase shift between the primary and secondary of the transformer is shown in the figure above.



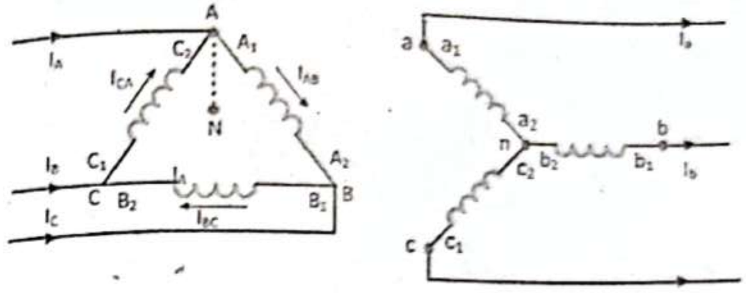
0° Phase Shift



180° Phase Shift

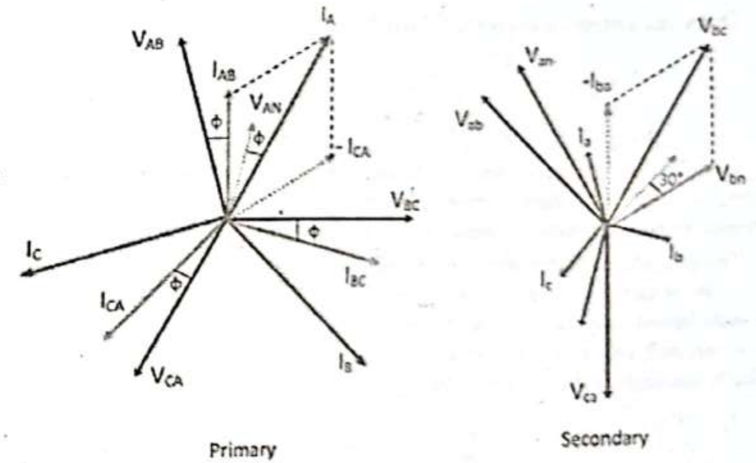
Star-Star Connection of Transformer

3. Delta-Star (Δ-Y) Connection: The Δ-Y connection of the three winding transformer is shown in the figure below. The primary line voltage is equal to the secondary phase voltage. The relation between the secondary voltages is $V_{LS} = \sqrt{3}\, V_{PS}$.



Delta Star Connection of Transformer

The phasor diagram of the Δ-Y connection of the three phase transformer is shown in the figure below. It is seen from the phasor diagram that the secondary phase voltage V_{an} leads the primary phase voltage V_{AN} by 30°. Similarly, V_{bn} leads V_{BN} by 30° and V_{cn} leads V_{CN} by 30°,This connection is also called +30° connection.

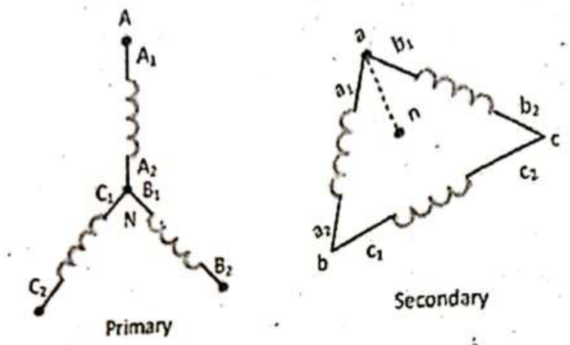


Phasor Diagram of Delta-Star Connection of Transformer

By reversing the connection on either side, the secondary system voltage can be made to lag the primary system by 30°. Thus, the connection is called -30° connection.

4. Star-Delta (Y-Δ) Connection: The star-delta connection of three phase transformer is shown in the figure above. The primary tine voltage is √3 times the primary phase voltage. The secondary line voltage is equal to the secondary phase voltage. The voltage ratio of each phase is

$$\frac{V_{\phi P}}{V_{\phi S}} = a$$



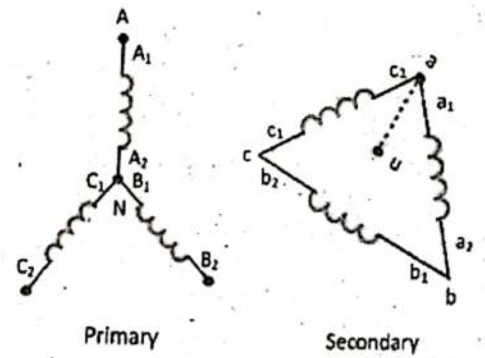
Star-Delta Connection of Transformer

Therefore line-to-line voltage ratio of Y-Δ connection is

$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}V_{\phi P}}{V_{\phi S}} = \sqrt{3}a$$

The phasor diagram of the configuration is shown in the figure above. There is a phase shift of 30 lead exists between respective phase voltage. Similarly, 30° leads exi between respective phase voltage. Thus the connection Is called +30° connection.

The phase shows the star-delta connection of transformer for a phase shift of 30 lag. This connection is called –30° connection. This connection has no problem with the unbalanced load and thirds harmonics. The delta connection provided balance the unbalanced load and thirds harmonics. The delta connection provided balanced phase on the Y side and provided a balanced path for the circulation of third harmonic without the used of the neutral wire.



Star-Delta Connection of a transformer

MEASURING INSTRUMENTS:

Electromagnetism

Refer to Q.1(i), Page: 13–2015

Refer to Q.4(b), Page: 18–2015

Different Torques in Indicating instruments: ***Refer to Q.6(a), Page: 34–2015***

Controlling Torque: ***Refer to Q.1(d), Page: 8–2016***

Moving Iron Instruments:

Construction & Principle: ***Refer to Q.6(a), Page: 26–2014***

Derivation of Torque: ***Refer to Q.6(a), Page: 18–2016***

Attraction and Repulsion type: ***Refer to Q.8(ii), Page: 24–2015***

Moving Coil instruments:

Permanent Magnet type (PMMC)

PMMC Construction and Working: ***Refer to Q.5(a), Page: 18–2015 or***

Refer to Q.6(b), Page: 34–2015

Derivation of Torque: ***Refer to Q.6(b), Page: 25–2017***

PMMC Numerical: ***Refer to Q.6(a), Page: 20–2015***

Refer to Q.6(b), Page: 18–2016

Refer to Q.7(a), Page: 26–2018

SOLVED EXAMPLES

Q.1. ***Refer to Q.1(e), Page: 13–2017***

Q.2. ***Refer to Q.6(a), Page: 24–2017***

Q.3. ***Refer to Q.6(a), Page: 23–2018***

Dynamometer type Instruments.

Refer to Q.7(a), Page: 28–2014

Damping: ***Refer to Q.1(e), Page: 11–2015***

Numerical: ***Refer to Q.6(b), Page: 27–2014***

Refer to Q.7(a), Page: 19–2016

Difference between MI and PMMC: ***Refer to Q.1(f), Page: 12–2015***

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IPC

UNIT – I DC Circuits

Introduction of Circuit parameters and energy sources (Dependent and Independent), Mesh and Nodal Analysis, Superposition, Thevenin's, Norton's, Reciprocity, Maximum Power Transfer and Millman's Theorems, Star-Delta Transformation and their Applications to the Analysis of DC circuits. [T1],[T2] **[No. of Hrs. 11]**

UNIT – II A.C. Circuits

A.C. Fundamentals, Phasor representation, Steady State Response of Series and Parallel R-L, R-C and R-L-C circuits using j-notation, Series and Parallel resonance of RLC Circuits, Quality factor, Bandwidth, Complex Power, ~~Introduction to balanced 3-phase circuits with Star-Delta Connections~~. [T1],[T2] **[No. of Hrs. 14]**

UNIT – III Measuring Instruments

Basics of measuring instruments and their types, Working principles and applications of moving coil, moving iron (ammeter & voltmeter) and Extension of their ranges, dynamometer-type Wattmeter, induction-type Energy Meter, Two wattmeter method for the measurement of power in three phase circuits, Introduction to digital voltmeter, digital Multimeter and Electronic Energy Meter. [T1],[T2],[R2] **[No. of Hrs. 11]**

UNIT–IV Transformer and Rotating Machines

Fundamentals of Magnetic Circuits, Hysteresis and Eddy current losses, working principle, equivalent circuit, efficiency and voltage regulation of single phase transformer and its applications, Introduction to DC and Induction motors (both three phase and single phase), Stepper Motor and Permanent Magnet Brushless DC Motor. [T1],[T2],[R2]

[No. of Hrs. 12]

Q.9. (b) List and explain the various Losses occurring in a transformer. (6.5)

Ans. The transfomer is a static machine and, therefore, there are no friction or windage losses. The various power losses occuring in a transformer are enumerated below:

1. Iron or Core Losses: Iron loss is caused by the alternating flux in the core and consists of hysteresis and eddy current losses.

(a) Hysteresis Loss. The core of a transformer is subjected to an alternating magnetizing force and for each cycle of emf a hysteresis loop is traced out. The hysteresis loss per second is given by the equation.

Hysteresis loss, $P_h = \eta'(B_{max})^x f v$ joules per second or watts

where f is the supply frequency in Hz, v is the volume of core in cubic metre. η' is the hysteresis coefficient, B_{max} is peak value of flux density in the core and x lies between 1.5 and 2.5 depending upon the material and is often taken as 1.6.

(b) Eddy Current Loss: If the magnetic circuit is made up of iron and if the flux in the circuit is variable, currents will be induced by induction in the iron circuit itself. All such currents are known as eddy currents.

Eddy current results in a loss of power, with consequent heating of the material. The eddy current loss is given by equation

$$P_e = K_e(B_{max})^2 f^2 t^2 v \text{ watts or joules per second}$$

From the above equation for eddy current loss in a thin sheet it is obvious that eddy current loss varies (*i*) as the square of maximum flux density (*ii*) as the square of the frequency and (*iii*) as the square of thickness of laminations.

The hysteresis and eddy current losses depends upon the maximum flux density in the core and supply frequency. Since it has been determined that the mutual flux varies somewhat with the load (its variation being 1 to 3% from no load to full load), the core losses will very somewhat with the load its power factor. It may be emphasized here that core losses are assumed to remain constant from no load to full load, the variation in losses from no load to full load being very small and negligible.

These losses are determined from the open circuit test.

The input to the transformer with rated voltage applied to the primary and secondary open circuited is equal to the core loss.

These losses are minimized by using steel of high silicon constant for the core and by using very thin laminations (0.3 mm to 0.5 mm) insulated from each other either by insulating varnish or by layer of papers.

2. Copper or Ohmic Losses. These losses occurs due to ohmic resistance of the transformer windings. If I_1 and I_2 are the primary and secondary current respectively and R_1 and R_2 are the respective resistance of primary and secondary winding then copper losses occuring in primary and secondary winding will be $I_1^2R_1$ and $I_2^2R_2$ respectively. So total copper losses will be $(I_1^2 R_1 + I_2^2 R_2)$. These losses vary as the square of the load current or kVA. For example if the copper losses at full load are P_c then copper losses at one-half or one-third of full load will be $\left(\frac{1}{2}\right)^2 P_c$ or $\left(\frac{1}{3}\right)^2 P_c$, *i.e.*, $\frac{P_c}{4}$ or $\frac{P_c}{9}$ respectively.

Copper losses are determined on the basis of constant equivalent resistance R_{eq} determined from the short-circuit test and then corrected to 75°C (Since the standard operating temperature of electrical machines is taken 75° C).

FIRST TERM EXAMINATION [SEPT. 2018]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

Time : 1.5 hrs. **M.M. : 30**

Note: Q. 1. is compulsory. Attempt any two questions from the rest.

Q.1. Answer the following questions. (2.5)

(a) State and explain reciprocity theorem.

Ans. Reciprocity Theorem

Reciprocity Theorem states that: The current I in any branch of a network, due to a single voltage source E anywhere else in the network, will equal the current through the branch in which the source was originally located if the source is placed in the branch in which the current I was originally measured. The reciprocity theorem is applicable only to single-source networks.

| OR |

In any linear and bilateral network, if a source of emf E in any branch produces a current I in any other branch, then after interchanging the positions of E and I, the same emf E acting in the second branch would produce the same current I in the first branch.

Illustration: Consider a network as shown in Fig. 1.(a). In the network, the current I due to the voltage source E is to be determined. If the position of each is interchanged as shown in Fig. I(b), the current I will be the same value as indicated. To demonstrate the validity of this statement and the theorem, consider the network of Fig. 2, in which values for the elements of Fig. 1.(a) have been assigned.

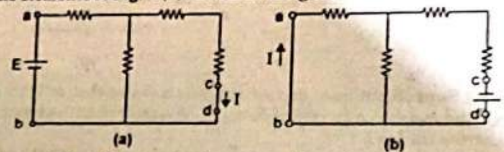

Fig. 1 Demonstrating the reciprocity theorem.

Finding the current I due to a source E

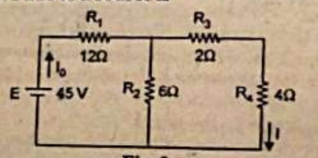

Fig. 2.

The total resistance is

$$R = R_1 + [R_2 \| (R_3 + R_4)]$$
$$= 12 + [6 \| (2+4)] = 12 + (6 \| 6)$$
$$= 12 + 3 = 15\ \Omega$$

$$I_S = \frac{E}{R} = \frac{45}{15} = 3A$$

and

$$I = \frac{1}{2} \times I_S = \frac{3}{2} = 1.5A$$

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[∵ I_B is divided into 2 equal half in 6 Ω and (2 + 4) Ω branch]

Interchanging the location of E and I of Fig. 2 to demonstrate the validity of the reciprocity theorem

For the network of Fig. 3, which corresponds to that of Fig. 1(b),

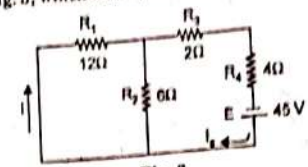


Fig. 3.

$$R = R_4 + R_3 + (R_1 \| R_2) = 4 + 2 + (12 \| 6) = 6 + 4 = 10\ \Omega$$

$$I_B = \frac{E}{R} = \frac{45}{10} = 4.5\text{A}$$

$$I = \frac{R_2}{R_2 + R_1} \times I_B = \frac{6}{6+12} \times 4.5 = \frac{6 \times 4.5}{18} = \frac{4.5}{3} = 1.5\text{A}$$

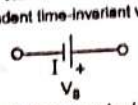
Q. 1. (b) What do you understand by "Dependent" and "Independent" energy sources? **(2.5)**

Ans. Energy Sources (Voltage and Current Sources)

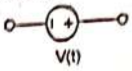
Independent Sources

1. Voltage Source: An ideal voltage source is a device that produces a constant voltage across its terminals, no matter what current is draw from it.

Independent time-invariant voltage source

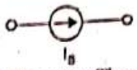


Independent time-variant voltage source



2. Current Source: An ideal current source is a device that delivers a constant current to any load resistance connected across it, no matter what the terminal voltage is developed across the load.

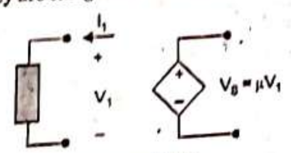
Independent time-invariant current source



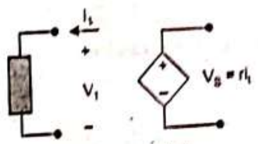
Independent time-invariant current source

Dependent Sources: The voltage and current sources may be dependent and either may be controlled by a voltage or current. A dependent source is represented by a diamond-shaped symbol.

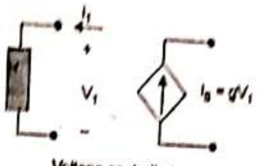
They are categorized into four sources.



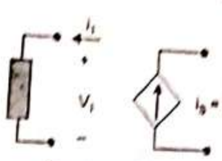
Voltage-controlled voltage source (VCVS)



Current-controlled voltage source (CCVS)

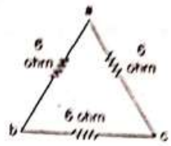


Voltage-controlled current source (VCCS)

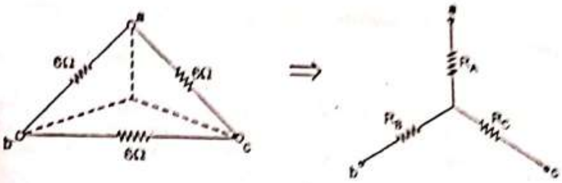


Current-controlled current source (CCCS)

Q. 1. (c) Convert delta network given in fig. in equivalent star network. **(2.5)**



Ans.



$$R_A = \frac{6 \times 6}{6+6+6} = \frac{36}{18} = 2\Omega$$

$$R_B = \frac{6 \times 6}{6+6+6} = \frac{36}{18} = 2\Omega$$

$$R_C = \frac{6 \times 6}{6+6+6} = \frac{36}{18} = 2\Omega$$

Q. 1. (d) Give statements of Thevenin's and Norton's theorem. **(2.5)**

Ans. Thevenin's Theorem: Thevenin's theorem states that any two-terminal, linear bilateral dc network can be replaced by an- equivalent circuit consisting of a voltage source, E_{Th} (or V_{Th}) and a series resistor, R_{Th} as shown in Fig. 1.

Here, V_{Th} is voltage across'two terminals (load terminals). It is also known as V_{oc} (open circuit voltage). R_{Th} is internal resistance of the network as viewed back into the open circuited network from terminals *a* and *b* with all voltage sources replaced by their internal resistance (if any) and current sources by infinite resistance.

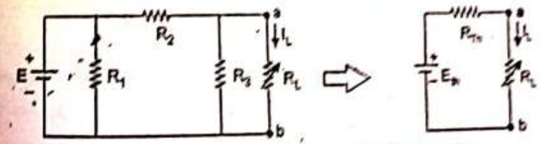


Fig. 1. Illustration of Thevenin's Theorem

Norton's Theorem: Norton Theorem states that any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source, I_N (or I_{sc}) and a parallel resistor, R_N as shown in Fig. 2.

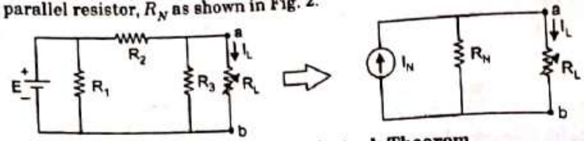


Fig. 2. Illustration of Norton's Theorem

Here, I_N is the constant current equal to the current which would flow in a short-circuit placed across the terminals a and b. R_N is internal resistance of the network as viewed back into the open circuited network from terminals a and b with all voltage sources replaced by their internal resistance (if any) and current sources by infinite resistance.

Q. 2. (a) State and prove max power transfer theorem. **(4)**

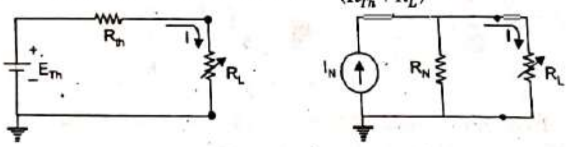
Ans. The maximum power transfer theorem states that a load will receive maximum power from a linear bilateral dc network when its total resistive value is exactly equal to the Thevenin resistance of the network as "seen" by the load.

For the Thevenin equivalent circuit of Fig. maximum power will be delivered to the load when $R_L = R_{Th}$

For the Norton equivalent circuit of Fig. maximum power will be delivered to the load when $R_L = R_N$

Consider a network consists of a generator of emf E and internal resistance R_{Th} as shown in Fig. in which a load resistance R_L is connected across the terminals A and B of a network. It is required to determine the value of R_L that will draw maximum power from the source.

The current delivered to the load resistance, $I = \dfrac{E}{(R_{Th}+R_L)}$



Thevenin Equivalent Circuit **Norton Equivalent Circuit**

Power delivered to the load resistance, $P = I^2 R_L = \dfrac{E^2 R_L}{(R_{Th}+R_L)^2}$

Differentiating the above expression w.r.t. R_L and equate to zero, we get

$$\frac{dP}{dR_L} = \frac{E^2(R_{Th}+R_L)^2 - 2R_L(R_{Th}+R_L)E^2}{(R_{Th}+R_L)^4} = 0$$

$$E^2(R_{Th}+R_L)[R_{Th}+R_L-2R_L] = 0 \quad \ldots \rightarrow R_L = R_{Th}$$

Thus, the condition for maximum power transfer is that the load resistance R_L shall be equal to internal resistance or

Thevenin resistance R_{Th}, of the network.

The value of the maximum power transferred is -

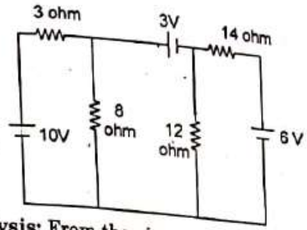
$$P_{max} = \frac{E^2}{4R_{Th}} \text{ or } P_{max} = \frac{V_{Th}^2}{4R_{Th}} \text{ or } P_{max} = \frac{V_{OC}^2}{4R_{Th}}$$

Similarly, for the current source, the power transferred will be maximum when load conductance- is equal to the source conductance i.e. $G_L = G_N$

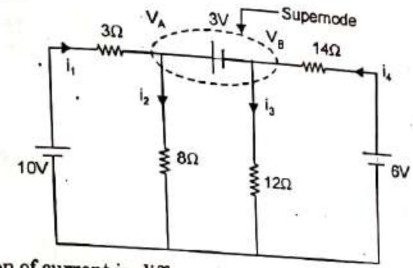
The value of the maximum power transferred is -

$$P_{max} = \frac{I_N^2}{4G_N} \text{ or } P_{max} = \frac{I_{SC}^2}{4G_N}$$

Q. 2. (b) For the circuit shown in fig. Find current across 8 ohm resistor by nodal analysis OR by mesh analysis. **(6)**



Ans. By Nodal Analysis: From the given circuit, it is clear that it is the case of super node.



Let the direction of current in different branches be i_1, i_2, i_3 and i_4 as shown in the modified circuit diagram.

By nodal analysis, we have

$$i_1 + i_4 = i_2 + i_3$$

$$\frac{10-V_A}{3} + \frac{6-V_B}{14} = \frac{V_A}{8} + \frac{V_B}{12}$$

$$\frac{(140-14V_A+18-3V_B)}{3\times 14} = \frac{3V_A+2V_B}{24}$$

$$4(158-14V_A-3V_B) = 7(3V_A+2V_B)$$

$$632-56V_A-12V_B-21V_A-14V_B = 0$$

$$77V_A+26V_B = 632 \quad \ldots(1)$$

From the super node, we have

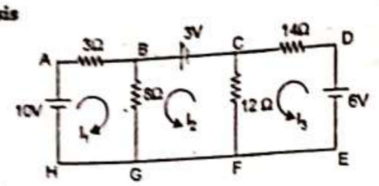
$$V_A - V_B = 3 \quad \ldots(2)$$

$$V_B = V_A - 3$$

$$77\,V_A + 26\,(V_A - 3) = 632$$
$$77\,V_A + 26\,V_A - 78 = 632$$
$$V_A = \frac{710}{103} = 6.893\,V$$

$\therefore$ The current through 8Ω resistor $= i_2 = \frac{V_A}{8} = \frac{6.893}{8} = 0.862\,A$

By Mesh Analysis



From loop ABGH, we get

$$10 - 3I_1 - 8(I_1 + I_2) = 0$$
$$10 - 3I_1 - 8I_1 - 8I_2 = 0$$
$$11I_1 + 8I_2 = 10 \quad ...(1)$$

From loop, BCFG, we get

$$3 - 8\,(I_1 + I_2) - 12\,(I_2 - I_3) = 0$$
$$3 - 8I_1 - 8I_2 - 12I_2 + 12I_3 = 0$$
$$8I_1 + 20I_2 - 12I_3 = 3 \quad ...(2)$$

From loop CFDE, we get

$$6 - 14\,I_3 + 12\,(I_2 - I_3) = 0$$
$$6 - 14I_3 + 12I_2 - 12I_3 = 0$$
$$12\,I_2 - 26\,I_3 = -6 \quad ...(3)$$

$$\Rightarrow \quad I_3 = \frac{6 + 12I_2}{26}$$

From eq. (2) we have

$$8I_1 + 20I_2 - 12\left(\frac{6+12I_2}{26}\right) = 3$$
$$208I_1 + 520I_2 - 72 - 144\,I_2 = 3 \times 26$$
$$208I_1 + 376I_2 = 150 \quad ...(4)$$

From eq. (1) we have $\quad I_2 = \frac{10 - 11I_1}{8}$

From eq. (4) we have

$$208\,I_1 + 376\left(\frac{10 - 11I_1}{8}\right) = 150$$
$$208\,I_1 + 47\,(10 - 11I_1) = 150$$
$$208\,I_1 + 470 - 517\,I_1 = 150$$
$$309\,I_1 = 320$$
$$\boxed{I_1 = 1.035A}$$

$$\Rightarrow \quad I_2 = \frac{10 - 11 \times 1.035}{8} \Rightarrow \boxed{I_2 = -0.173A}$$

$\therefore$ Current though 8Ω resistor $= I_1 + I_2$

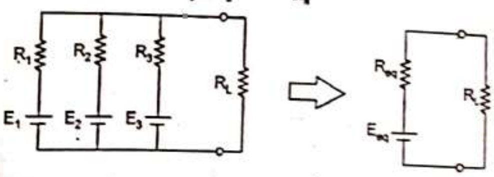
$$= 1.035 - 0.173 = 0.862\text{ A}$$

Q. 3. (a) Explain Mill- man's theorem. (3)

Ans. Millman's Theorem is stated as:

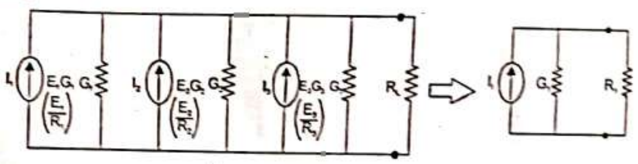
(i) As Applicable to Voltage Sources: If 'n' voltage sources $E_1, E_2, ... E_n$ having internal resistances $R_1, R_2, ... R_n$ are in parallel, then these sources may be replaced by a single voltage source V_{eq} having a series resistance R_{eq}, such that V_{eq} and Z_{eq} has the values given as -

$$V_{eq} = \frac{\frac{E_1}{R_1} + \frac{E_2}{R_2} + ... + \frac{E_n}{R_n}}{\frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}} = \frac{E_1G_1 + E_2G_2 + ... + E_nG_n}{G_1 + G_2 + ... + G_n} = \frac{\Sigma EG}{\Sigma G}$$



$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}} = \frac{1}{G_1 + G_2 + ... + G_n} = \frac{1}{\Sigma G}$$

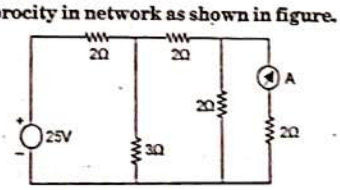
(ii) As Applicable to Current Sources: If 'n' current sources $I_1, I_2, ... I_n$, having internal admittances $G_1, G_2, ... G_n$, are in series, then these sources may be replaced by a single current source I_{eq} having a parallel admittance G_{eq}, such that I_{eq} and G_{eq} has the values given as -



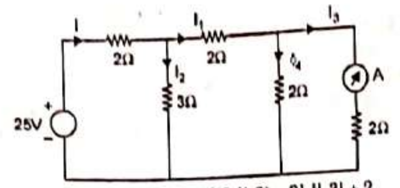
$$I_{eq} = \frac{\frac{I_1}{G_1} + \frac{I_2}{G_2} + ... + \frac{I_n}{G_n}}{\frac{1}{G_1} + \frac{1}{G_2} + ... + \frac{1}{G_n}} = \frac{I_1R_1 + I_2R_2 + ... + I_nR_n}{R_1 + R_2 + ... + R_n} = \frac{\Sigma IR}{\Sigma R}$$

$$G_{eq} = \frac{1}{\frac{1}{G_1} + \frac{1}{G_2} + ... + \frac{1}{G_n}} = \frac{1}{R_1 + R_2 + ... + R_n} = \frac{1}{\Sigma R}$$

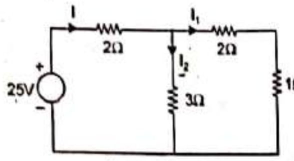
Q. 3. (b) Verify reciprocity in network as shown in figure. (7)

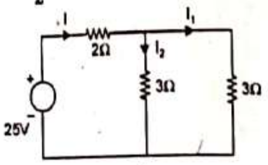


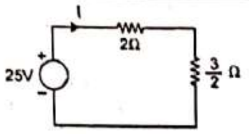
Ans.



$$R_{eq} = [[(2 \parallel 2) + 2] \parallel 3] + 2$$
$$= [(1 + 2) \parallel 3] + 2$$
$$= \frac{3}{2} + 2 = \frac{7}{2}\,\Omega$$







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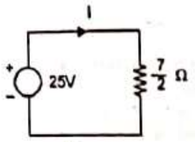
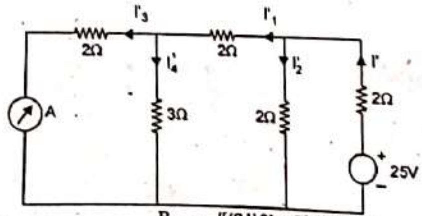


$$V = I R_{eq}$$
$$25 = I \times \frac{7}{2} \Rightarrow I = \frac{50}{7}A$$
$$I_1 = \frac{3}{3+3}\times I = \frac{1}{2}\times\frac{50}{7} = \frac{25}{7}A$$
$$I_3 = \frac{2}{2+2}\times I_1 = \frac{1}{2}\times\frac{25}{7} = \frac{25}{14}A$$

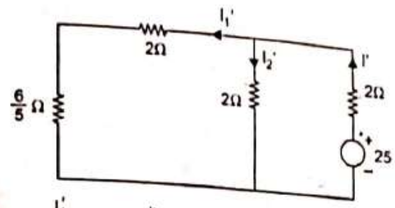
∴ Ratio $\frac{V}{I_3} = \frac{25}{25/14} = 14$

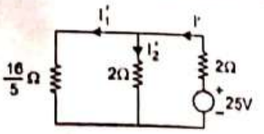
Now, interchanging the position of source voltage and ammeter, we get the modified circuit diagram.



$$R_{eq} = [[(2 \parallel 3) + 2] \parallel 2] + 2$$

$$= \left[\left(\frac{6}{5}+2\right) \parallel 2\right] + 2$$
$$= \left(\frac{16}{5} \parallel 2\right) + 2$$
$$= \frac{\frac{16}{5}\times 2}{\frac{16}{5}+2} + 2 = \frac{16}{13} + 2 = \frac{42}{13}$$





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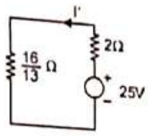
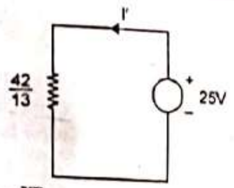


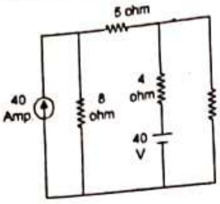


$$V = I'R_{eq}$$
$$25 = I' \times \frac{42}{13}$$
$$I' = \frac{325}{42}A$$
$$I'_1 = \frac{2}{2+\frac{16}{5}}\times I' = \frac{2\times 5}{26}\times\frac{325}{42}$$
$$I'_3 = \frac{3}{3+2}\times I'_1 = \frac{\cancel{3}}{\cancel{5}}\times\frac{\cancel{2}\times\cancel{5}}{\cancel{26}_{13}}\times\frac{325}{\cancel{42}_{14}} = \frac{25}{14}A$$

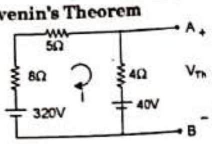
∴ Ratio $\frac{V}{I'_3} = \frac{25}{25/14} = 14$

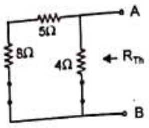
Hence, Reciprocity Theorem is verified.

Q. 4. (a) Draw equivalent Thevenin's circuit for Network shown in fig. Take 12 Ohm as load resistance. (5)



Ans. By Thevenin's Theorem





$$R_{Th} = (5+8)\,||\,4 = 13\,||\,4 = \frac{13\times 4}{17} = \frac{52}{17}\Omega$$

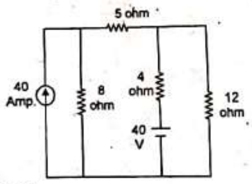
$$320 - 8I - 5I - 4I - 40 = 0$$
$$17I = 280$$
$$I = \frac{280}{17} = 16.47A$$

$$\Rightarrow \quad 40 + 4I - V_{Th} = 0$$
$$V_{Th} = 40 + 4\times 16.47$$
$$= 105.88\text{ V}$$

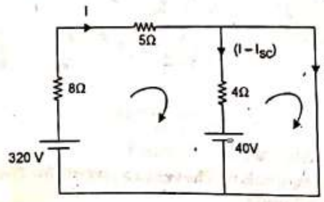
$$\therefore \quad I_L = \frac{V_{Th}}{R_{Th}+R_L} = \frac{105.88}{12+\frac{52}{17}}$$
$$= 7.03\text{ A}$$

Or

Q. 4. (a) Draw equivalent Norton's circuit for Network shown in fig. Take 12 Ohm as load resistance. **(5)**



Ans. By Norton's Theorem



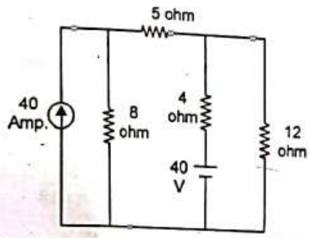
$$R_N = R_{Th} = \frac{52}{17} = 3.06\Omega$$
$$320 - 13I - 4(I - I_{sc}) - 40 = 0$$
$$280 - 17I + 4I_{sc} = 0$$
$$17I - 4I_{sc} = 280$$
$$40 + 4(I - I_{sc}) = 0$$
$$I - I_{sc} = -10 \qquad \text{...(1)}$$
$$I = I_{sc} - 10$$

From eq. (1) and (2), we get

$$17(I_{sc} - 10) - 4I_{sc} = 280 \qquad \text{...(2)}$$
$$13I_{sc} = 450$$
$$I_{sc} = \frac{450}{13} = 34.61A$$

$$\therefore \quad I_L = \frac{R_N}{R_L + R_N}\times I_{sc} = \frac{3.06}{12+3.06}\times 34.61$$
$$= 7.03\text{ A}$$

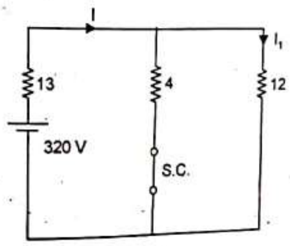
Q. 4. (b) Find current across. 12 ohm resistor in fig. by superposition theorem. **(5)**



Ans. By Super position Theorem

Case 1: Considering the 320 V source voltage only.

$$R_{eq} = (12\,||\,4) + 13$$
$$= \frac{12\times 4}{16} + 13 = 16\,\Omega$$



$$V = IR_{eq}.$$
$$320 = I\times 16$$

$$I = \frac{320}{16} = 20A$$

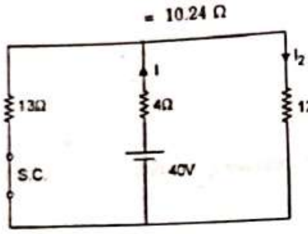
$$I_1 = \frac{4}{4+12} \times I = \frac{4}{16} \times 20 = 5A$$

Case 2: Considering the 40 V source voltage only

$$R_{eq} = (13 \| 12) + 4$$

$$= \frac{13 \times 12}{25} + 4$$

$$= 10.24\ \Omega$$



$$V = IR_{eq}$$

$$40 = I \times 10.24$$

$$I = \frac{40}{10.24} A$$

$$I_2 = \frac{13}{13+12} \times I = \frac{13}{25} \times \frac{40}{10.24} = 2.03A$$

$\therefore$ Total current through 12 Ω resistor $= I_1 + I_2$

$$= 5 + 2.03$$

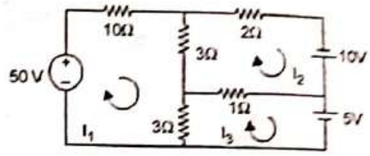
$$= 7.03\ A$$

END TERM EXAMINATION [NOV-DEC. 2018]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

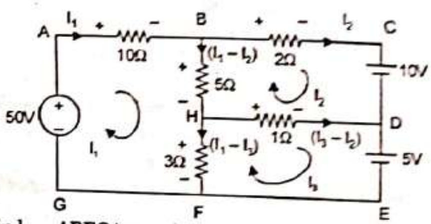
Time : 3 hrs. **M.M. : 75**

***Note:** Attempt any five questions including Q. No. 1 which is compulsory. Select one question from, each unit. Assume missing data if any.*

Q.1. (a) Find the mesh currents I_1, I_2, and I_3 in the circuit shown below in fig. (5)



Ans.



Applying KVL in loop ABFGA, we get

$$50 - 10I_1 - 5(I_1 - I_2) - 3(I_1 - I_3) = 0$$

$$50 - 10I_1 - 5I_1 + 5I_2 - 3I_1 + 3I_3 = 0$$

$$18I_1 - 5I_2 - 3I_3 = 50 \quad ...(1)$$

Applying KVL in loop BCDHB, we get

$$-2I_2 - 10 + (I_3 - I_2) \times 1 + 5(I_1 - I_2) = 0$$

$$-2I_2 - 10 + I_3 - I_2 + 5I_1 - 5I_2 = 0$$

$$5I_1 - 8I_2 + I_3 = 10 \quad ...(2)$$

Applying KVL in loop HDEFH, we get

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

$$-I_3 + I_2 - 5 + 3I_1 - 3I_3 = 0$$

$$3I_1 + I_2 - 4I_3 = 5 \quad ...(3)$$

Solving eq. (1), (2) and (3), we get

$$I_1 = \frac{1175}{356} A = 3.3A$$

$$I_2 = \frac{355}{356} A = 0.997A$$

$$I_3 = \frac{525}{356} A = 1.474A$$

Q. 1. (b) Explain the terms complex power, apparent power, real power and reactive power. **(5)**

Ans. Complex Power: In any circuit, let the applied voltage and current flowing be

$$V = V(\cos\alpha + j\sin\alpha) \text{ and } I = I(\cos\beta + j\sin\beta)$$

respectively, $(\alpha - \beta)$ is the phase difference between V and I so, power factor of the circuit is $\cos(\alpha - \beta)$.

But multiplying V and I, we get,

The product of V and I_c is called the **complex power** where I_c is the conjugate of I.

$VI_c = V(\cos\alpha + j\sin\alpha) \times I(\cos\beta - j\sin\beta) = VI[\cos(\alpha-\beta) - j\sin(\alpha-\beta)]$

The real part VI $\cos(\alpha - \beta)$ gives the true power and the imaginary part VI $\sin(\alpha - \beta)$ gives the reactive power. Here, Inductive VARs have a positive sign and Capacitive VARs have a negative sign.

Active Power: The power which is actually consumed in an ac circuit is called the true or active power of the circuit. Power is consumed only in resistance. It is measured in watts. It is expressed as —

$$P = VI\cos\phi \text{ Watts}$$

Reactive Power: A pure inductor and a pure capacitor do not consume any power, as in half cycle, whatsoever power is drawn from the supply source by these components, the same is returned to the supply source in the other half cycle. This power which flows back and forth is called reactive power. This is also known as Wattless power. It is measured in reactive volt-amperes. It is expressed as -

$$Q = VI\sin\phi \quad \text{VAR}$$

Apparent Power: The product of rms values of current and voltage, VI is called the apparent power. It is measured in volt-amperes. It is expressed as -

$$S = VI \quad \text{VA}$$

$$\therefore \quad S^2 = P^2 + Q^2$$

Q. 1. (c) Differentiate between moving iron and moving coil instruments. **(5)**

Ans. Refer to Q.6.(a) of End Term Examiation 2017.

Q. 1. (d) What are the different types of losses in a transformer? How do they depend on voltage and frequency? **(5)**

Ans. 1. Iron or Core Losses: Iron loss is caused by the alternating flux in the core and Hysteresis and Eddy Current losses.

(a) Hysteresis Loss: The core of a transformer is subjected to an alternating magnetizing force and for each cycle of emf, a hysteresis loop is traced out.

The hysteresis loss per second is —

$$P_h = \eta'(B_{max})^x fV \text{ Joules/sec or Watts}$$

where,
η' – Hysteresis Coefficient
B_{max} – Peak value of flux density in core
f – Supply frequency in Hertz
V – Volume of core in m^3.

$1.5 < x < 2.5$ depending upon the material. Usually, $x = 1.6$

(b) Eddy Current Loss: If the magnetic circuit is made up of iron and if the flux in the circuit is variable, currents will be induced by induction in the iron circuit itself. All such currents are known as eddy currents. Eddy currents result in a loss of power with consequent heating of the material.

The eddy current loss is given as -

$$P_e = K_e(B_{max})^2 f^2 t^2 V \text{ Watts}$$

where,
K_e – Eddy Current Constant of Proportionality
B_{max} – Peak value of flux density in core
f – Supply frequency in Hertz
V – Volume of core in m^3
t – Thickness of laminations.

The iron losses are minimized by using steel of high silicon content for the core and by using very thin laminations (0.3 to 0.5 mm) insulated from each other.

2. Copper or Ohmic Losses: These losses occur due to ohmic resistance of the transformer windings.

Copper losses occur in primary windings = $I_1^2 R_1$

Copper losses occur in secondary windings = $I_2^2 R_2$

$\therefore$ Total Cu losses = $I_1^2 R_1 + I_2^2 R_2$

The copper losses vary as the square of the load current or kVA. Copper losses are determined on the basis of constant equivalent resistance R_{eq}, determined from the short-circuit test.

It is known that for a transformer,

$$V = 4.44 f\Phi_m N = 4.44 f B_m A N$$

Where A = area

$B_m \propto (V/f)$ (For constant A and N)

Thus as voltage changes, the maximum flux density changes and both eddy current and hysteresis losses also changes. As voltage increases, the maximum flux density in the core increases and total iron loss increases.

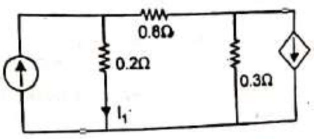
As frequency increases, the flux density in the core decreases but as the iron loss is directly proportional to the frequency hence effect of increased frequency is to increase the iron losses. Thus iron loss increases as the voltage and frequency increases for the transformer.

Q. 1. (e) What is the significance of back e.m.f in a DC motor? **(5)**

Ans. When the motor armature continues to rotate due to motor action, the armature conductors cut the magnetic flux and, therefore, emfs are induced in them. The direction of this induced emf, known as back emf, is such that it opposes the applied voltage. The significance of back emf in DC motor is that the presence of back emf makes the dc motor a self regulating machine i.e. it makes the dc motor to draw as much armature current as is just sufficient to develop the required load torque.

UNIT-I

Q. 2. (a) Find the voltage across the 0.8 Ω resistor using nodal analysis for circuit shown in Fig. **(4.5)**



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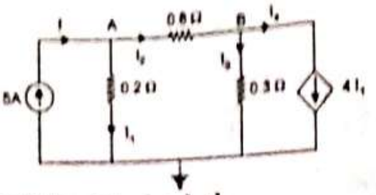
Ans.



Applying KCL at node A, we get

$$I = I_1 + I_2$$

$$5 = \frac{V_A}{0.2} + \frac{V_A - V_B}{0.8}$$

$$5 = 5V_A + \frac{5}{4}(V_A - V_B)$$

$$20 = 20V_A + 5V_A - 5V_B$$

$$25V_A - 5V_B = 20$$

$$5V_A - V_B = 4 \quad \text{...(1)}$$

Applying KCl at node B, we get

$$I_2 = I_3 + I_4$$

$$\frac{V_A - V_B}{0.8} = \frac{V_B}{0.3} + 4I_1$$

$$\frac{5}{4}(V_A - V_B) = \frac{10}{3}V_B + \frac{4V_A}{0.2}$$

$$\frac{5}{4}(V_A - V_B) = \frac{10V_B}{3} + 20V_A$$

$$15(V_A - V_B) = 4(10V_B + 60V_A)$$

$$15V_A - 15V_B = 40V_B + 240V_A$$

$$225V_A = -55V_B$$

$$V_A = -\frac{55}{225}V_B = -\frac{11}{45}V_B \quad \text{...(2)}$$

From eq (1) and (2), we get

$$V_B = 5V_A - 4$$

$$\Rightarrow \quad V_A = -\frac{4}{45}(5V_A - 4)$$

$$45V_A = -55V_A + 44$$

$$100V_A = 44$$

$$V_A = \frac{44}{100}V \Rightarrow \boxed{V_A = 0.44\ V}$$

$$\Rightarrow \quad V_B = 5 \times 0.44 - 4$$

$$\boxed{V_B = -1.80\ V}$$

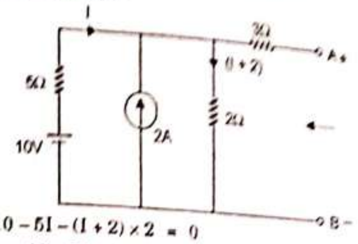
$\therefore$ Voltage across $0.8\ \Omega = V_A - V_B$

$= 0.44 - (-1.80) = 2.24$ V

Q. 2. (b) Find maximum power that can be transferred to R_L in the circuit shown in Fig. **(8)**

Ans. *For maximum power transfer,* $R_L = R_{Th}$ and $P_{max} = \frac{V_{Th}^2}{4R_L}$

In the given circuit, removing the load resistor R_L, we get
Applying KVL in the loop, we get



$$10 - 5I - (I + 2) \times 2 = 0$$

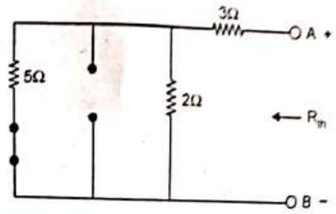
$$10 - 5I - 2I - 4 = 0$$

$$7I = 6$$

$$I = \frac{6}{7}A$$

$$\Rightarrow \quad V_{Th} = 2(I + 2) = 2 \times \left(\frac{6}{7} + 2\right) = 2 \times \frac{20}{7} = \frac{40}{7}V$$

$$\Rightarrow \quad R_{Th} = (5 \| 2) + 3$$



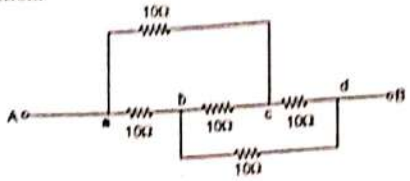
$$= \frac{5 \times 2}{5 + 2} + 3 = \frac{10}{7} + 3 = \frac{31}{7}\ \Omega$$

$$\therefore \quad \boxed{R_L = \frac{31}{7}\Omega}$$

$$\Rightarrow \quad P_{max} = \frac{V_{Th}^2}{4R_L} = \frac{\left(\frac{40}{7}\right)^2}{4 \times \frac{31}{7}}$$

$$= \frac{40 \times 40 \times 7}{7 \times 7 \times 4 \times 31} = \frac{400}{217} = 1.84\ \text{W}$$

Q. 3. (a) Find equivalent resistance between A and B in Fig. below using star delta transformation. **(5)**



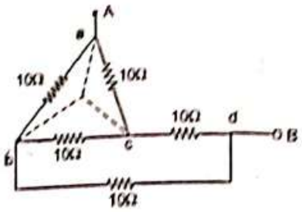
Ans. Rearranging the Network, we get

$$R_1 = \frac{10\times 10}{30} = \frac{10}{3}\,\Omega$$

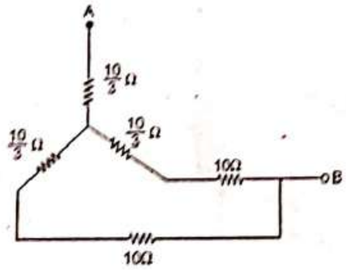
$$R_2 = \frac{10\times 10}{30} = \frac{10}{3}\,\Omega$$

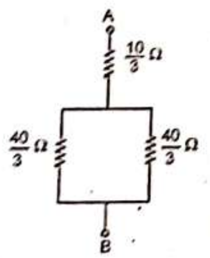
$$R_3 = \frac{10\times 10}{30} = \frac{10}{3}\,\Omega$$

$$r = \frac{10}{3} + 10 = \frac{40}{3}\,\Omega$$

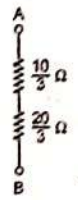


$$R = \frac{\frac{40}{3}\times\frac{40}{3}}{\frac{80}{3}} = \frac{20}{3}\,\Omega$$





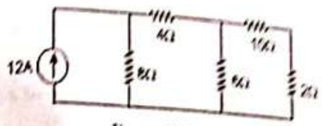
$\Rightarrow$



$$R_{AB} = \frac{10}{3} + \frac{20}{3}$$

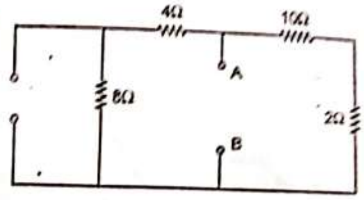
$$\Rightarrow \quad \boxed{R_{AB} = 10\Omega}$$

Q. 3. (b) Find current in 8 Ω resistor using Norton's theorem for Fig. shown below. **(7.5)**



Ans. Here $R_L = 8\Omega$

Rearranging the network for Norton's Resistance, R_N

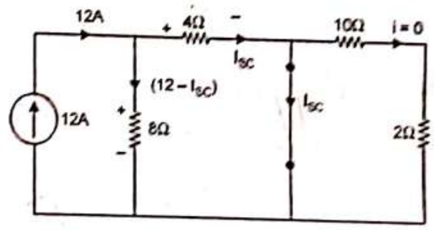


$$\therefore \quad R_N = (4+8)\,||\,(10+2)$$

$$= 12\,||\,12$$

$$= \frac{12\times 12}{24} = 6\Omega$$

Rearranging the network for Norton's current, I_N (in I_{sc})



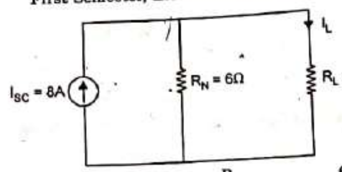
Applying KVL in a loop, we get

$$8(12 - I_{sc}) - 4I_{sc} = 0$$

$$96 - 8I_{sc} - 4I_{sc} = 0$$

$$I_{sc} = \frac{96}{12} = 8A$$

The Norton's Equivalent Circuit is shown as



$\therefore$
$$I_L = \frac{R_N}{R_N + R_L} \times I_{Sc} = \frac{6}{6+6} \times 8 = 4\text{ A}$$

UNIT-II

Q. 4. (a) Calculate the average and RMS value of a full rectified sine wave. **(4.5)**

Ans. RMS Value:

→ RMS value is defined based on heating effect of the wave form.

→ The voltage (A.C) at which heat dissipation in AC circuit is equal to heat dissipation in DC circuit is called V_{rms}.

→ $$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V^2 d\omega t}$$

→ $$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 dt}$$

Average Value: Average value is defined based on charge transfer in a circuit.

→ The voltage (A.C) at which charge transfer in AC is equal to charge transfer in DC circuit, called the Average value.

$$\boxed{V_{ag} = \frac{1}{\pi}\int_0^{\pi} V d\omega t}$$

→ **Form factor:** Form factor is the ratio of RMS value of wave form to average value of wave form.

$$\boxed{\text{Form factor} = \frac{V_{rms}}{V_{av}} = \frac{I_{rms}}{I_{ag}}}$$

Average Value for sinusoidal current or voltage.

$$i = I_m \sin \omega t$$

→ Half cycle i.e. when wt varies from o to π.

$$I_{av} = \frac{\text{Area of first half cycle}}{\pi}$$

$$= \frac{1}{\pi}\int_0^{\pi} i\,d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_{max} \sin \omega t\, d\omega t$$

$$I_{av} = \frac{I_{max}}{\pi}[-\cos \omega t]_0^{\pi} = \frac{2}{\pi} I_{max} = 0.631_{max}$$

$$\boxed{I_{av} = 0.6371_{max}}$$

RMS of effective value for sinusoidal current:

$$i = I_{max} \sin \omega t$$

$$= \frac{\text{Area of I}^{st}\text{ half cycle of i}^2}{\pi}$$

$$= \frac{i}{\pi}\int_0^{\pi} i^2 d\omega t = \frac{1}{\pi}\int_0^{\pi} I_{max}{}^2 \sin^2 \omega t\, d\omega t$$

$$= \frac{I_{max}{}^2}{2\pi}\int_0^{\pi}[1-\cos 2\omega t]d\omega t$$

$$= \frac{I_{max}{}^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}$$

$$= \frac{I_{max}{}^2}{2\pi} \times \pi = \frac{I^2_{max}}{2}$$

$$I_{rms} = I_{max}/\sqrt{2}$$

$$\text{Form factor} = \frac{I_{rms}}{I_{avg}} = \frac{I_m/\sqrt{2}}{2I_m/\pi}$$

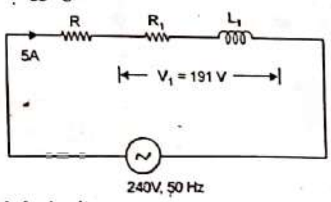
$$\boxed{\text{Form factor} = 1.11}$$

Q. 4. (b) When a resistor and inductor in series are connected to 240V, 50 Hz AC mains, a current of 5A flows lagging 38° behind the supply voltage, while the voltage across the inductor is 191 V. Find the resistance, and the resistance and reactance of inductor. Draw the phasor diagram of the circuit. **(8)**

Ans. Impedance of the whole circuit.

$$Z = \frac{V}{I} = \frac{240}{5} = 48\,\Omega$$

Phase angle, $\phi = 38°$ (lagging)



Resistance of the whole circuit,

$$R + R_1 = Z\cos\phi = 48 \cos 38° = 37.82\,\Omega$$

Inductive reactance of the whole circuit,

$$X_L = Z \sin\phi = 48 \sin 38° = 29.55\,\Omega$$

Impedance of the inductor, $Z_1 = \frac{V_1}{I} = \frac{191}{5} = 38.2\,\Omega$

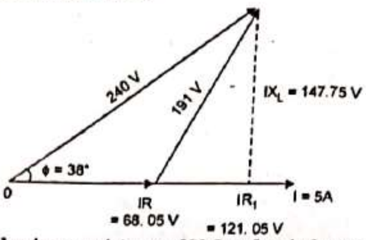
Reactance of inductor, $X_1 = X_L = 29.55\,\Omega$

$\Rightarrow$ $Z_1^2 = X_1^2 + R_1^2$

Resistance of the inductor, $R_1 = \sqrt{Z_1^2 - X_1^2} = \sqrt{(38.2)^2 - (29.55)^2} = 24.21\,\Omega$

Resistance of resistor,
$$R + R_1 = 37.82$$
$$R + 24.21 = 37.82$$
$$R = 13.61\ \Omega$$

The phasor Diagram is shown below



Q. 5. (a) A circuit having a resistance of 20 Ω and an inductance of 0.8H and a variable capacitor in series is connected across a 200V, 50Hz supply. Calculate: (7)

(i) The capacitance to give resonance.

(ii) The voltage across the inductor and the capacitor

(iii) The Q factor of the circuit

Ans. Given, $R = 20\Omega;\ L = 0.8\ H;\ V = 200\ V;\ f = 50\ Hz$

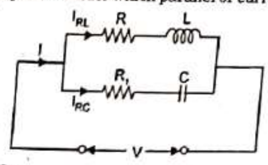
(i) Under Resonant condition, we have
$$X_L = X_C$$
$$2\pi f L = \frac{1}{2\pi f c}$$
$$C = \frac{1}{(2\pi f)^2 L} = \frac{1}{(2\pi \times 50)^2 \times 0.8} = 12.66\ \mu F$$

(ii) At resonance, current through the circuit,
$$I = \frac{V}{R} = \frac{200}{20} = 10A$$
$$\therefore \quad V_L = IX_L = I \times 2\pi f_r L = 10 \times 2\pi \times 50 \times 0.8$$
$$= 2513.27\ V \approx 2514\ V$$
$$\Rightarrow \quad V_C = IX_C$$
$$= I \times \frac{1}{2\pi f_r C} = \frac{10}{2\pi \times 50 \times 12.66 \times 10^{-6}}$$
$$= 2514.3\ V \approx 2514\ V$$

(iii) Q-factor of the circuit,
$$Q = \frac{2\pi f_r L}{R} = \frac{2\pi \times 50 \times 0.8}{20} = 12.57$$

Q. 5. (b) Derive $f_0 = 1/(2\pi\sqrt{LC})\dfrac{\sqrt{R^2 - L/C}}{R_1^2 - L/C}$ for a parallel resonant circuit when R_1 is the resistance in series with the inductor and R_1 is the resistance in series with the capacitor. (5.5)

Ans. When an inductive reactance and a capactive reactance are connected in parallel as shown in fig. condition may reach under which parallel or current resonance takes place.



– For parallel resonance–

Reactive component of RL branch = Reactive component of RC branch.

i.e.
$$I_{RL} \sin\phi_{RL} = I_{Rc} \sin\phi_{RC} \qquad (1)$$

– From fig.
$$I_{RL} = \frac{V}{\sqrt{R^2 + (W_r L)^2}}$$
and
$$\sin\phi_{RL} = \frac{X_L}{Z_{RL}} = \frac{W_r L}{\sqrt{R^2 + (W_r L)^2}}$$
and
$$I_{RC} = \frac{V}{Z_{Rc}} = \frac{V}{\sqrt{R_1^2 + \left(\frac{1}{W_r C}\right)^2}}$$
and
$$\sin\phi_{RC} = \frac{X_C}{Z_{Rc}} = \frac{1/W_r C}{R_1^2 + \left(\frac{1}{W_r C}\right)^2}$$

From equations (2) and (3) in (1) we get-
$$\frac{V}{\sqrt{R^2 + (W_r L)^2}} \times \frac{W_r L}{\sqrt{R_2 + (W_r L)^2}} = \frac{V}{\sqrt{R_1^2 + \left(\frac{1}{W_r C}\right)^2}} \times \frac{1/W_r C}{\sqrt{R_1^2 + \left(\frac{1}{W_r C}\right)^2}}$$

or
$$\frac{W_r L}{R^2 + (W_r L)^2} = \frac{1/W_r C}{R^2 + (1/W_r C)^2}$$

or
$$\frac{W_r L}{R^2 + W_r^2 L^2} = \frac{W_r C}{W_r^2 R_1^2 C^2 + 1}$$

or
$$L(W_r^2 R_1^2 C^2 + 1) = C(R^2 + W_r^2 L^2)$$

or
$$W_r^2 LC (R_1^2 C - L) = CR^2 - L$$

or
$$W_r = \frac{1}{\sqrt{LC}} \sqrt{\frac{CR^2 - 1}{CR_1^2 - 1}}$$

Resonant Frequency
$$f_r = \frac{1}{2\pi} W_r$$

or
$$f_r = \frac{1}{2\pi\sqrt{LC}} \sqrt{\frac{CR^2 - L}{CR_1^2 - L}}$$

UNIT-III

Q. 6. (a) What is the necessity of controlling torque in an indicating instrument. Discuss the gravity control method of producing controlling torque. (7.5)

Ans. Controlling Torque: The magnitude of the movement of the moving system would be some what indefinite under the influence of deflecting torque unless some controlling torque existed. This torque opposes the deflecting torque and increases with the increase in deflection of the moving system, thus limits the movement and ensures that the magnitude of the deflection is always the same for a given value of quantity to be measured.

Under the influence of the controlling torque, the pointer will return to its zero position on removing the source producing the deflecting torque. Without controlling system, the pointer would swing over its maximum deflected position irrespective of magnitude of current and moreover, once deflected it would not return to its zero position on removing the current.

The controlling torque in indicating instruments is created either by a spring control or gravity control.

Attraction type moving iron instruments are the gravity control method of producing controlling torque.

There are two types of moving Iron instruments. Those are given below:

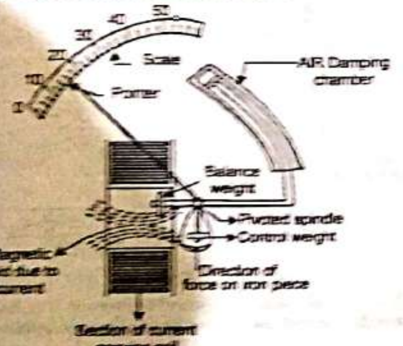
→ attraction type moving Iron.

→ repulsion type moving Iron.

Attraction type moving Iron instruments: The simplest form of attraction type moving Iron instrument uses a solenoid and moving oval shaped soft iron pivoted eccentrically as shown in figure. Solenoid is attached to this iron so that it may deflect along with the moving iron over a graduated scale. The iron is made of sheet metal specially shaped to give a scale a nearly uniform as possible. The moving iron is drawn into the field of solenoid when current flows through it. The movement of the iron is always from weaker magnetic field outside the coil into the stronger magnetic field inside the coil regardless the direction of flow of current.

When the current to be measured is passed through a Solenoid, a magnetic field is set up inside the solenoid, which in turn magnetises the iron. Thus the iron is attracted into the coil causing the spindle and the pointer to rotate. Such instruments normally have spring control and pneumatic damping.

Such an instrument has a scale cramped at the lower end and greatly expanded at the upper end, as the iron torque is quite low. When the moving Iron is just entering the solenoid and increases rapidly as iron is drawn further in.



Q. 6. (b) Discuss working of digital multimeter. **(5)**

Ans. Digital Multimeter: (DMM)

→ A digital Multimeter is a versatile and accurate instrument used in Labotories and field works.

→ On account of developments in the integrated circuit (IC) technology, it has become possible to reduce the size, power requirements and cost of multimeter.

→ Digital multimeter eliminates error and increases speed.

→ The basic function performed by a digital multimeter is an analog to digital (A/D) conversion for example the voltage value may be charged into a proportional time internal, which starts and stops a clock oscillator. In turn the oscillator output is applied to an electronic counter which is provided with a readout in terms of voltage. There are many ways of converting the analog reading into digital form but the most common way is to use ramp voltage.

→ The operating principle of a ramp type Digital Multimeter is simple. A ramp voltage increases linearly from zero to a predetermined level in a given time interval. The ramp voltage value is continuously compared with the voltage being measured. At the instant the value of ramp voltage becomes equal to that of unknown voltage, a coincidence circuit called input comparator generates a pulse which opens the gate as shown in the block diagrams shown in fig.

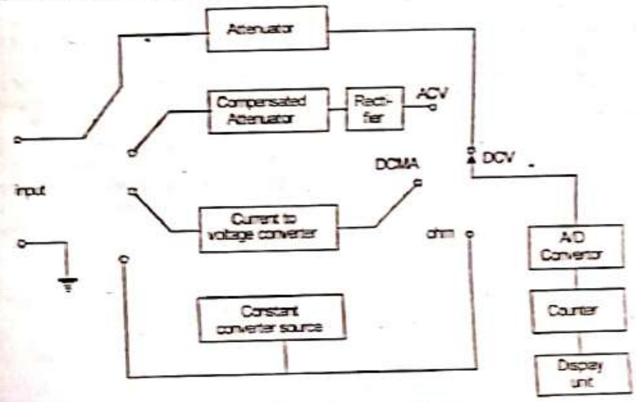


Fig. Block diagram of DMM

→ The ramp voltage continues to decrease till it reaches the ground level. At this instant another comparator gernerates a pulse and closes the gate. The time interval between the opening and closing of the gate is measured with an electronic time interval counter. This count is displayed as a number in digits.

The main parts of digital multimeter are -> digital display unit:

→ ON - OFF switch → Input terminals → Mode switch ·

→ Range switch.

Typical specification of DMM

→ large size LCD display, $3\frac{1}{2}$ digits → Auto zero/Auto polarity

→ Over range indication, → weight 200 g with battery.

Q. 7. (a) Give the principle, construction and applications of moving coil ammeter. Also derive the expression for its deflection torque. **(7.5)**

Ans. Moving Coil Ammeter is an example of PMMC.

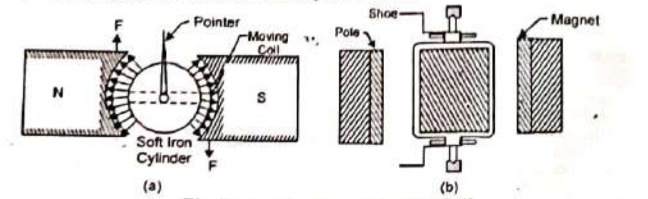


Fig. Permanet Magnet Moving Coil

Construction: A permanent magnet moving coil (PMMC) instrument is shown in Fig. It consists of permanent powerful magnet with soft iron pole pieces. A cylindrical iron core is mounted between the two poles of the magnet giving very narrow air gap in which the sides of a pivoted light rectangular coil lies. The rectangular coil is wound of many turns from fine wire on light aluminium or copper former and acts as moving element. The purpose of using core is to make the field uniform and to reduce the reluctance of the magnetic circuit. A low reluctance helps to retain permanence of the magnet for a longer period.

The current is led into and out of the coil by means of phosphor bronze hair springs provided at both ends. The springs also provide the controlling torque. The springs are spiraled in opposite directions to neutralize the effect of change in temperature.

Principle: When the current to be measured is passed through the coil, say in the direction shown in Fig. a deflecting torque is produced on account of reaction of the permanent magnetic field with the coil magnetic field. The direction of deflecting torque can be determined by Fleming's Left Hand rule.

Torque Equation: If i is the current in amperes flowing through the coil of turns N and length l meters and B is the flux density in tesla in the air gap.

Then deflecting-force, $F = B\,i\,l\,N$ newtons

If r is the distance in metres between the centre of the coil and the force F, then

Deflecting Torque, $T_d = F \times r = BilNr$ Nm

If flux density B in the air gap is constant, then

Deflecting Torque, $T_d \propto i$

Since such instruments are spring controlled,

$\therefore$ Controlling torque, $T_c \propto$ deflection θ

Since in steady deflection position, $T_c = T_d$

$$\therefore \theta \propto i$$

Application: When PMMC is used as an ammeter, except for a very small current range, the moving coil is connected across a suitable low resistance shunt, so that only small part of the main current flows through the coil. The shunt consists of a number of thin plates made up of alloy metal, which is usually magnetic and has a low-temperature coefficient of resistance, fixed between two massive blocks of copper. A resistor of the same alloy is also placed in series with the coil to reduce errors due to temperature variation.

Q. 7. (b) A PMMC instrument gives a reading of 25mA when the potential difference across its terminals is 75mV. **(5)**

Ans. Meter resistance, $R_m = \dfrac{75mV}{25mA} = 3\Omega$

Main circuit current, $I = 50$ A

Meter current for full-scale deflection, $I_m = 25$ mV

$= 0.025$ A

Multiplying factor, $N = \dfrac{I}{I_m} = \dfrac{50}{0.025} = 2000$

$\therefore$ Shunt Resistance, $R_S = \dfrac{R_m}{N-1} = \dfrac{3}{2000-1}$

$= \dfrac{3}{1999} = 0.0015\,\Omega$

UNIT-IV

Q. 8. (a) Draw the equivalent circuit of a single phase transformer referred to primary side. Give the significance of each parameter of the equivalent circuit. Also explain why a transformer draws more current from the supply when the secondary is loaded. **(8.5)**

Ans.

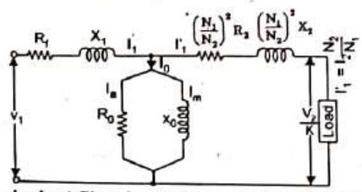


Fig. 1. Exact Equivalent Circuit of a Single Phase Transformer referred to Primary side

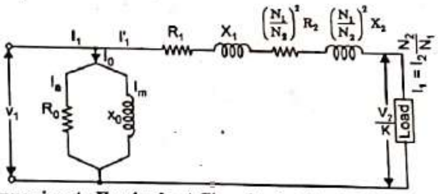


Fig. 2. Approximate Equivalent Circuit of a Single Phase Transformer referred to Primary side

Since I_0 is very small compared to it is less than 5% of full load primary current, I_0 changes the voltage drop insignificantly. Hence, it is good approximation to ignore the excitation circuit in approximate equivalent circuit of transformer. The winding resistance and reactance being in series can now be combined into equivalent resistance and reactance of transformer, referred to primary side.

Reason of more current drawn from supply (when loaded): When the transformer is on no-load, it draws no-load current I_0 from the supply. I_0 sets up an mmf $N_1 I_0$ which produces flux ϕ in the core.

When an impedance is connected across the secondary terminals, current I_2 flows through the secondary winding. The secondary current I_2 sets up its own mmf N_2I_2 and hence creates a secondary flux ϕ_2. This ϕ_2 opposes the main flux ϕ due to I_0 according to Lenz's Law. The opposing secondary flux ϕ_2 weakens the main flux ϕ momentarily, so primary back emf E_1 tends to be reduced. So, difference of applied voltage V_1 and back emf E_1 increases, therefore, more current is drawn from the primary source until the original value of flux ϕ is obtained. It again causes increase in back emf E_1 and it adjusts itself as such that there is a balance between applied voltage V_1 and back emf E_1.

Let the additional primary current be I'_1. The current I_1' is in phase opposition with secondary current I_2 and is called the counter-balancing current. The additional current I_1' sets up an mmf $N_1I'_1$ producing flux ϕ_1' in the same direction as that of main flux ϕ and cancels the flux ϕ_2 produced by secondary mmf N_2I_2 being equal in magnitude.

So, $$N_1I_1' = N_2I_2 \quad \ldots\ldots \rightarrow \quad I_1' = \frac{N_2}{N_1}I_2$$

$\because I_0$ is small, $$\therefore \quad I_1 = I_1' = \frac{N_2}{N_1}I_2 \quad \ldots\ldots \rightarrow \quad I_1 = I_1' = KI_2$$

where, K is the transformation ratio

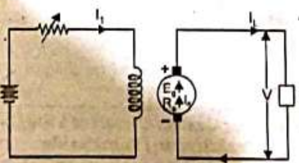
Q. 8. (b) Draw and explain the circuit diagrams of different types of DC generators. (4)

Ans. Types of DC Generators: Generators are generally classified according to these methods of field excitation. On this basis, DC generators are divided into the following two classes:

1. Separately excited DC generators
2. Self-excited DC generators

Separately Excited D.C. Generators: A DC generator whose field magnet winding is supplied from an independent external D.C. source (e.g., a battery etc.) is called a separately excited generator.

The figure shows the connections of a separately excited generator. The voltage output depends upon the speed of rotation of armature and the field current (Eg = φZNP/60 A). The greater the speed and field current, greater is the generated e.m.f. Separately excited DC generators are rarely used in practice.



Armature current, $I_a = I_L$

Terminal voltage, $V = E_g - I_aR_a$

Electric power developed $= E_gI_a$

Power dilevered to load $= E_gI_a - IR = IE - IR = VI_a$

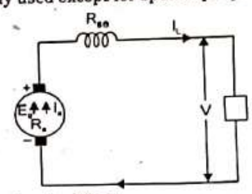
Self-Excited D.C. Generators: A DC generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator.

There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;

- i. Series generator
- ii. Shunt generator
- iii. Compound generator

DC Series generator: In a series wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load.

The figure shows the connections of a series wound generator. Since the field winding carries the whole of load current, it has a few turns of thick wire having low resistance. Series generators are rarely used except for special purposes e.g., as boosters.



Armature current. $I_a = I_{se} = I_L = I$(say)

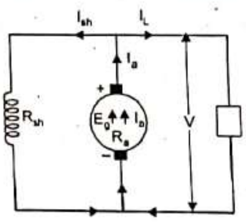
Terminal voltage, $V = E_g - I(R_a + R_{se})$

Power developed in armature $= E_gI_a$

Power delivered to load $= VI_L$

DC Shunt generator: In a shunt generator, the field winding is connected in parallel with the armature winding so that the terminal voltage of the generator is applied across it.

The shunt field winding has many turns of fine wire having high resistance. Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load. The figure below shows the connections of a shunt-wound generator.



Shunt field current $I_{sh} = V/R_{sh}$

Armature current, $I_a = I_L + I_{sh}$

Terminal, voltage, $V = E_g - I_aR_a$

Power developed in armature $= E_gI_a$

Power delivered to load $= VI_L$

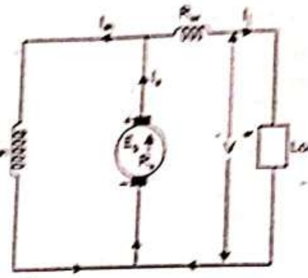
DC Compound generator

In a compound-wound generator, there are two sets of field windings on each pole - one is in series and the other in parallel with the armature.

A compound-wound generator may be:

1. **Short Shunt** in which only shunt field winding is in parallel with the armature winding.

2. **Long Shunt** in which shunt field winding is in parallel with both series field and armature winding.



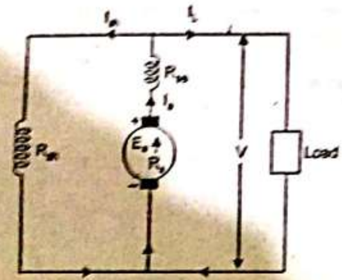
Series field current, $I_{se} = I_L$

Shunt field current, $I_{sh} = V/R_{sh}$

Terminal voltage, $V = E_g - I_a R_a - I_{se} R_{se}$

Power developed in armature $= E_g I_a$

Power delivered to load $= VI_L$



Series field current $I_{se} = I_a = I_L + I_{sh}$

Shunt field current, $I_{sh} = V/R_{sh}$

Terminal voltage, $V = E_g - I_a(R_a + R_{se})$

The power developed in armature $= E_g I_a$

Power delivered to load $= VI_L$

OR

Q. 2. (a) Show that a transformer can be designed to have maximum efficiency at rated load condition if the iron losses and copper losses are equal. **(5)**

Ans. Condition for Maximum Efficiency

As we know that, the transformer efficiency is given by -

$$\eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + x^2 P_{Cu}} = \frac{xP}{xP + P_i + x^2 P_{Cu}}$$

where, P is equal to full-load VA or kVA × load power factor $\cos\phi$

P_i is the total iron loss,

P_{Cu} is the full-load copper loss, and

x is the fraction of full-load kVA at which efficiency is maximum.

Differentiating above equation w.r.t. x, we get

$$\frac{d\eta}{dx} = \frac{d}{dx}\left[\frac{xP}{xP + P_i + x^2 P_{Cu}}\right]$$

$$= \frac{(xP + P_i + x^2 P_{Cu})P - xP(P + 2xP_{Cu})}{(xP + P_i + x^2 P_{Cu})^2} = \frac{P(P_i - x^2 P_{Cu})}{(xP + P_i + x^2 P_{Cu})^2}$$

Efficiency will be maximum if

$$\frac{d\eta}{dx} = 0$$

$$\frac{P(P_i - x^2 P_{Cu})}{(xP + P_i + x^2 P_{Cu})^2} = 0 \longrightarrow P_i - x^2 P_{Cu} = 0$$

$$P_i = x^2 P_{Cu} \quad \text{or} \quad x = \sqrt{\frac{P_i}{P_{Cu}}}$$

Hence, if the iron losses and copper losses are equal, the transformer can be designed to have maximum efficiency at rated full load.

Power transformers employed for bulk power transmission are operated continuously near about full load and are, therefore, designed to have maximum efficiency at full-load.

Q. 2. (b) The equivalent resistance and reactance of a transformer are respectively 0.6 Ω. At what power factor the voltage regulation will be zero? **(3)**

Ans. Given, $R_{02} = 0.6\,\Omega, \quad X_{02} = 0.8\,\Omega$

Voltage Regulation is given as–

$$VR = \frac{I_2 R_{02}\cos\phi + I_2 X_{02}\sin\phi}{E_2}$$

Condition for zero voltage Regulation is

$$I_2 R_{02}\cos\phi + I_2 X_{02}\sin\phi = 0$$

$$\tan\phi = -\frac{R_{02}}{X_{02}} = -\frac{0.6}{0.8} = -0.75$$

$$\phi = \tan^{-1}(-0.75)$$

$$= -36.87°$$

$\Rightarrow$
$$\text{p.f} = \cos\phi$$

$$= \cos(-36.87°) = 0.8$$

Q. 9. (c) Define the slip of 3-phase induction motor. Give some industrial uses of 3-phase induction motors. (4.5)

Ans. Slip: The difference between the speed of the stator field, known as synchronous speed (N_s) and the actual speed of the rotor (N) is known as the slip and is denoted by s. Slip can be expressed in radians per second (rpm), but usually it is expressed as a fraction of N_s.

$$s = \frac{\text{Synchronous speed} - \text{Rotor speed}}{\text{Synchronous speed}} = \frac{N_S - N}{N_S}$$

$$\%s = \frac{N_S - N}{N_S} \times 100$$

- At no-load, the slip is 0.5 %.
- At normal load, the slip is usually between 2 and 5 %.

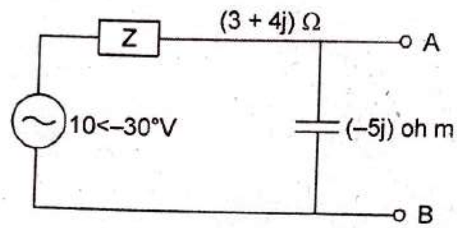
Applications of 3-phase Induction Motors: Wound rotor (or slip-ring) induction motors are used for loads requiring severe starting conditions or for loads requiring speed control such as driving line shafts, lifts, pumps, generators, winding machines, cranes, hoists, elevators, compressors, small electric excavators, printing presses, turn tables, strokers, large ventilating fans, crushers, etc.

FIRST SEMESTER (B. TECH)
FIRST TERM EXAMINATION [2014]
ELECTRICAL TECHNOLOGY [ETEE-107]

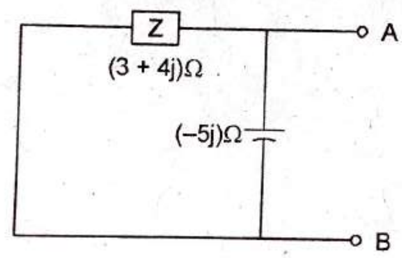
Time : 1.30 hrs. **M.M. : 30**

Note: *No. 1 is compulsory. Attempt any two more questions from the rest.*

Q.1 (*a*) A loudspeaker is connected across terminal A and B of the network shown in fig. 1. To obtain maximum power dissipation in the loudspeaker, the impedance should be .... Ohm. **(2.5 × 4 = 10)**

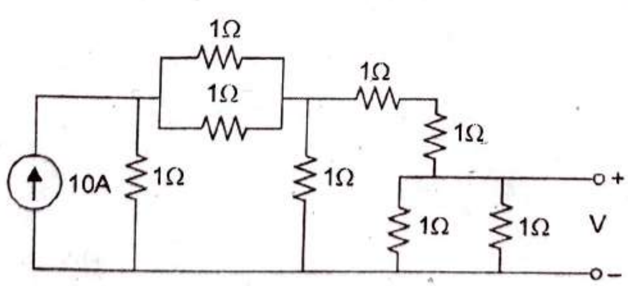


Ans. According to maximum power transfer theorm equivalent impedance is equal with thenenin equivalent impedance. So in the above circuit, one independent voltage source is present, make it short, then th circuit becomes

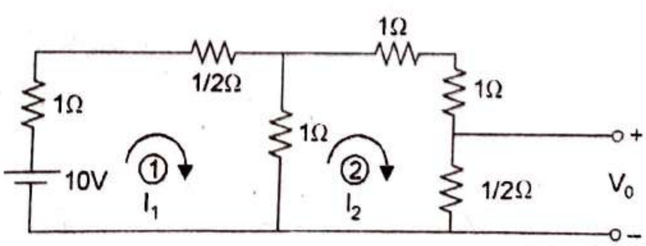


$$Z_{eq} = (3 + 4j) \parallel (-5j)$$
$$= (7.5 + j\,2.5)\ \Omega \text{ Ans.}$$

Q.1. (*b*) The voltage V_0 in the Fig. 2 will be ...... Volt.



Ans. The voltage V_0 in the fig. 2. will be 20/31 = 0.645 Volt.



By using Source conversion

$$10\,A \times 1\,\Omega = 10 \text{ Volt}$$

Apply KVL in loop 1

$$10 - I_1\left(1+\frac{1}{2}\right) - 1\,(I_1 - I_2) = 0$$

$$\Rightarrow \quad 10 - \frac{3}{2}I_1 - I_1 + I_2 = 0$$

$$\Rightarrow \quad 10 - \frac{5}{2}I_1 + I_2 = 0$$

$$\Rightarrow \quad -I_2 = \left(10 - \frac{5}{2}I_1\right)$$

$$\Rightarrow \quad I_2 = \frac{5}{2}I_1 - 10$$

Apply KVL in loop 2

$$-(I_2 - I_1)\,1 - 2\,I_2 - \frac{1}{2}I_2 = 0$$

$$\Rightarrow \quad -3\,I_2 - \frac{1}{2}I_2 + I_1 = 0 \Rightarrow \frac{-7}{2}I_2 + I_1 = 0$$

$$\Rightarrow \quad -\frac{7}{2}\left(\frac{5}{2}I_1 - 10\right) + I_1 = 0$$

$$\Rightarrow \quad \frac{-35}{4}I_1 + \frac{70}{2} + I_1 = 0$$

$$-7.75\,I_1 = -35$$

$$\Rightarrow \quad I_1 = 4.51 \text{ Amp}$$

$$I_2 = \frac{5}{2}I_1 - 10$$

$$= \frac{5}{2}(4.51) - 10 = 1.275 \text{ Amp}$$

$$V_o = I_2 R_{eq} = 1.275 \times 0.5$$

$$= 0.645 \text{ Volt.}$$

Q.1(c) The frequency at which maximum voltage occurs across the inductance in an RLC series circuit is?

Ans. $$\frac{1}{2\pi\sqrt{LC}} = f_r\,(Hz)$$

Q.1(d) In a serious RL circuit R = 20Ω, L = 0.1H and frequency is 50 Hz. The impedance of the circuit would be doubled by making R = ... ohms.

Ans. $$Z = \sqrt{(20)^2 + (2\times\pi\times 50\times 0.1)^2}$$

$$Z = 37.24\ \Omega$$

according to question impedance becomes doubled.

$$Z + Z = 2Z$$

$$\Rightarrow \quad 2Z = \sqrt{R^2 + x_1^{\,2}}$$

$$\Rightarrow \quad 2(37.24) = \sqrt{(R)^2 + (2\times\pi\times 50\times 0.1)^2}$$

$$R = 67.5\ \Omega$$

Q.2 (a) Find the following from the given circuit diagram in fig.3:

(i) Current I_1 using mesh current method.

(ii) Find the Thevenin's equivalent between therminal c and d removing the current source of 2A and 50 ohm resistance across current source.

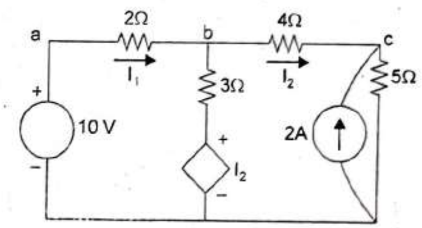
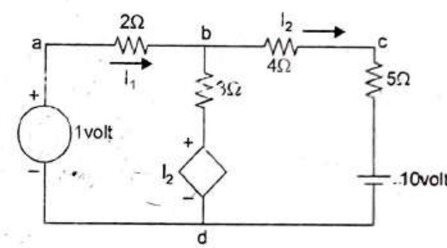


Fig. 3

Ans.



Apply *KVL*/mesh analysis in the loop *abda*.

$$10 - 2\,I_1 - 3\,(I_1 - I_2) - I_2 = 0 \qquad ...(1)$$

$$10 - 5\,I_1 + 2\,I_2 = 0$$

$$I_2 = \frac{10 - 5I_1}{-2} \qquad ...(2)$$

Apply *KVL* in the loop *bcdb*,

$$-I_2 - 3\,(I_2 - I_1) - 4\,I_2 - 5I_2 - 10 = 0$$

$$-13\,I_2 + 3I_1 - 10 = 0 \qquad ...(3)$$

Put $I_2 = \dfrac{10 - 5I_1}{-2}$ in equation (3)

So equation (3) becomes

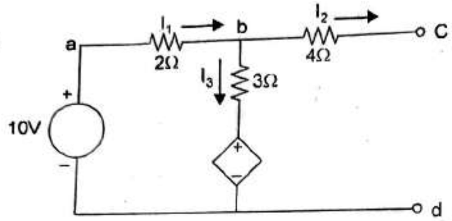
$$-13\left(\frac{10 - 5I_1}{-2}\right) + 3\,I_1 - 10 = 0$$

$$I_1 = 1.83 \text{ amp}$$

$$= 1.83 \text{ Amp } \textbf{(Ans)}$$

(*ii*) Thevenin equivalent circuit between terminal *c* & *d*.

Step 1. Removing the current source of 2 *AR* 5 Ω resistance across current source. The circuit becomes



Step 2: Find out open circuit voltage.

$V_{open\,(cd)}$

Apply KCL at node *b*.

$$I_1 = I_2 + I_3$$

$$\frac{10 - V_b}{2} = \frac{V_b - I_2}{3} \Rightarrow \frac{10 - V_b}{2} = \frac{V_b}{3}$$

[∵ As it is open circuit at cd terminal, so $I_2 = 0$]

$$3(10 - V_b) = 2V_b$$

$$\Rightarrow \quad 30 - 3V_b = 2V_b$$

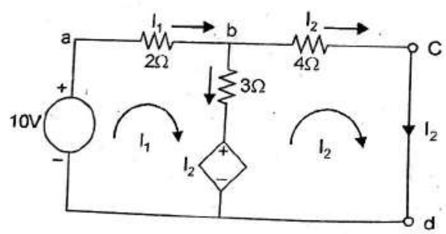
$$\Rightarrow \quad V_b = 6 \text{ Volt} \Rightarrow V_{oc} = 6 \text{ Volt} \qquad [\because V_{cd} = V_b]$$

Step 3: Find out short circuit current

[*N.B.* In this question dependent source is present,

so that we can find out $R_{th} = \dfrac{\text{open circuit voltage}}{\text{short circuit current}}$]

⇒ Short the *cd* terminal; the circuit becomes



here $\quad I_2 = I_{sc}$

where $\quad I_{sc}$ = short circuit current

Apply KVL in LOOP 1,

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

$$10 - 5I_1 + 2I_2 = 0$$

$$I_1 = \frac{10 + 2I_2}{5}$$

Apply KVL in Loop 2

$$I_2 - 3(I_2 - I_1) - 4I_2 = 0$$

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

$$\Rightarrow \quad -6I_2 + 3\left(\frac{10 + 2I_2}{5}\right) = 0$$

Where $\quad I_1 = \dfrac{10 + 2I_2}{5}$

$$\Rightarrow \quad -6I_2 + \frac{30 + 6I_2}{5} = 0$$

$$\Rightarrow \quad -30I_2 + 30 + 6I_2 = 0$$

$$\Rightarrow \quad -24I_2 + 30 = 0$$

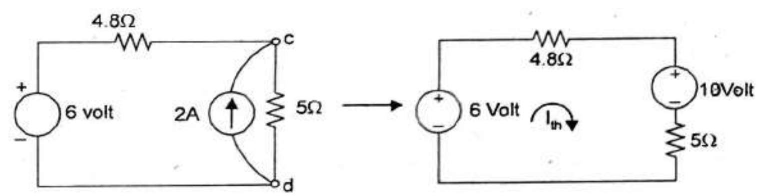
$I_2 = 30/24 = 5/4 = 1.25$ Amp. $\Rightarrow I_2 = I_{\text{short circuit}} = 1.25$ Amp.

Step 4: Find R_{th}

$$R_{th} = \frac{V_{oc}}{I_{sc}}$$

$$= 6/1.25 = 4.8\Omega$$

Step 5: Thevenin equivalent circuit



$$I_{th} = \frac{V_{th}}{R_{th} + R_L} = \frac{6 - 10}{4.8 + 5}$$

$$= -4/9.8 = -0.40 \text{ Amp.}$$

Q.2 (*b*) Derive expression for Resonance in parallel RLC circuit. (3)

Ans. When an inductive reactance and a capacitive reactance are connected in parallel as shown in fig. condition may reach under which parallel or current resonance takes place.

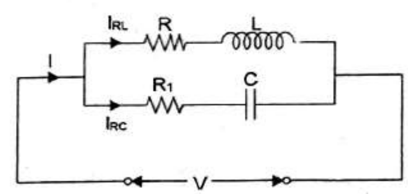


Fig.

– For parallel resonance –

Reactive component of RL branch = Reactive component of RC branch.

i.e $\quad I_{RL} \sin \phi_{RL} = I_{Rc} \sin \phi_{RC} \quad (1)$

– From fig

$$I_{RL} = \frac{V}{\sqrt{R^2+(W_rL)^2}}$$

and
$$\sin\phi_{RL} = \frac{X_L}{Z_{RL}} = \frac{W_rL}{\sqrt{R^2+(W_rL)^2}} \quad (2)$$

and
$$I_{RC} = \frac{V}{Z_{Rr}} = \frac{V}{\sqrt{R_1^{\,2}+\left(\frac{1}{W_rC}\right)^2}} \text{ and.}$$

$$\sin\phi_{Rc} = \frac{X_C}{Z_{Rc}} = \frac{1/W_rC}{\sqrt{R_1^{\,2}+\left(\frac{1}{W_rC}\right)^2}} \quad (3)$$

form equations (2) and (3) in (1) we get-

$$\frac{V}{\sqrt{R^2+(W_rL)^2}} \times \frac{W_rL}{\sqrt{R^2+(W_rL)^2}} = \frac{V}{\sqrt{R_1^{\,2}+\left(\frac{1}{W_rC}\right)^2}} \times \frac{1/W_rC}{\sqrt{R_1^{\,2}+\left(\frac{1}{W_rC}\right)^2}}$$

or
$$\frac{W_rL}{R^2+(W_rL)^2} = \frac{1/W_rC}{R^2+(1/W_rC)^2}$$

or
$$\frac{W_rL}{R^2+W_r^{\,2}L^2} = \frac{W_rC}{W_r^{\,2}R_1^{\,2}C^2+1}$$

or
$$L(W_r^{\,2}R_1^{\,2}C^2+1) = C(R^2+W_r^{\,2}L^2)$$

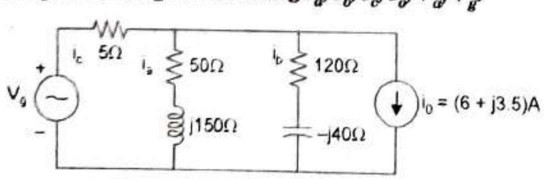
or
$$W_r^{\,2}LC(R_1^{\,2}C-L) = CR^2-L$$

or
$$W_r = \frac{1}{\sqrt{LC}}\sqrt{\frac{CR^2-1}{CR_1^{\,2}-1}}$$

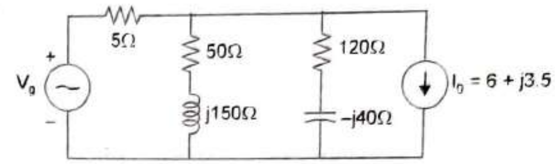
Resonant Frequency
$$f_r = \frac{1}{2\pi}W_r$$

or
$$f_r = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{CR^2-L}{CR_1^{\,2}-L}}.$$

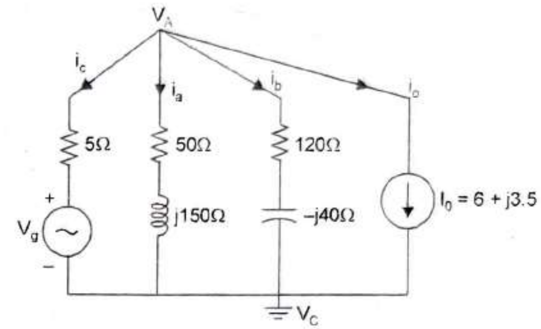
Q.3 (a) The current I_a in the circuit shown in fig. 4 is $2\angle 0°$ A.
(i) Find I_b, Ic and V_g
(ii) Draw the phasor diagram showing $I_a, I_b, I_c, I_o, V_a, V_g$. **(3 × 2)**



Ans. Given $i_a = 2\angle 0°\text{A} = 2$ Amp



Apply KCL / nodal analysis



$$i_c = i_a + i_b + i_o$$

$$\Rightarrow \quad \frac{V_g - V_A}{5} = 2\angle 0° + \frac{V_A}{(120-j40)} + (6+j\,3.5)$$

$$\frac{V_g - V_A}{5} = 2 + V_A\left(\frac{3}{400}+j\frac{1}{400}\right) + (6+j\,3.5)$$

$$V_A = i_a \times Z_a$$
$$= 2\angle 0° \times (50+j\,150)$$
$$= 2\times(50+j\,150)$$
$$V_A = 100+j\,300$$

$$\frac{V_g-(100+j\,300)}{5} = 2+\left(\frac{3V_A}{400}\right) + 6 + j\left(\frac{1}{400}+3.5\right)$$

$$\frac{V_g-(100+j\,300)}{5} = 2+\left(\frac{3}{400}(100+j300)\right) + 6 + j\left(\frac{1}{400}+3.5\right)$$

$$\frac{Vg-(100+j\,300)}{5} = 8+\left(\frac{3}{4}+j\frac{9}{4}\right)+j\,(3.5)$$

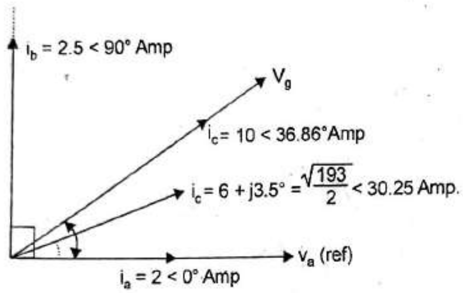
$$Vg = 5\,[8.75+j5.75]+(100+j300)$$
$$Vg = 143.73+j\,328.75 = 358.47\angle 67° \text{ Volt}$$

$$i_b = \frac{V_A}{120-j40} = (100+j\,300)/(120-j\,40)$$
$$= 0+j\,2.5 = 2.5\angle 90° \text{ Amp}$$

$$i_c = \frac{V_g - V_a}{5} = \frac{(143.75 + j328.75) - (100 + j300)}{5}$$

$$= 10 \angle 36.87° \text{ Amp}$$

(*ii*) Phasor diagram



Q.3 (*b*) A circuit consits of R = 35Ω in series with unknown impeance Z, for a sinusoid current of 2A, the observed voltage are 200V across R and Z together and 150V across impedance Z. Find the impedance Z. (4)

Ans.

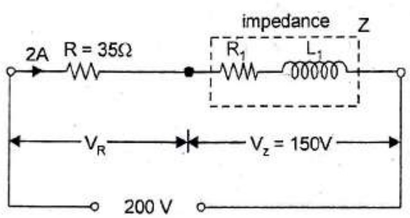


Fig. (*a*)

Voltage across resistance

$$R_1 (V_R) = IR = 2 \times 35 = 70V$$

$$\text{Supply Voltage V} = 200V$$

Voltage across impedance Z, (V_z) = 150 V

Form Δ OAB (fig(*b*)).

$$OB^2 = OA^2 + AB^2 + 2 \times OA \times AB \times \cos\theta$$

or

$$\cos\theta = \frac{OB^2 - OA^2 - AB^2}{2 \times OA \times AB}$$

$$= \frac{200^2 - 70^2 - 150^2}{2 \times 70 \times 150} = 0.6$$

$$\text{Impedance, } Z = \frac{V_Z}{I} = \frac{150}{2} = 75\Omega$$

Resitance of impedance Z,

$$R_1 = Z\cos\theta = 75 \times 0.6 = 45\Omega \text{ Ans.}$$

$$\text{Reactance of coil, } X_1 = \sqrt{Z^2 - R_1^2}$$

$$= \sqrt{75^2 - 45^2} = 60\ \Omega \text{ Ans.}$$

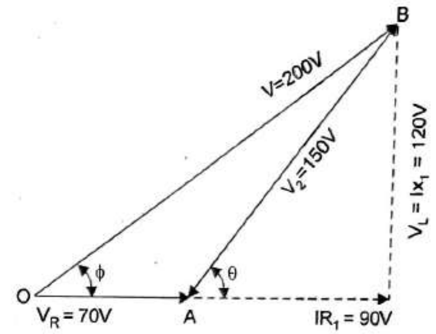


Fig. (*b*)

Q.4 (*a*) Using Norton's theorem, find current which would flow in a 25Ω resistor connected between points N and O in fig. 5.

Ans.

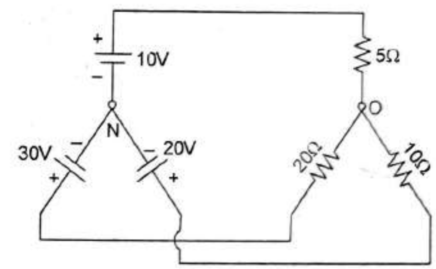


Fig. 5

– Equivalent resistance of network when viewed from terminals N and O in fig.5.

$$R_N = 5 \parallel 10 \parallel 20 = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{20}} = \frac{20}{7}\Omega$$

– Short – circuit current i.e, the current in zero resistance conductor connected across terminals ON . fig. 6 (*a*)

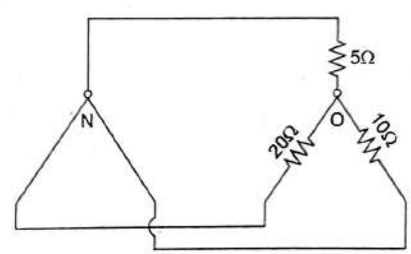


Fig. 6 (*a*)

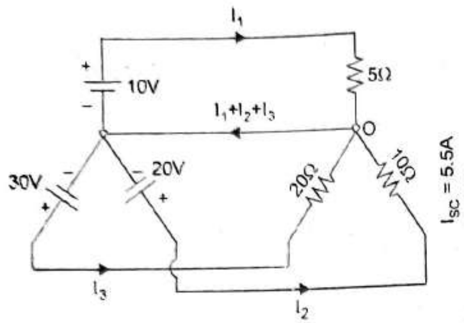


Fig. 6 (*b*)

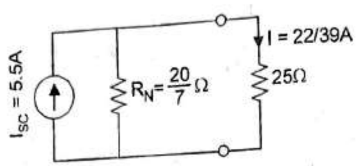


Fig. 6 (*c*)

$$I_{sc} = I_1+I_2+I_3 = \frac{10}{5}+\frac{20}{10}+\frac{30}{20} = 5.5\text{A}$$

– Current through a resistace of 25Ω connected between points O and N,

$$I = \frac{I_{sc}}{R_N+R_L}\times R_N = \frac{5.5\times\frac{20}{7}}{\frac{20}{7}+25} = \frac{22}{39}\ A.\ \textbf{Ans}$$

Q.4 (*b*) Determine the frequency at which the voltage V_{out} is zero in fig. 6 (3)

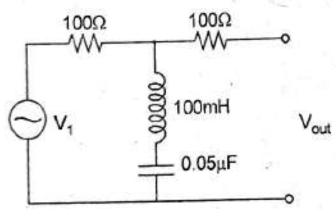


Fig. 6

Ans. The voltage V_{out} will be zero in the circuit when voltage drop across 100 mH inductor becomes equal to voltage drop across 0.05 μ*F* capacitor i.e when the frequency becomes equal to resonant frequency.

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} = \frac{1}{2\pi}\sqrt{\frac{1}{(100\times10^{-3})\times(0.05\times10^{-6})}}$$

$$f_r = 2{,}250\ \text{Hg}\ \textbf{Ans.}$$

FIRST SEMESTER (B. TECH)
SECOND TERM EXAMINATION [2014]
ELECTRICAL TECHNOLOGY [ETEE-107]

Time : 1.30 hrs. **M.M. : 30**

Note: *No. 1 is compulsory. Attempt any two more questions from the rest.*

Q.1 (*a*) Draw phasor diagram of a transformer in following conditions:

(*i*) No load

(*ii*) Capacitive load connected to practical transformer.

Ans. (*i*) No load

where

V_1 = Primary voltage (volt)

E_1 = Primary side induced emf (volt)

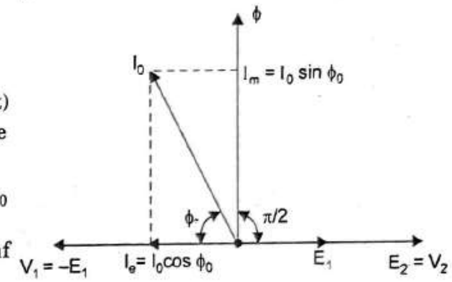
I_0 = no load current at primary side

I_e = active current = $I_0 \cos\phi_0$

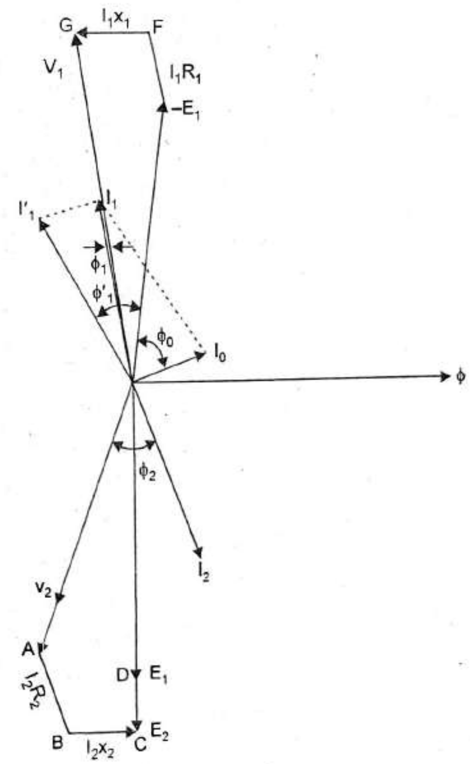
I_m = magnetising current = $I_0 \sin\phi_0$

V_2 = secondary side voltage (volt)

E_2 = Secondary side induced emf (volt)



(*ii*) Capacitive load with practical trnsformer.



Q.1 (b) Compare PMMC and MI type instruments.

Ans.

PMMC type	MI type
1. Only suitable for DC voltage and currents.	1. Suitable for both AC and DC voltages and currents.
2. Scale is linear.	2. Scale is non-linear.
3. Relatively expensive	3. Due to simple and robust construction, relatively cheap.
4. High torque to weights ratio.	4. Relatively low torque to weight ratio.
5. Well-shielded from any stray magnetic field	5. These are affected by stray magnetic fields.
6. Spring control damping is used.	6. Air friction damping is used.

Q.1 (c) Discuss various types of errors in induction type Energy meters.

Ans. There are different types of errors in Induction type energy meters. Those ar given below:

(1) Phase and speed errors: Such type of error has occured due to incorre adjustment of shading band. Speed error can be eliminated by adjustment of the positio of the brane magnet.

Phase error can be eliminated by bringing the shading band nearer to the disc vice versa.

(2) Friction compensation and creeping error: Two shading bands embrace th flux contained in the two outer limbs of the shunt electromagnet and eddy currents ar induced in them. As a result, a small driving torque is exerted on the disc, this torqu being adjusted, by variation of the position of these bands to compansate for frictio torque in the instrument. In energy meters, the disc continues rotating when th potential coils are excited but with no load current flowing. This is called as creepin and it is prevented by cutting two holes or slots in the disc on opposite sides of the spindl

(3) Temperature and frequency error: Temperture error due to variation temperature and frequency error is very minimum.

Q.1 (d) Discuss Repulsion type Moving Iron instrument. (2.5*)

Ans. Repulsion type Moving iron instrument:

– If two iron vanes or iron pieces are placed near the coil and current passed throug the coil, both iron vane are magnetized.

– Repulsion will take place between them become like poles are adjacent to on another.

– The force or torque of repulsion is used for measurement with one vane as fixe and other as movable.

– The deflection torque produced in the moving iron instruments is given as–

$$T = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

where, I is the current in the coil (A), L is the in ductance (in Henry) of instrume and θ is the deflection angle in radian.

Q.2 (a) A moving coil ammeter has a fixed shunt of 0.02 Ω with a co resistance of R = 100 Ω and a potential difference of 500 m V across it full sca deflection is obtained.

(i) To what shunt current does this respond.

(ii) What value of R is 40% deflection with I = 100 A. (2.5*2

Ans. (i) Current through shunt,

$$I_s = \frac{PD \text{ across shunt}}{\text{shunt resistance}}$$

$$= \frac{500 \times 10^{-3}}{0.02} = 25 \text{ A Ans.}$$

Current through instrument,

$$I_m = \frac{V}{R_m} = \frac{500 \times 10^{-3}}{100}$$

$$= 0.005 \text{ A}$$

$$\text{Total current, } I = I_s + I_m = 25 + 0.005$$

$$= 25.005 \text{A.}$$

(ii) Instrument current for 40% deflection –

$$I_m = \frac{40}{100} \times 0.005 = 0.002 \text{ A}$$

$$\text{shunted current, } I_s = I - I_m \text{ [assuming } \theta \ \alpha \ I]$$

$$= 100 - 0.002 = 99.998 \text{ A}$$

PD applied across the instrument, $V = I_s R_s$

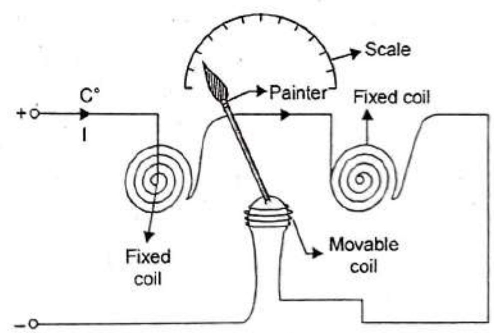
$$= 99.998 \times 0.02 = 1.99996 \text{ V}$$

$$\text{Required instrument resistance, R} = \frac{1.99996}{0.002}$$

$$= 999.98 \ \Omega \textbf{ Ans.}$$

Q.2 (b) Explain Dyanometer type wattmeter with neat diagram and derive expression also. **(5)**

Ans. It uses a fixed carries which is divided into two equal portions in order to provide uniform field. The fixed coil carries the current flowing through the circuit and the moving coil or pressure coil carries the current proportional to the voltage across the circuit. A high non inductive resistance is connected in series with the moving coil in order to limit the current. The magnetic fields of the fixed and the moning coil react on one another causing the moving coil to turn about its axis. The movement is controlled by hair springs which also lead the current into and out of the moving element and Damping is provided by the air friction damping. The pointer is fixed to the moving coil spindle and moves a suitably calibrated scale.



Let v be the supply voltage, i the load current and R the total resistance of the moving coil circuit.

Current through fixed coil, $i_f = 2°$

Current through moving coils, $i_m = v/R$

Deflecting torque

$$T_d \,\alpha\, i_f i_m \,\alpha\, \frac{iv}{R}$$

in a dc circuit, power is given by the product of voltage and current, hence deflecting torque is directly proportional to the power.

However in ac circuit, the instantaneous torque is proportional to instantaneous power.

$$T_{\text{instantaneous}} = \alpha vi$$
$$T_{\text{instantaneous}} = kvi$$

Where k is a constant, i and v is the instantaneous current of fixed coil and voltage of moving coil respectively.

Average deflecting torque is given by

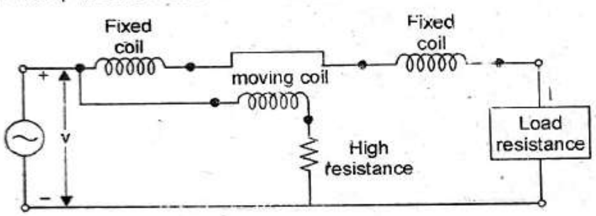
$$T_{avg} \,\alpha\, \text{average value of } v_i;\ \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta \times I_m \sin(\theta-\phi)\, d\theta$$

taking

$$v = V_m \sin\theta$$
$$i = I_m \sin(\theta-\phi)$$

$$T_{av} \,\alpha\, \frac{V_m I_m}{2\pi}\int_0^{2\pi} \sin\theta \sin(\theta-\phi)\, d\theta$$

$\Rightarrow T_{avg} \,\alpha$ VI cos ϕ where V and I are the rms values.



Q.3. (a) Each phase of a delta connected load has a resistance of 25 Ω. an inductance of 0.15 H and a capacitance of 120μF in series. The load is connected across a 400 V, 50 Hz, 3-φ supply. Determine the line current. active power and reactive volt ampere.

Ans. Resistnce per phase, $R_p = 25\ \Omega$

inductive reactance per phase, $X_{LP} = 2\pi f L$

$$= 2\pi \times 50 \times 0.15$$
$$= 47.124\ \pi.$$

Capacitive reactance per phase $X_{CP} = \dfrac{1}{2\pi fc}$

$$= \frac{1}{2\pi \times 50 \times 120 \times 10^{-6}} = 26.526\ \Omega$$

Net reactance per phase $X_p = X_{LP} - X_{CP} = 47.124 - 26.526 = 20.6\ \Omega$

Impednce per phase, $Z_P = \sqrt{R_P^2 + X_P^2} = \sqrt{25^2 + 20.6^2}$

$$= 32.4\ \Omega$$

Phase angle $\phi = \text{Tan}^{-1}\dfrac{x_p}{R_p} = \text{Tan}^{-1}\dfrac{20.6}{25} = 39.5°\log$

Phase current $I_P = \dfrac{V_P}{Z_p} = \dfrac{V_L}{Z_P} = \dfrac{400}{32.4} = 12.35$ A

Line current $I_L = \sqrt{3}\, I_P = \sqrt{3} \times 12.35 = 21.38$ Amp

active power $p = \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3} \times 400 \times 21.38 \times \cos 39.5°$

$= 11430$ watt

Reactive Volt amperes $= \sqrt{3}\, V_L I_L \sin\phi$

$= \sqrt{3} \times 400 \times 21.38 \times \sin 39.5° = 9420\ VAR$

Q.3 (b) A 40 ampere, 230 V energymeter on full load test makes 60 revolutions in 46 second. If the normal disc speed in 500 revolution per Kwh, find % error with proper sign by assuming the load to be purely resistive (5)

Ans. Energy confumed in 46 seconds $= \dfrac{VI\cos\phi}{1{,}000} \times t$ kwh

$$= \frac{230 \times 40 \times 1}{1{,}000} \times \frac{46}{(60 \times 60)} = 0.117555 \text{ kwh}$$

($\because$ for purely resistive load power factor is unity)

Energy consumption registered by meter

$$= \frac{\text{Number of revolutions made}}{\text{Meter constant}} = \frac{60}{500} = 0.12 \text{ kwh}$$

$$\text{Percentage error} = \left(\frac{\text{Actual regutration} - \text{True energy Consumption}}{\text{True energy consumption}}\right) \times 100$$

$$= \left(\frac{0.12 - 0.117555}{0.117555}\right) \times 100 = +2.08\%$$

or 2.08% fast **Ans.**

Q.4 (a) Discuss various types of losses occurs in a practical transformer. (5)

Ans. Due to static device, no friction losses in a transformer. So mainly two types of losses in tranformer. Those are

(i) Core loss (P_e)

(ii) Copper loss (P_{cu})

Core loss : It is also called iron loss.

It occurs 24 hours

Such type of loss has occured due to alternating flux in the core.

It is two types

(a) eddy current loss :

$\Rightarrow$ $P_{eddy} = K_e (B_{max})^2 f^2 vt^2$ watt or j/sec.

where

K_e : Proportinality constant

f : frequency in Hz

v : volume in m³

t : thickness of lamination

B_{max} : maximum flux density

⇒ There losses are minimised by lamination.

(*b*) hysteresis loss (P_h)

$\Rightarrow P_h = \eta'(B_{max}) f v$ watt

where

η' = hysteresis coefficients

$(B_{max})^x$ = Peak value of flux density

x varies from 1.5 to 2.5 ($x \cong 1.6$)

f = frequency in (Hz)

v = volume of core in (m^3)

→ The core of a transformer is subjected to an alternting magnetizing force and for each cycle of emf, a hysteresis loop is traced out.

Copper loss or ohmic loss (P_{cu}):

→ This losses occured due to ohmic resistance of the transformer windings.

→ so that copper loss is

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$
$$P_{cu} = I_1^2 R_{01}$$
$$P_{cu} = I_2^2 R_{o2}$$

Q.4 (*b*) A voltage V = 200 sin 314t is applied to a transformer winding in a no load test. The resulting current is found to be *i* = 3 sin (314t–60°). Determine the core loss and the paramters of no load approximate equivalent circuit. (5)

Ans. No load current $I_0 = \dfrac{3}{\sqrt{2}} = 2.12\text{ A}$

Core loss = input at no load

$$= VI_0 \cos\phi_0 = \frac{200}{\sqrt{2}} \times \frac{3}{\sqrt{2}} \cos 60° = 150 \text{ watt}$$

Energy Component of no load current

$$I_e = I_0 \cos\phi_0 = \frac{3}{\sqrt{2}} \cos 60° = 1.06\ A$$

Magnetising component of no load current

$$I_m = \sqrt{I_0^2 - I_e^2} = \sqrt{(2.12)^2 - (1.06)^2}$$
$$= 1.836\text{ A}$$

No load resistance $R_0 = \dfrac{V}{I_e} = \dfrac{200/\sqrt{2}}{1.06} = 1.33.42\ \Omega$

No load reactance $X_0 = \dfrac{V}{I_m} = \dfrac{200/\sqrt{2}}{1.836}$

$$= 77\ \Omega$$

FIRST SEMESTER (B. TECH)
END TERM EXAMINATION [2014]
ELECTRICAL TECHNOLOGY [ETEE-107]

Time : 3 hrs. **M.M. : 75**

Note: *Attempt any five questions including Q.no.1 which is compulsory. Select one question from each Unit. Assume missing data suitably if any.*

Q.1 (*a*) Define power factor, Q factor and form factor. (5 × 5 = 25)

Ans. Power factor: defined as the ratio of true power to apparent power i.e.

$$\frac{\text{True power}}{\text{Apparent power}} = \frac{P}{S}$$

where

$$P = VI\cos\phi \text{ (watt)}$$
$$S = \sqrt{P^2 + \theta^2}$$

Reactive power ⇒ $Q = VI\sin\phi$

Q Factor : Reciprocal of power factor of a coil is called as Q factor of the coil

$$\text{Q-factor} = \frac{1}{PF} = \frac{1}{\cos\phi} = \frac{Z}{R} = \frac{WL}{R}$$

Form factor : defind as the ratio of following –

$$= \frac{\text{Effective value}}{\text{Average value}}$$

from factor for sinusoidal wave $K_f = \dfrac{E_{rms}}{E_{av}}$

$$K_f = \frac{\dfrac{E_{max}}{\sqrt{2}}}{\dfrac{E_{max}}{(\pi/2)}} = 1.11$$

Q.1 (*b*) Define and explain Millman theorem.

Ans. Millman's Theorem: States that if *n* number of votlage sources along with series impedances are connected in parallel across the terminal then this combination can be replaced by a signal voltage source V_m and single series impedance Z_m.

 # Explaination:

– Consider a network s shown in fig (*a*), with two common terminals A and B between which 3 voltage sources E_1, E_2, and E_3 of internal resistance R_1, R_2 and R_3 respectively are connected.

– As per theorem, voltage sources between terminal A and B can be replaced by a single voltage source V_{AB} in series with an equivalant resistance R_{AB} where–

$$V_{AB} = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3} \Big/ \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{E_1G_1 + E_2G_2 + E_3G_3}{G_1 + G_2 + G_3} = \frac{\Sigma EG}{\Sigma G.}$$

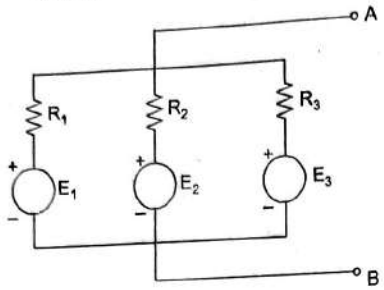
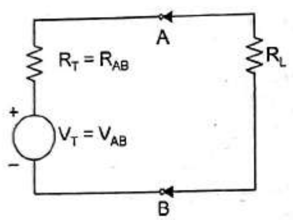


Fig. (a)

and
$$R_{AB} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} = \frac{1}{G_1+G_2+G_3} = \frac{1}{\Sigma G}$$



Q.1 (c) Define active, reactive and apparent power.

Ans. Active power :

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

or
$$= \frac{VI\cos\phi}{1,000}(kw)$$

Active power in an ac circuit is obtained by multiplying the apparent power by the power factor and is expressed in watts or killo watts.

Reactive power (Q) = VI sin ϕ (VAR) or $\frac{VI\sin\phi}{1,000}$ (K VAR) defined as product of apparant power, VI and the sine of the angle betwwen voltage and current, sin ϕ.

Apparent power (S) = VI (Volt amperes) or

$$= \frac{VI}{1,000} \text{ (KVA)}$$

defined as product of rms values of current and voltage.

Q.1 (d) What are Hysteresis and eddy current losses?

Ans. Transformer has two main losses. Those are (i) Iron loss (ii) Cupper loss. Iron loss is of two types.

(*a*) eddy current loss (*b*) hysteresis loss

→ **(*a*) eddy current loss:** This loss is due to change in magnetising force during each cycle i.e. this loss is due to reversal of magnetisation of the core.

$$w_h = k_h (B_{max})^{1.6} f v \text{ watt}$$

where k_h is a constant
B_{max} is maximum flux density
f : Supply freq (Hz)
v : Volume (m^3) of core

or $w_h \alpha (B)^{1.6}_{max}$ f

→ **(*b*) hysteresis loss:** The magnetic circuit of a transformer is made up of Iron. Therefore when an alternating flux passes through Iron. an emf is induced in iron. Since the resistance of Iron is low, current will set up in iron itself. This current is called eddy current and corresponding losses is called eddy current loss.

$$w_e = k_e (B_{max})^2 f^2 t^2 \text{ V watt}$$
$$w_e \alpha B_{max}^{\ 2} f^2 t^2 v$$

therefore, eddy current losses are reduced by reducing '*t*' the thicknes of the mass. That is why we laminate the core of the transformer.

Q.1 (*e*) What is an ideal trandformer? Discuss.

Ans. Ideal transformer is nothing but a hypothetical tranformer it is supposed to consists of two purely inductive coils wound on a loss-free core. The assumptions for an ideal transformer are:

(*i*) The primary and secondary windings have no winding resistance
(*ii*) There is no leavage flux
(*iii*) There are no losses in the transformer
(*iv*) There is no magnetising current
(*v*) Voltage regulation is 0%
(*vi*) efficiency is 100%.

UNIT-I

Q.2 (*a*) State and explain Norton theorem. **(6.5)**

Ans. Statement: "Any two terminal, linear, bilateral network can be replaced by an equivalent circuit conisting of a current source parallel with the resistance (impedance) seen from that terminals. The equivalent current source, I_N is the short circuit between the terminals and equivalent resistance, R_N, is the ratio of the open circuit voltage to the short circuit current at these terminals."

Explaination:

– Consider a netwoek an fig (a)
– Short circuit terminals AB to find out short circuited current

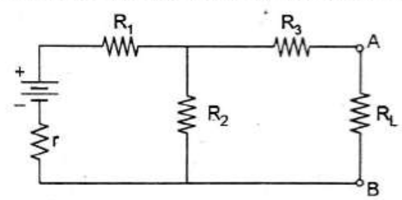


fig. (a)

I_{sc} (By replacing reistance R_L with a zero resistance thick wire) fig (b)

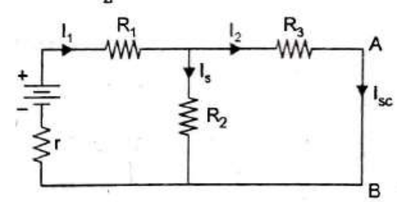


Fig. (b)

– Equialent resistance of the fig. (c) network, $R_N = ((R_1 + r) \| R_2) + R_3$

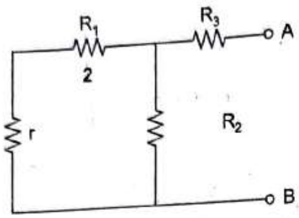


Fig. (c)

– Nortons equivalent circuit will be as per fig (d)

$$I_L = \frac{I_{sc} R_N}{R_N + R_L}$$

(applying current dimension in fig. (d)

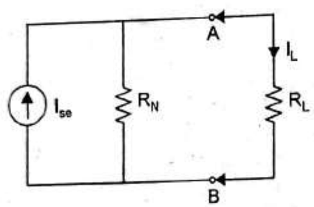
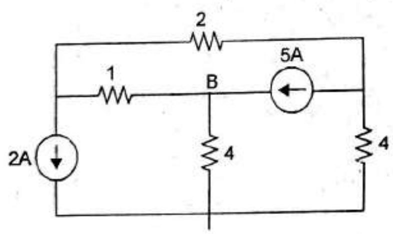
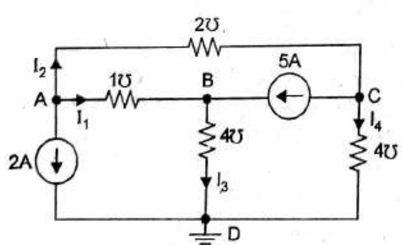


Fig. (d)

Q.2 (b) Using the node nodal analysis, find the different branch current in the circuit of figure shown. All Branch conductances are in Siemens. (6)



Ans.



At node A, apply KCL/nodal analysis

$$2 + I_1 + I_2 = 0$$

$$\Rightarrow 2 + (V_A - V_B)\,1 + (V_A - V_C)\,2 = 0$$

$$\Rightarrow 2 + V_A - V_B + 2V_A - 2V_C = 0$$

$$\Rightarrow 2 + 3V_A - V_B - 2V_C = 0$$

$$\Rightarrow 3V_A - V_B - 2V_C = -2 \quad \text{....(1)}$$

at node B, apply KCL/nodal analysis

$$I_1 + 5 = I_3$$

$$\Rightarrow (V_A - V_B)\,1 + 5 = V_B.4$$

$$\Rightarrow V_A - V_B + 5 = 4V_B$$

$$\Rightarrow V_A - V_B - 4V_B = -5$$

$$\Rightarrow V_A - 5V_B = -5 \quad (2)$$

at node C, apply KCL/nodal analysis

$$I_2 = 5 + I_4$$

$$\Rightarrow (V_A - V_C)\,2 = 5 + V_C.4$$

$$\Rightarrow 2V_A - 2V_C = 5 + 4V_C$$

$$\Rightarrow 2V_A - 2V_C - 4V_C = 5$$

$$\Rightarrow 2V_A - 6V_C = 5 \quad (3)$$

we solve equation (1), (2) & equation (3), then we get

$$V_A = -5/4,\; V_B = 3/4,\; V_C = -5/4$$

$$I_1 = (V_A - V_B)1 = \left(-\frac{5}{4} - \frac{3}{4}\right)1 = \frac{-8}{4} = -2\text{ Amp.}$$

$$I_2 = (V_A - V_C)\,2 = \left(-\frac{5}{4} - \left(-\frac{5}{4}\right)\right) 2 = 0\text{ Amp}$$

$$I_3 = V_B 4 = \frac{3}{4} \times 4 = 3\text{ amp}$$

$$I_4 = 4V_c = 4 \times \left(-\frac{5}{4}\right) = -5\text{ amp } \textbf{Ans.}$$

Q.3 (a) State and explain maximum power transfer theorem. (6.5)

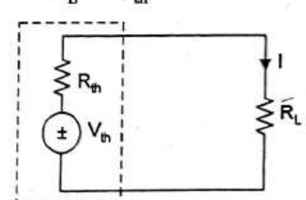
Ans. Statement : For maximum power transfer, load resistance should be equal to the resistance of the Thevenin equivalent (or Norton equialent) of the network to which is connected. However the efficiency of the system is 50%.

Explaination:

– Consider circuit as in fig (a).

– For maximum power transfer as per theorem

$$R_L = R_{th}.$$



– Load current I

$$I = \frac{V_{th}}{R_{th} + R_L}$$

– Power consumed by the load Network. will be –

$$P = I^2 R_L = \frac{V_{th}^2}{(R_{th}+R_L)^2}.R_L$$

– The value of load resistance R_L for the maximum power to be consumed by the load can be obtained as –

$$\frac{\delta P}{\delta R_L} = 0 = \frac{V_{th}^2}{(R_L+R_{th})^2} - \frac{2V_{th}^2}{(R_L+R_{th})^3} R_L = 0$$

or $$R_L + R_{th} - 2R_L = 0$$

or $$\boxed{R_L = R_{th}}$$

$$P_{max} = \frac{V_{th}^2}{(R_L+R_L)^2} \times R_L = \frac{V_{th}^2}{4R_L}$$

$$P_{lon} = \frac{V_{th}^2}{(R_L+R_L)^2} \times R_{th} = \frac{V_{th}^2}{4R_L}$$

– At maximum power transfer, the efficiency (η) of the system will be

$$\eta = \frac{\text{output}}{\text{input}} = \frac{V_{th}^2/4R_L}{(V_{th}^2/4R_L)} + (V_{th}^2/4R_L)$$

Thus the efficiency of the system is 0.50 or 50%

Q.3 (b) State and explian superposition theorem **(6)**

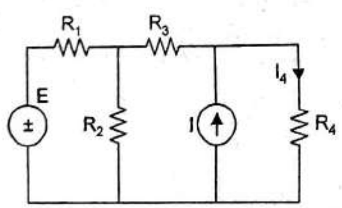
Ans. Statement: The total current or voltage in any part of a linear bilateral network having more than one source is equal to the algebraic sum of the currents or voltage with the sources acting individually while other sources are replaced by their internal resistances (short circuiting the voltage sources and open circuiting the current sources)

Explaination –

– Consider a network as per fig (a)

– Procedure/steps for applying Superposition theorem :

(a) Select any one source in the circuit and remove all other sources (replace voltage source by short circuit and current source by open circuit keeping the internal resistances).



(b) Calculate the desired voltage or current in an element with only or source selected in the step 1.

(c) Repeat the step 1 and step 2 for all the sources one by one.

(d) Add all the computed values of elements obtained with each source acting alone. The sum is the actual voltage or current when all the sources are present and acting simultaneously. The polarity of voltage and direction of current must be taken carefully while adding the quantities.

UNIT - II

Q.4 (a) A Coil takes a current of 6 A when connected to a 24 V DC supply. To obtain the same current with a 50 Hz a.c. supply the voltage required was 30 V. Find (i) Inductance of coil (ii) the power factor of the coil. **(6.5)**

Ans. When dc voltage is applied

applied voltage, V_{dc} = 24 volt

current through the coil I_{dc} = 6 A

Resistance of coil, $$R = \frac{V_{dc}}{I_{dc}} = \frac{24}{6} = 4\Omega$$

when ac voltage is applied

applied voltage V_{ac} = 30 volt

Resistance of coil R = same as when dc is applied i.e. 4 Ω

current, I_{ac} = 6 Amp

coil impedance, $$Z = \frac{V_{ac}}{I_{ac}} = 30/6 = 5\ \Omega$$

Inductive reactance of coil

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{5^2 - 4^2} = 3\ \Omega$$

inductance of coil

$$X_L = 2\pi fL = 3\ \Omega$$

$$\Rightarrow L = 3/2\pi f = 3/2\pi \times 50 = \frac{3}{100\pi} = 9.54 \text{ mH}$$

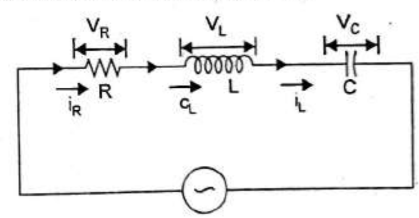
$$\text{power factor} = \cos\phi = \frac{R}{Z}$$

$$\cos\phi = \frac{4}{5}$$

$$\cos\phi = 0.8 \text{ (lag).}$$

Q.4 (b) Discuss resonance the Series RLC circuits. How the resonant frequency is calculate. Give graphical representation of resonance. **(6)**

Ans. Consider an ac circuit containing a resistance R, an inductance L and capacitance C connected in series. as shown in figure.



Impedance of the circuit

$$Z = \sqrt{R^2 + (x_L - x_c)^2} = \sqrt{R^2 + \left(wL - \frac{1}{wc}\right)^2}$$

if for some frequency of applied voltage

$x_L = x_c$ in magnitude then

(*i*) Net reactance is zero ie. $X = 0$

(*ii*) Impedance of the circuit $Z = R$

(*iii*) The current flowing through the circuit is maximum and in phase with the applied voltage. The magnitude of the current will be equal to V/R.

(*iv*) $I x_L = I x_c$

(*iv*) $\cos\phi = 1$

when the above condition exists, the circuit is said to be in resonace and the frequency at which it occurs is known as resonant frequency.

If resonant frequency is denoted by f_r

If, then

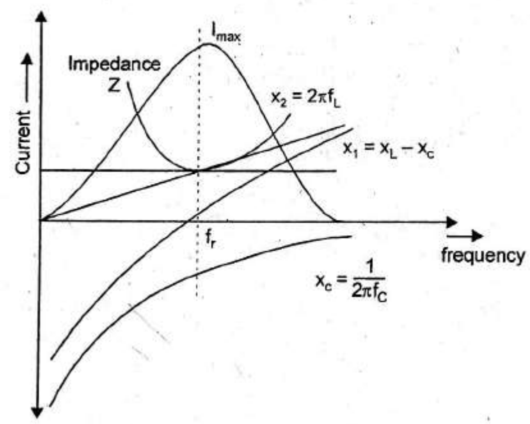
$$x_L = wL = 2\pi f_r L$$

$$x_c = \frac{1}{2\pi f_r c}$$

$$x_L = x_c \Rightarrow \quad 2\pi f_r L = \frac{1}{2\pi f_r c}$$

$$\Rightarrow \quad f_r = \frac{1}{2\pi\sqrt{Lc}} \Rightarrow w_r = \frac{1}{\sqrt{Lc}}$$

graphical representation of resonance.



→ The circuit can be made resonant in two different ways namely,

(*i*) by varying L& C paramerer at a constant supply or frequency.

(*ii*) by varying the supply frequency & with Parameters L and C constant.

→ In the above graphical representation, Resistance R is independent of supply frequency, therefore, remains constant. It has been represented by a straight line. i.e. parallel to the X-axis.

$$\rightarrow \quad x_L = \omega_L$$

$$\Rightarrow \quad x_L = 2\pi f_r L$$

$$\Rightarrow \quad f_r \; \alpha \; x_L$$

Due $x_L \, \alpha f_r$, so it is represented by a straight line passing through the origin. and it lies on the first quadrant. Similary

$$x_c = \frac{1}{2\pi f_r c}$$

$$\rightarrow \quad x_c \, \alpha \, (1/\text{fr}).$$

So x_c inversely proprtional to the resonant frequency and it is represented by a rectangular hyperbola. It lies in the fourth quadrant.

→ The net reactance is the difference of inductive reactance x_L and capacitive reactance x_c and the curve drawn between the net reactance $(x_L - x_C)$ and frequency will be a hyperbola. The frequency at which the reactance curve crosses the frequency axis is called the resonant frequency. (f_r)

→ The impedance of the circuit, Z being equal to $\sqrt{R^2 + (x_L - x_c)^2}$ is minimum at resmant frequny f_r.

→ At frequencies lower than resonant frequency f_r the impedance Z is large and capacitive as $x_C > x_L$ and the power factor is leading. and at frequencies higher than resonant frequency f_r, the impedance Z is large but $x_L > x_C$ and power factor is lagging. The power factor has the maximum value of unity at resonant frequency.

Q.5 (*a*) A coil of inductance 9 henry and resistance 50 ohm in series with a capacitor is supplied at constant voltage from a variable frequency source. If the maximum current of 1 A occurs at 75 Hz, Find the frequency at which current is 0.5 A. (6.5)

Ans. Given

Inductance L = 9 Henry

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

Resistance = 50 **ohms**

maximum current I_{max} = 1 A

frequency = 75 Hz

$$X_L = 2\pi f L = 2\pi \times 75\times 9 = 4241.15\ \Omega$$

$$I_{max} = \frac{V}{R} \Rightarrow 1 = \frac{V}{50} \Rightarrow V = 50 \text{ Volt.}$$

$$f_r = \frac{1}{2\pi\sqrt{Lc}} \Rightarrow 75 = \frac{1}{2\pi\sqrt{9\times c}}$$

$$\Rightarrow \quad C = 1/(75\times 2\pi)^2 \,.\, 9$$

$$C = 1/(471.23)^2 .9$$

$$C = 5 \times 10^{-7} \text{ Farud}$$

when current is 1 amp

$$V_L = I x_L$$

$$V_L = 1\,(2\pi f L)$$

$$= 2\pi \times 75 \times 9$$

$$V_L = 4241.5 \text{ Volt.}$$

when current is 0.5 amp.

$$V_L = Ix_L$$
$$4241.5 = (0.5)(2\pi f L)$$
$$4241.5 = 0.5\times 2\times\pi\times f\times 9$$
$$\Rightarrow f = 150.01 \text{ Hz. Ans.}$$

Q.5 (b) Write down the advantges of 3 phase system over single phase. (6)

Ans. Although single phase system is employed for the operation of almost all the domestic & commercial appliances e.g. lamps, fans, electric irons, Tv sets, computer etc. But it has own limitations in the field of generation, transmission, distribution and Industrial applications. Therefore 3-phase system is universalhy adopted for generation, transmission, and distribution of electric power due to the following main advantages over 1 ϕ system.

→ **(1) constant power:** In single phase circuits, the power deliverd is pulsating. Even when the voltage and current are in phase, the power is zero twice in each cycle. whereas in 3 ϕ system, power delivered is almost constant when the loads are balanced.

→ **(2) Higher rating:** The rating of 3ϕ supply is nearly 1.5 times the rating of a 1ϕ machine of the same size.

→ **(3) Power transmission economics:** To transmit the same power over a fixed distance at a given voltage. 3 ϕ system requires only 75% of the weight of conducting material of that required by 1ϕ system.

→ **(4) Superiority of 3ϕ induction motors :** The three phase induction motors have wide spread field of applications in the industries because:

3 ϕ Induction motors are self starting

3 ϕ Induction motors have higher power factor and efficiency than that of 1 ϕ.

UNIT–III

Q.6 (a) Explain the working principle and construction of moving iron instruments. (6.5)

Ans. There are two types of moving Iron instruments. Those are given below:

→ attraction type moving Iron.

→ repulsion type moving Iron.

Attraction type moving Iron instruments: The simplest form of attraction type moving Iron instrument uses a solenoid and moving oval shaped soft iron pivoted eccentnically as shown in figure. Solenoid is attached to this iron so that it may deflect along with the moving iron over a graduated scale. The iron is made of sheet metal specially shaped to give a scale a nearly uniform as possible. The moving iron is drawn into the field of solenoid when current flows through it. The movement of the iron is always from weaker magnetic field outside the coil into the stronger magnetic field inside the coil regardless the direction of flow of current.

When the current to be measured is passed through a Solenoid, a magnetic field is set up inside the solenoid, which in turn magnetises the iron. Thus the iron is attracted into the coil causing the spindle and the pointer to rotate. Such instruments normally have spring control and pneumatic damping.

Such an instrument has a scale cramped at the lower end and greatly expanded at the upper end, as the iron torque is quite low. When the moving Iron is just enterning the solenoid and increases rapidly as iron is drawn further in.

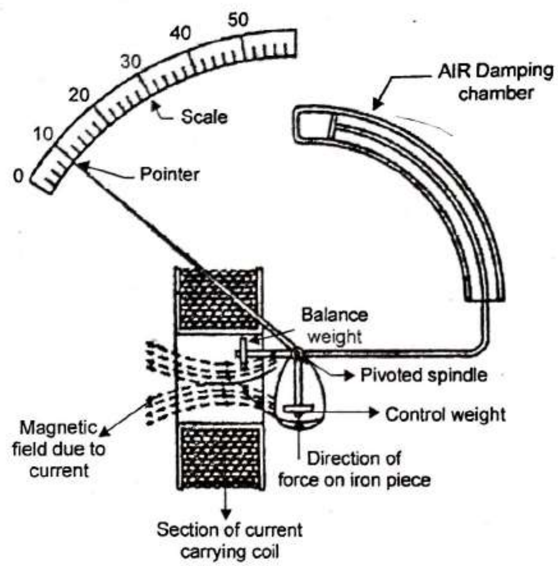
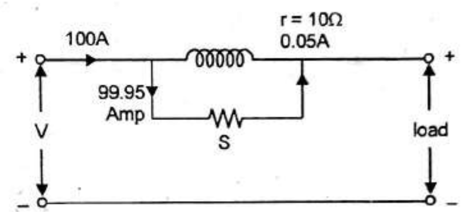


Fig. Attraction type moving Iron Instrument.

Q.6 (b) A moving coil instrument has a resistance of 10 Ω and gives full scale deflection when carrying a current of 50 mA. Show how it can be adopted to measure voltage up to 750 V and current up to 1000 A.

Ans.

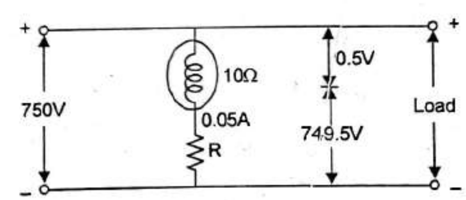


***(a)* As Ammeter :** As discused above, current range of the meter can be extended by using a shunt across it [fig a]

obviously

$$10\times 0.05 = S\times 99.95$$
$$\Rightarrow \quad S = 0.005\ \Omega$$

(b)



As Voltmeter: In this case, the range can be extended by using a high resistance R in series with it.

Obviously, R must drop a voltage of

$$750 - 0.5 = 749.5 \text{ V while carrying } 0.05 \text{ A}$$
$$0.05 \text{ R} = 749.5$$
$$\Rightarrow \quad \text{R} = 14.990\ \Omega$$

Q.7 (a) Discuss and explain the construction and working of dynamometer type wattmeter. (6.5)

Ans. When the instrument of this type is used a wattmeter, the fixed coil, which is divided into two equal portions in order to provide uniform field, is employed as current coil and the moving coil is used as a pressure coil i.e. the fixed coil carries the current flowing through the circuit and the moving coil carrie the current proportional to the voltage across the circuit. A high non inductive resistance is connected in series with the moving coil in order to limit the current. The magnetic field of the fixed and moving coil reacts one another causing the moving coil to turn about its axis. The movement is controlled by hair spring which also leads the current into and out of the moving element damping is provided by light aluminium vanes moving in an air dash pot. The pointer is fixed to the moving coil spindle and moves over a suitable calibrated scale.

let v be the supply voltage, i the load current and R the total resistance of the moving coil circuit.

Current through fixed coil, $i_f = i$

Current through moving coil, $i_m = V/R$

Deflecting torque $T_d \propto i_f i_m \propto \frac{iv}{R}$

For a dc circuit the deflecting torque is proportinal to the power. For any circuit with fluctuating torque the intantaneous torque is proportional to the instantaneous power.

Advantages:

→ applicable for both dc and ac supply

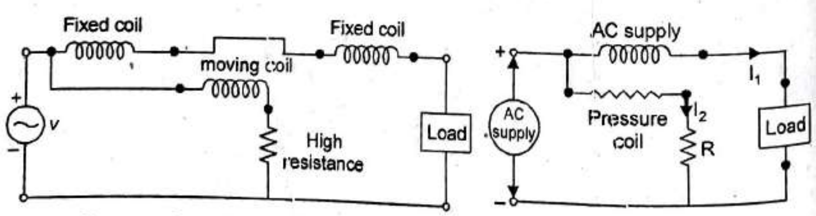
→ scale of the instrument is uniform

→ High degree of accuracy can be obtain by careful design. Hence these are used as standard for calibration purpose.

Disadvantages:

→ Error due to pressure coil, at low power factor is very serious and it reduces its effect.

→ The reading of the instrument may be affected by stray field acting on the moving coil.



Connection diagram of wattmeter for measurement of power.

Q.7 (b) Describe the construction details and application of digital multimeters. (6)

Ans. Digital Multimeter : (DMM)

→ A digital Multimeter is a versatile and accurate instrument used in Labrotories and field works.

→ on account of developments in the integrated circuit (IC) technology, it has become possible to reduce the size, power requirements and cost of multimeter.

→ Digital multimeter eliminates error and increases speed.

→ The basic function performed by a digital multimeter is an analog to digital (A/D) conversion for example the voltage value may be charged into a proportional time internal, which starts and stops a clock oscillator. In turn the oscillator output is applied to an electronic counter which is provided with a readout in terms of voltage. There are many ways of converting the analog reading into digital form but the most common way is to use ramp voltage.

→ The operating principle of a ramp type Digital Multimeter is simple. A ramp voltage increases linearly from zero to a predetrmined level in a given time interval. The ramp voltage value is continuously compared with the voltage being measured. At the instant the value of ramp voltage becomes equal to that of unknown voltage, a coincidence circuit called input comparator generates a pulse which opens the gate as shown in the block diagrams shown in fig. 1.

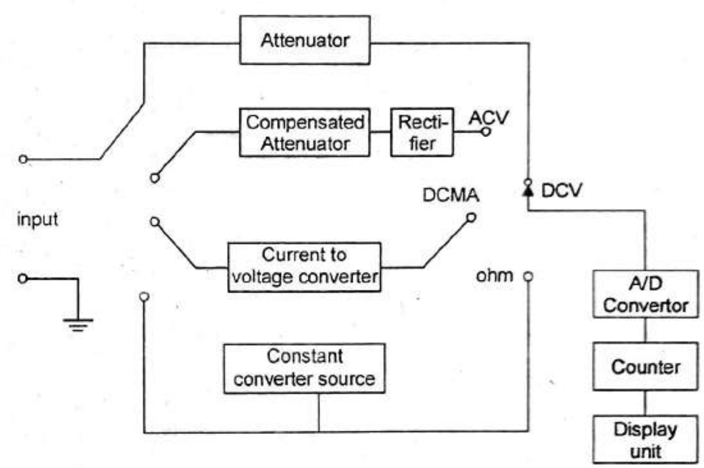


Fig. 1. Block diagram of DMM

→ The ramp voltage continues to decrease till it reaches the ground level. At this instant another comparator gernerates a pulse and closes the gate, The time interval between the opening and closing of the gate is measured with an electronic time interval counter. This count is displayed as a number in digits.

The main parts of digitel multimeter are → digital display unit:

→ ON – OFF switch → Input terminals → Mode switch

→ Range switch.

Typical specification of DMM

→ large size LCD display, $3\frac{1}{2}$ digits → Auto zero/ Auto polarity

→ Over range indication, → weight 200 g with battery.

UNIT- IV

Q.8 (a) Discuss about regulation, losses and efficieny of a transformer. **(6.5)**

Ans. Voltage regulation of a transformer :

(*i*) It is defined a the ratio of change in voltage from no load to full load.

(*ii*) For a good transformer the voltage change across the load from no load to full load should be minimum.

(*iii*) If E_2 is the voltage across the load at no load condition and

V_2 is the full load voltage across the load

so voltage regulation $= \dfrac{E_2 - V_2}{V_2}$

% $\quad V.R = \dfrac{E_2 - V_2}{V_2} \times 100$

or % V. R. = (% resistive drop) cos $\phi \pm$ (% reactive drop) sin ϕ

$$= \left(\frac{I_2 R_2}{N_2} \times 100\right) \cos\phi \pm \left(\frac{I_2 x_2}{V_2} \times 100\right)$$

Where, '+' sign is used for lagging power factor

'–' sign is used for leading power factor

R_2 : Secondary side resistance of transformer

x_2 : Secondary side reactance of transformer

I_2 : Secondary side current.

Losses of a transformer : Due to static device, no friction losses in a tranformer. So mainly two types of losses in transformer.

(*i*) Core loss (P_e)

(*ii*) Cupper loss (P_{cu})

Core loss

→ It is also called iron loss.

→ It occurs for 24 hours.

→ Due to alternating flux in the core, core loss has occured.

→ It is 2 types.

* eddy current loss (P_{eddy})

* hysteresis loss (P_n)

→ Hysteresis loss

* The core of a transformer is subjected to an alternationg magnetisiong force. and for each cycle of emf, a hysteresis loop is traced out. The hysteresis loss/second is

$P_n = \eta'(B_{max})x$ of υ joules/sec. or watt

→ $P_n \propto$ Bf

where η' = hysteresis coefficients

B^x_{max} = peak value of flux density & x varies from 1.5 to 2.5 ($x \cong 1.6$)

f = frequency in (hz)

v = volume of core (m^3)

→ eddy current loss (Peddy)

It the magnetic circuit is made up of Iron and if the flux in the circuit is variable currents will be induced by induction in the Iron circuit itself. All such currents are known as eddy currents.

$P_{eddy} = K_e (B_{max})^2 f^2 \upsilon t^2$ watt or j/sec.

where K_e = Proportinality constant

f = frequency (Hz)

v = Volume (m^3)

t = thickness of laminations

B_{max} : maximum flux density.

→ These losses are minimised by using steel of high silicorn content for the core and by using very thin laminations insulated from each other by insulating varnish or by layer of papers.

Copper loss or ohmic loss (P_{cu})

→ This losses occured due to ohomic resistance of the transformer windings.

→ so total cupper loss is

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2 = I_1^2 (R_1) + (R_2) I_2^2$$
$$P_{cu} = I_1^2 R_{01}$$
$$P_{cu'} = I_2^2 R_{02}$$

Transformer efficiency : (η)

$$\eta = \frac{o/p}{i/p} \times \frac{i/p - losses}{i/p} \times 100$$

$$= \frac{o/p}{o/p + losses} \times 100$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + P_{cupper}(x)^2} \times 100$$

For full loud $\quad x = 1$

$$\Rightarrow \quad \eta_{full} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + P_{cu}} \times 100$$

where $V_2 I_2 \cos\phi_2$ = total active power in watt

$V_2 I_2$ = apparent power in volt ampere

P_{cu} = Cupper loss (watt)

P_e = core loss (watt)

Total losses $= P_e + x^2 P_{cu}$

where $x = \dfrac{\text{load current}}{\text{full load current}}$

$$\text{or } \%\eta = \frac{\text{KVA rating} \times \cos\phi}{\text{KVA rating} \times \cos\phi + p_e + x^2 P_c} \times 100$$

for full load $x = 1$

for half load $x = 1/2$

$$\%\eta = \left[\frac{\frac{1}{2} \times KVA \text{ rating} \times \cos\phi}{\frac{1}{2} \times KVA \text{ rating} \times \cos\phi + P_e + \left(\frac{1}{2}\right)^2 P_c}\right] \times 100$$

for $\left(\frac{1}{3}\right)^{rd}$ load

$$\%\eta = \left[\frac{\frac{1}{3} \times KVA \text{ rating} \times \cos\phi}{\frac{1}{3} KVA \text{ rating} \times \cos\phi + P_e + \left(\frac{1}{3}\right)^2 P_{cu}}\right] \times 100$$

→ condition for maximum efficiency:

$$\frac{d\eta}{dx} = \frac{d}{dx}\left(\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + x^2 P_c}\right) = 0$$

$$\Rightarrow \quad x^2 P_c = P_e$$

$$\Rightarrow \quad x = \sqrt{P_e / P_c}$$

$$\Rightarrow \quad x = \sqrt{P_e / I_2^2 Ro_2}$$

$[\because P_{cu} = I_1^2 R_{01} \text{ or } I_2^2 R_{02}]$

Q.8 (*b*) Discuss the methods of speed control of DC series motors. (6)

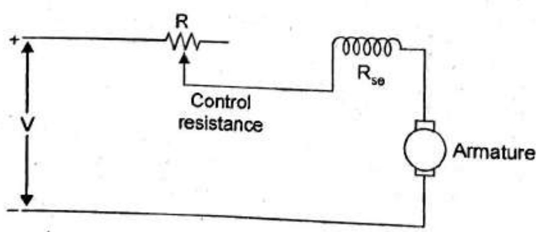
Ans. There are 2 types of methods for speed control of DC series motor.

→ Armature control: method

→ Field control method

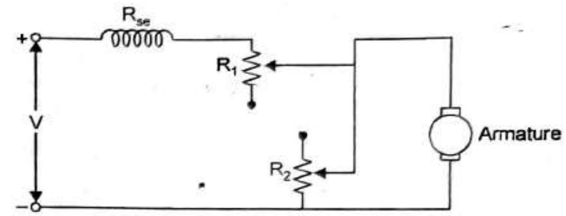
→ Armature control method:

(*a*) Armature resistance control speed variation is obtained by varing armature voltage drops. The maximum range of speed control will be available on the load. This is most economical for constant torque drives.



(*b*) Shunted armature control:

This method gives slow speeds at light loads, there is speed control both by lowering armature Voltage and flux varing by series rheostat, 'R_1' and flux is varing by Rheostat 'R_2'. Its torque economical due to power losses.



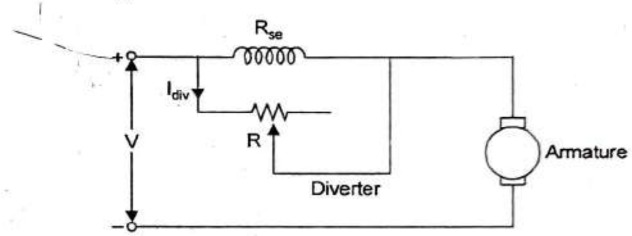
(*c*) Armature voltage control:

Speed varies by varying supply voltage using adjustable electronic rectifiers.

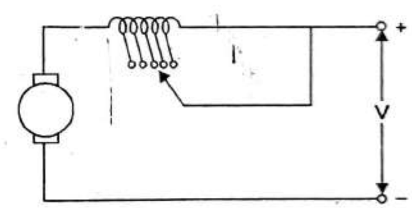
→ Field control method :

(*a*) field divertor

Flux can be reduced by shunting a portion of field winding. This method gives speed above normal speed. This method is economical and provides speed control in range not exceeding 2:1.



(*b*) Tapped field control: This is another method of increasing speed by reduced flux. It is obtained by reducing number of turns of field winding. This method is generally used in traction.



(*c*) Paralleling field control method

By regrouping the field coils in series or parallel, the variable speed is obtained its used in electric traction.

Q.9.(*a*) What is meant by 'slip' in an induction motor? Discuss about torque-slip characteristics of an induction motor. (6.5)

Ans. Induction motor rotor rotating at synchronous speed then there would be no cutting flux by the rotor conductors, no generated voltage no current and no torque. So rotor speed is slightly less than the synchronous speed.

The difference between the synchronous speed and the actual rotor speed is called slipspeed.

If N_s : synchronous speed (rpm)

N_r : actual speed of rotor (rpm)

$$\text{slip speed} = N_s - N_r \text{ p.u. [P.U. = per unit]}$$

$$\text{percentage slip} = \frac{N_s - N_r}{N_s} \times 100$$

The slip speed at full load varies from about 5 % for small motors to about 2 % for large motors.

→Torque–slip characterstics of an Indusction motor.

The expression for the torque is as follows

$$T = \frac{K_s R_2 E_2^2}{R_2^2 + S^2 x_2^2}$$

Form the above expression it is evident that

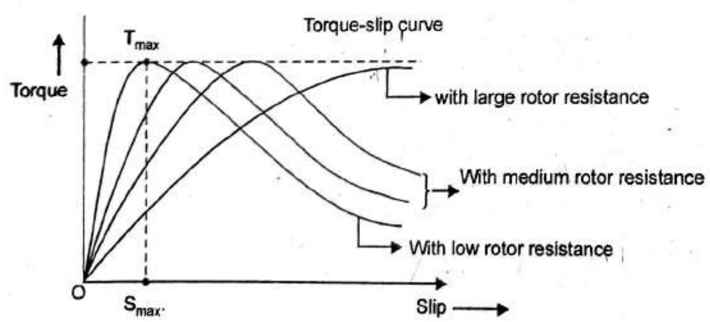
(*i*) Torque is zero when slip S = 0 ie. speed is synchronous. When the slip is very low, the value of Sx_2 is very small and is negligible in comparision with R_2, therfore T is proportional to slip if rotor resistance R_2 is constant. This mean torque slip curves are approximtely straight lines as shown in figure.

(*ii*) when the slip 's' increases, then torque increase and reches its maximum value when $s = R_2/x_2$. The maximum torque is also known as pullout or Breandown torque.

(*iii*) when the slip is further increased, the torque decreases. The result is that motor slows down and eventually stops. The motor operates for the value of slip between zero and that corresponding to maximum torque.

with higher slip, R_2 becomes negligible as compared to sx_2 and torque varies as follows

$$T \propto \frac{S}{S^2 x_2^2} \propto \frac{1}{s} \text{ if standstill reactance } X_2 \text{ is constant.}$$



Q.9 (*b*) Derive the expression for torque development by a 3- phase induction motor and obtain the expression for starting torque nd maximum torque. (6)

Ans. An induction motor develops gross torque T_g, due to gross rotor output P_m.

$$T_g = \frac{P_g}{w_s} = \frac{P_g}{2\pi ns} \text{ in terms of rotor input}$$

$$= \frac{P_m}{\omega} = \frac{P_m}{2\pi n} \quad \because \text{ in terms of rotor output}$$

shaft torque T_{sn} due to output power P_0

$$T_{sn} = \frac{p_0}{w} = \frac{p_0}{2\pi n}$$

$$T_g = \frac{\frac{p_g}{2\pi n_s}}{60} = 9.55 \frac{p_g}{ns} \text{ Nm}$$

$$= \frac{p_m}{2\pi n_s/60} = 9.55 \frac{pm}{ns} \text{ Nm}$$

$$T_{sn} = P_0/(2\pi n/60) = 9.55 \frac{p_0}{ns} \text{ Nm}$$

The torque of an induction motor, being due to interaction of the rotor and stator fields, depends on the strength of those fields and the phase relation between them. Thus the torque developed by the rotor of an Induction motor is directly proportinal to rotor current I_2, stator flux/pole ϕ m power factor of rotor circuit cos ϕ_2.

$$\text{i.e. } T \propto \phi I_2 \cos\phi_2$$

since rotor emf per phase at standstill

$$E_2 \propto \phi$$

Torque developed $T \propto E_2 I_2 \cos\phi_2$

or $\quad T = k E_2 I_2 \cos\phi_2$

where $\quad K$ = proportionality constant.

$$T = k.E_2\left(\frac{SE_2}{\sqrt{R_2^2 + S^2 x_2^2}}\right)\left(\frac{R_2}{R_2^2 + S^2 x_2^2}\right)$$

$$\Rightarrow \quad T = \frac{KsRE_2^2}{R_2^2 + S^2 x2^2}$$

where $\quad I_2 = SE_2/\sqrt{R_2^2 + S^2 x_2^2}$

$$\cos\phi_2 = R_2/\sqrt{R_2^2 + S^2 x_2^2}$$

→ starting torque (T_{St})

At start, the rotor is Stationary

$\Rightarrow \quad$ slip S = 1

$$T = \frac{KSRE_2^2}{R_2^2 + S^2 x_2^2}$$

if $S = 1$

$$T_{st} = \frac{K R_2 E_2^2}{R_2^2 + X_2^2}$$

Stator supply V is constant. So rotating flux ϕ set up by the stator currents and rotor induced emf. E_2 are also cosntant.

$$T_{st} = \frac{K_1 R_2}{R_2^2 + x_2^2} = \frac{K_1 R_2}{Z_2^2}$$ where K_1 is another proportionality constant.

→ **maximum Torque:**

$$T = \frac{KR_2E_2^2S}{R_2^2+S^2x_2^2}$$

if $S = R_2/x_2$

then,

$$T_{max} = \frac{KR_2E_2^2(R_2/x_2)}{R_2^2+\left(\frac{R_2}{x_2}\right)^2 x_2^2} = \frac{(KR_2^2\,E_2^2)/x_2}{R_2^2+R_2^2}$$

$$= \frac{KR_2^2E_2^2}{2R_2^2.x_2}$$

$$= \frac{KE_2^2}{2x_2}$$

→ **for maximum starting torque**

$$S = \frac{R_2}{x_2} = 1 \Rightarrow R_2 = x_2$$

FIRST TERM EXAMINATION [SEPT. 2015]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

Time. 1.30 Hours. **M.M. : 30**

Note: *Q No.1 is compulsory. Attempt any two more Questions from the rest.*

Q.1. (*a*) Chose the correct option (Justify your answer) (2×5 = 10)

Circuit show in Fig. 1 contains ideal sources. Current flowing through 6 ohm resistor is- (A) 2A (B) 5 A (C) 7A (D) 3A

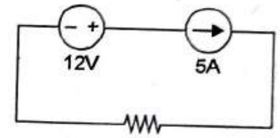


Fig. 1

Ans. From the above circuit diagram, current through '6Ω' resistance is 5 Amp. Because when a voltage source and current source connected in series in a circuit, then current source will dominate. So option 'B' is correct.

Q.1. (*b*) Rewrite the complete and correct statement: "Internal resistance of ideal voltmeter is....whereas internal resistance of ideal voltage source is...."

Ans. "Internal resistance of ideal voltmeter is "O"... whereas internal resistance of ideal voltage source is "∞" infinite.

Q.1. (*c*) (*i*) For a circuit shown in Fig. 2, the reading of ideal voltmeter is.....

(*ii*) For a network in Fig. 3, if we find the Thevenin's Equivalent Circuit at terminal X & Y then Thevenin's Voltage will be

Ans. 1.(*c*) (*i*)

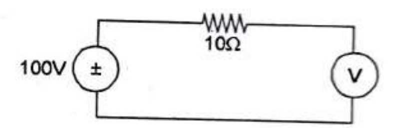


Fig. 2

From the Fig. 2 the reading of ideal voltmeter is 100*V*.

Ans. 1.(*c*) (*ii*) For finding the Thevenin's equivalent, short the voltage source and open current source.

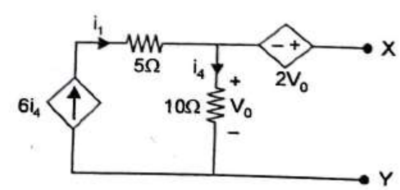


Fig. 3

Now,

$$i_4 = \frac{V_0}{10}$$

$$R_{xy} = 5 + 10 = 15\,\Omega$$

$$6\,i_4 - 2V_o = 0$$

$$\frac{6V_0}{10} - 2V_0 = 0$$

$$6V_0 - 20\,V_0' = 0$$

$$\boxed{V_o = 0}$$

Because there is no independent source.

Q.1. (d) For a series RL circuit shown in Fig 4. Draw a phasor diagram showing all the electrical quantities (Voltage and Current) marked in the circuit. Also write the impedance of circuit in j notation.

Ans.

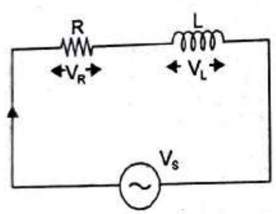
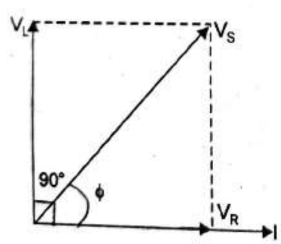


Fig. 4

From the above circuit

$$V_s = \sqrt{V_R^{\,2} + V_L^{\,2}} \qquad ...(1)$$

Phasor diagram of RL circuit



and impedance of RL circuit is given by

$$\boxed{Z = R + jX_L} \qquad ...(2)$$

Q.1. (e) What is a form factor? Give its value for Sinusoidal voltage.

Ans. From factor is the ratio of rms value of wave form to Average value of Wave form.

$$\text{Form factor} = \frac{V_{rms}}{V_{avg}} = \frac{I_{rms}}{I_{avg}} = \frac{I_m/\sqrt{2}}{2\frac{I_m}{\pi}} = 1.11$$

- "Value of form factor for sinusoid is "1.11."

Q.2. (a) For a network shown in Fig. 5, find all the marked mesh currents. (6 + 4 = 10)

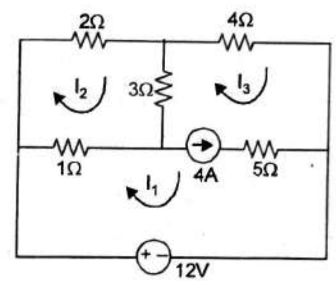


Fig. 5

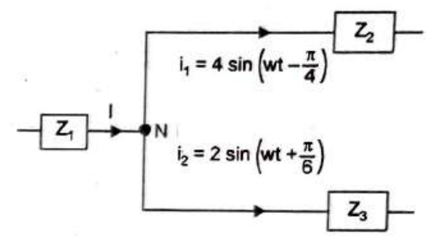
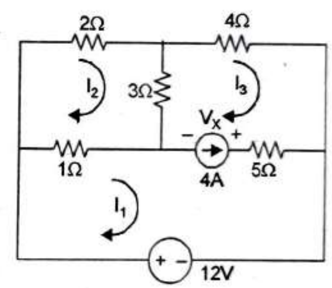


Fig. 6

Ans

$$I_1 = ?$$
$$I_2 = ?$$
$$I_3 = ?$$



(Applying Mesh Analysis)

$$12 + V_x = 6\,I_1 - I_2 - 5\,I_3 \qquad ...(1)$$

$$0 = -I_1 + 6\,I_2 - 3\,I_3 \qquad ...(2)$$

$$-V_x = -5\,I_1 - 3\,I_2 + 12\,I_3 \qquad ...(3)$$

Adding equation (1) to (3), we get

$$12 = I_1 - 4\,I_2 + 7I_3 \qquad ...(4)$$

- The relation between the source current and mesh currents is given by

$$I_s = I_1 - I_3$$

$$4 = I_1 - I_3 \qquad ...(5)$$

→ Now from equation (3), (4), (5) the value of I_1, I_2 and I_3 can be determine.

→ Multiply equation (3) by 2, equation (4) by 3, and adding the results to eliminate I_2.

We get

$$I_1 + 15 I_3 = 36 \quad ...(6)$$

$$I_1 - I_3 = 4 \quad ...(7)$$

• From above equation $I_1 = 6\text{ Amp}, I_3 = 2\text{ Amp}$

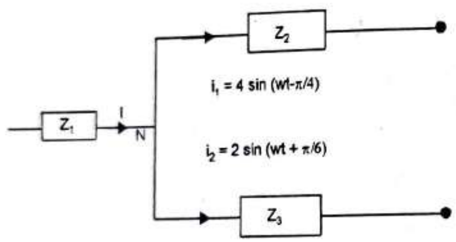
Put the value in equation (3), we get

$$I_2 = 2\text{ Amp}$$

So, $I_1 = 6\text{ Amp}, I_2 = 2\text{ Amp}, I_3 = 2\text{ Amp}$ **Ans.**

Q.2. (b) For a network shown in Fig. 6, find the current 'I' entering the node N. Express 'I' in polar form.

Ans.



• From the above, 'I' is the phasor sum of currents

i.e. $$I = i_1 + i_2 \quad ...(1)$$

• $$I = 4\sin(\omega t - \pi/4) + 2\sin(\omega t + \pi/6)$$

$$= 4\sin\omega t.\cos\frac{\pi}{4} - 4\cos\omega t\sin\frac{\pi}{4} + 2\sin\omega t\cos\pi/6 + 2\cos\omega t\sin\pi/6$$

$$= \frac{4}{\sqrt{2}}\sin\omega t - \frac{4}{\sqrt{2}}\cos\omega t + 2.\frac{\sqrt{3}}{2} + 2.\frac{1}{2}\cos\omega t$$

$$I = 4.560\sin\omega t - 1.828\cos\omega t \quad ...(2)$$

Standard form of equation is. $i = I_m \sin(\text{wt} + \alpha)$

$$i = (I_m\cos\alpha)\sin\text{wt} + (I_m\sin\alpha)\cos\text{wt} \quad ...(3)$$

By comparing, we find, $I_m\cos\alpha = 4.560$

$$I_m\sin\alpha = 1.828$$

• Squaring and adding these quantities we get

$$I_m^2\cos^2\alpha + I_m^2\sin^2\alpha = (4.560)^2 + (-1.828)^2$$

$$Im^2(\cos^2\alpha + \sin^2\alpha) = 20.79 + 3.34$$

$$I_m^2 = 24.13$$

⇒ $$I_m = 4.91\text{ Amp.}$$

⇒ $$\frac{I_m\sin\alpha}{I_m\cos\alpha} = \frac{-1.828}{4.560} \Rightarrow \tan\alpha = -0.400$$

$$\boxed{\alpha = -21.8^\circ}$$

⇒ Now standard current equation – $i = I_m\sin(\omega t + \alpha)$

⇒ $i = 4.91\sin(\omega t - 21.8^\circ)$ **Ans.**

Q.3. (a) Find the current through R_L in the network shown in Fig. 7 using Norton Theorem. (5)

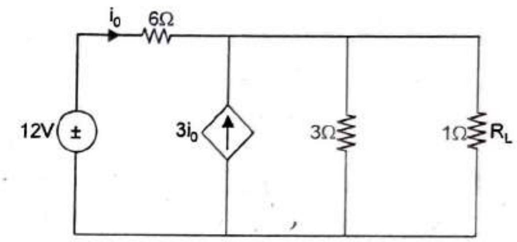
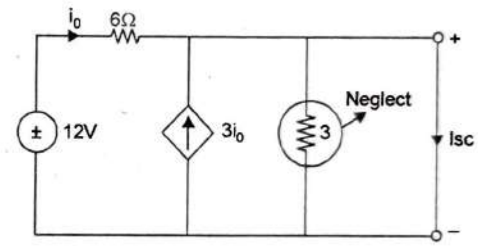


Fig. 7

Ans. First remove R_L and short terminals



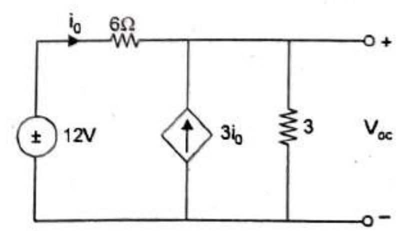
$$I_{sc} = 3i_o + i_o = 4i_o$$

But $$i_o = \frac{12}{6} = 2\text{ Amp}$$

$$I_{sc} = 4 \times 2 = 8\text{ Amp}$$

⇒ $$\boxed{I_{sc} = I_N = 8\text{ Amp}}$$

Now open the terminals



Nodal Analysis

$$i_o + 3i_o - \frac{V_{oc}}{3} = 0$$

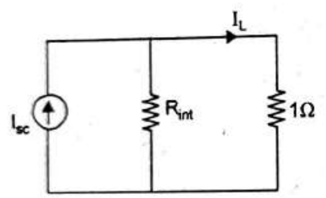
$$\Rightarrow \quad 4i_o = \frac{V_{oc}}{3}$$

$$\Rightarrow \quad 4\left[\frac{12 - V_{oc}}{6}\right] - \frac{V_{oc}}{3} = 0$$

$$8 - \frac{2V_{oc}}{3} - \frac{V_{oc}}{3} = 0$$

$$\boxed{V_{oc} = 8V}$$

Now $$R_{in} = \frac{V_{oc}}{Isc} = \frac{8}{8} = 1\Omega$$



Ans.

Q.3. (b) For a AC network shown in Fig. 8, if the reading of voltmeter (indicating RMS value) is 60V then find the reading of Ammeter. Note Ammeter is also indicating the RMS value. (5)

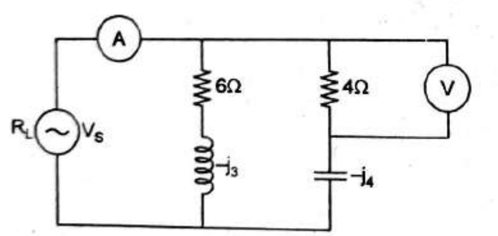
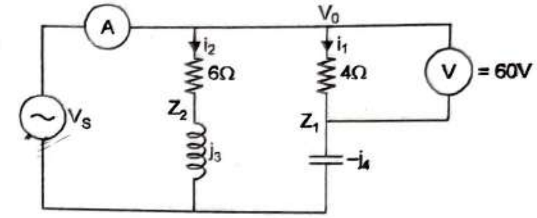


Fig. 8

Ans.

$$V = 60V\text{ (rms) Ammeter reading}$$
$$i_1 = 60/4 = 15\text{ Amp}$$
$$Z_1 = (4 - j_4)\ Z_2 = (6 + j_3)$$
$$V_0 \Rightarrow 15\,(4 - j_4)$$
$$V_1 = (60 - j\,60)\text{ volt}$$



Now $$\boxed{i_2 = \frac{V_1}{Z_2}}$$

Because in parallel voltage is same so it directly appears to Z_2.

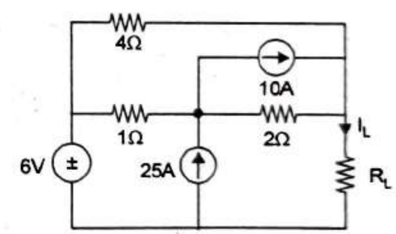
$$i_2 = \frac{60 - j60}{6 + j_3} = (10 - j20)$$

Now
$$i = i_1 + i_2$$
$$= (15 + j0) + (10 - j\,20)$$
$$i = (25 - j20)\text{ Amp}$$

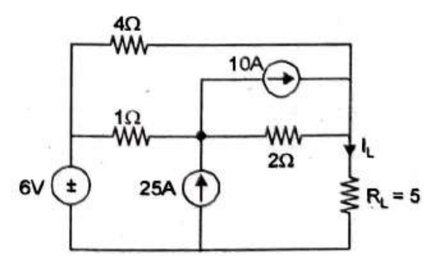
Now Ammeter reads $\boxed{i = 25\text{Amp}}$ **Ans.**

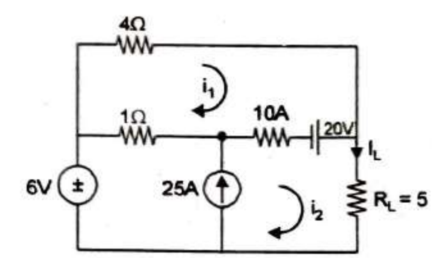
Q.4. (a) For a network shown in Fig. 9, if R_L is load resistance & I_L is current flowing through it then complete the table given below. (7)

S.No.	R_L	I_L
1		5 Ohm
2		10 Ohm
3		15 Ohm



Ans.





$$\Rightarrow \quad 4i_1 + 20 + 10(i_1 - i_2) + 1(i_1 - i_2) = 0$$

$$\Rightarrow \quad 15 i_1 - 11 i_2 = -20 \qquad \text{...(1)}$$

$$i_2 - i_1 + 10(i_2 - i_1) - 20 + 5 i_2 = 0$$

$$-11 i_1 + 16 i_2 = 20 \qquad \text{...(2)}$$

$$15i_1 - 11i_2 = -20 \times 16$$

$$11i_1 - 16i_2 = -20 \times 11$$

$$\Rightarrow \quad 240i_1 - 121i_1 = -320 + 220$$

$$119 i_1 = -100$$

$$\boxed{i_1 = -0.840 \text{ Amp.}}$$

$$-(15 \times 0.840) = 11 i_2 = -20$$

$$-12.6 - 11 i_2 = -20$$

$$-11 i_2 = -20 + 12.6$$

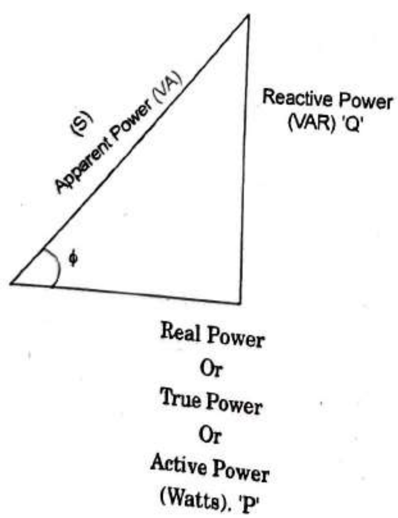
$$-11 i_2 = -7.4$$

$$\boxed{i_2 = 0.672}$$

$$\boxed{I_1 = I_2 = 0.672 \text{ Amp}}$$

Q.4. (b) Draw the Power Triangle. Also indicate different types of powers in AC network along with their units.

Ans. Power triangle is used to define the different types of power.



⇒ **Real** Power is denoted by 'P' and its unit is "watt".

⇒ **Reactive Power is denoted by 'Q' and its unit is "VAR *i.e.* voltage-amp Reactive".**

⇒ Apparent Power is denoted by 'S' and its unit is "VA", *i.e.* voltage- Amp.

⇒ From the power triangle

$$\boxed{S^2 = P^2 + Q^2}$$

PRE UNIVERSITY EXAMINATION [NOV. 2015]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE-107]

Time. 3 Hours **M.M. : 75**

***Note:** Q No.1 is compulsory. Attempt any four more Questions from the rest.*

Q.1. (a) Discuss the limitations of Superposition Theorem? (2)

Ans. Limitations of Super Position Theorem:

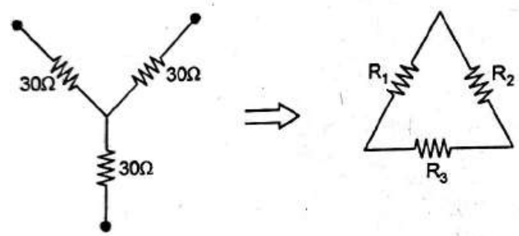
(1) Superposition theorem is valid for all types of linear circuits.

(2) Superposition theorem is not valid for power relationships. Because it is based on the principle of "linearity".

(3) Superposition is not applicable to circuits containing only dependent sources.

Q.1. (b) A star connection contains three equal resistances of 30 ohm. Find the resistances of the equivalent Delta connection. (2)

Ans.



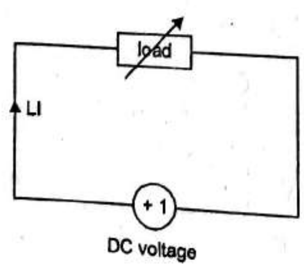
From star to delta transformation:

$$R_1 = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1} = \frac{(30\times 30)+(30\times 30)+(30\times 30)}{30}$$
$$= 90\ \Omega$$
$$R_2 = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2} = \frac{(30\times 30)+(30\times 30)+(30\times 30)}{30}$$
$$= 90\ \Omega$$
$$R_3 = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3} = \frac{(30\times 30)+(30\times 30)+(30\times 30)}{30}$$
$$= 90\ \Omega$$

$\Rightarrow$ $\boxed{R_1 = R_2 = R_3 = 90\Omega}$ **Ans.**

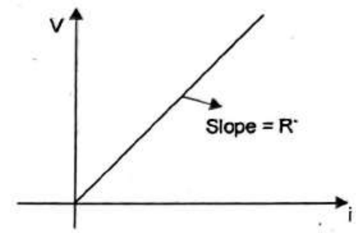
Q.1. (c) If a variable load is connected across a Non Ideal DC Voltage source, then draw the graph between terminal voltage across the source and current supplied by the source. (3)

Ans.

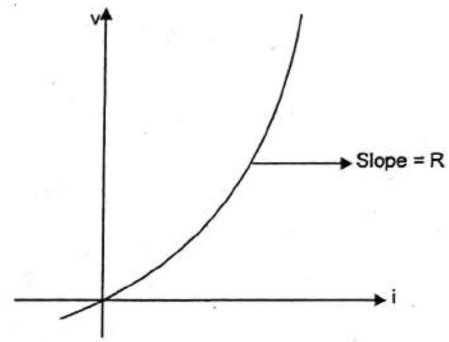


When voltage is connected across the variable load and if circuit is closed, then there flow a current, which is changes according to value of the load.

$\rightarrow$ If the load is resistor (linear) then it follow the ohm's law rule and graph comes straight line.



$\rightarrow$ If the load is non-linear, then it does not follow the ohm's law, and graph comes like



Q.1. (d) Evaluate J^j (3)

Ans. $J^j - ?$

We know that

$$j^n = \cos\left(\frac{n\pi}{2}\right) + j\sin\left(\frac{n\pi}{2}\right)$$

For calculating J^j, we have to use Euler's formula

$$i.e.\ j^j = \left(e^{j(\pi/2+2k\pi)}\right)^j$$
$$= 2^{j^2(\pi/_2+2k\pi)}$$
$$= e^{-(\pi/_2+2k\pi)}$$

where $K \in Z$, the set of integers.

The prinicple value for k = 0 is $e^{-\pi/2}$ which is approximately 0.207879576. **Ans.**

Q.1. (e) Why eddy current damping is not preferred in Dynamometer type. Wattmeter? Which type of damping system is preferred in such instruments? (3)

Ans. Dynamometer type Wattmeter is made of iron material which is ferrous (magnetic material) and eddy current damping based on the principle of when a non-magnetic moves in currents, a force opposes the motion.

$\rightarrow$ Thats why eddy current damping is not possible in Dynamometer type Wattmeter.

→ Spring control damping is preferred in the Dynamometer type Wattmeter.

Q.1. (f) Scale of PMMC instrument is uniform whereas scale of MI type instrument in non uniform. What is the reason behind this difference in their scales? (3)

Ans. Permanent Magnet Moving coil, work only on dc supply and it have uniform scale because the deflection torque produces a linear function of 'θ' and current

$$\boxed{T_d \alpha I}$$

Moving Iron instruments, having non-uniform scale because the deflection torque is function current which is square in nature. *i.e.*

$$\boxed{T_d \alpha I^2}$$

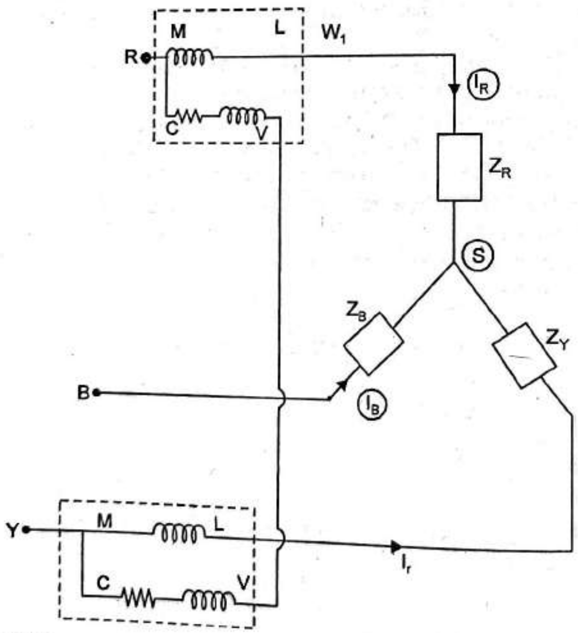
So it does not have uniform scale.

Q.1. (g) Two Wattmeter method is used to measure power in three phase inductive load having power factor of 0.3. Current coil of W1 is in series with Y phase and its pressure coil is connected across Y and B phases. Current coil of W2 is in series with R phase and its pressure coil is connected across R and B phase. Which Wattmeter will give negative reading and why? Given that phase sequences of three phase supply is RYB. (3)

Ans.

From the Fig.

$$W_1 = I_L V_L \text{Cos}(30 - \phi) \quad ...(1)$$
$$W_2 = V_L I_L \text{Cos}(30 + \phi) \quad ...(2)$$



when $\phi = 60°$, then one wattmeter gives negative reading *i.e.*

$$w_1 = V_L I_L \cos(30° - 60°) = \frac{-\sqrt{3}}{2} V_L I_L$$

$$w_2 = V_L I_L \cos(30° + 60°) = 0$$

Wattmeter 'W_1' gives negative reading, because angle is about 60°.

Now the entire power is measured by only one wattmeter.

Q.1. (h) There are three different Transformers. Core of one Transformer is made of Iron. Core of other Transformer is made of Silicon Steel. Core of third Transformer is made of Aluminum. Which of these transformers has the lowest Hysteresis loss? Which one has the lowest eddy current loss? (3)

Ans. (1) Transformer having iron core having highest Hystersis loss, because, while magnetizing and demagnetizing the iron core having some residual voltage in it which causes Hysteresis and eddy current loss.

(2) Transformer having silicon steelcore having Hysteresis loss, less as compare to iron core transformer because of less residual voltage. The eddy current loss in it is also very less, because silicon steel core having less area in B-H curve, and used to minimize the eddy current also.

(3) Transformer having aluminium core, does not effect with magnetic field, because it is a non-magnetic material.

Q.1. (i) If an iron piece is subjected to alternating magnetic field. Then which one of the following statement is true and why.

(1) Magnetic flux density (B and Magnetic field intensity (H) are in same phase.; (2) B lags behind H (3) H lags behind B; (4) B and H are in phase opposition. (3)

Ans. If an iron piece is subjected to an alternating field that means, we are magnetize that iron piece, and when we remove magnetic field that means we demagnetize it.

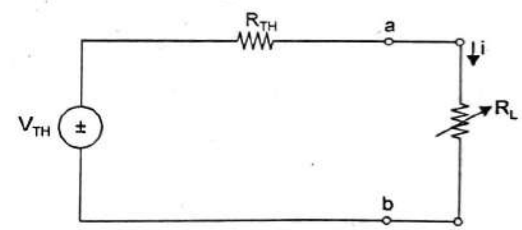
While magnetizing and demagnetizing it will follow the B-H curve or Hysteresis curve.

→ In B-H or Hysteresis curve the 'B' leads the 'H' by 90° or 'H' lags the 'B' by 90°. So for this, H lags behind 'B'. Hence option (3) is correct.

Q.2. (a) State and prove Maximum Power Transfer Theorem. Also prove that if a system is delivering maximum power according to maximum power transfer theorem then the efficiency of system is 50% (7.5)

Ans. Maximum Power Transfer: Maximum power is tranferred to the load when load resistance is equal to the Thevenin's resistance $R_L = R_{TH}$."

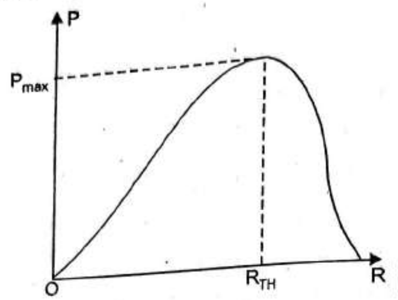
→ Thevenin's equivalent is useful in finding the maximum power a linear circuit can deliver to the load.



$$P = i^2.R_L = \left(\frac{V_{TH}}{R_{TH} + R_L}\right)^2.R_L \quad ...(1)$$

→ Power is small for small or large value of R_L but maximum for some value of R_L between 0 to ∞.

→ **Maximum power occurs when R_L is equal to R_{TH}.**



$$P = \left(\frac{V_{TH}}{R_L + R_{TH}}\right)^2 . R_L$$

$$\frac{dp}{dR_L} = V_{TH}^2\left[\frac{(R_{TH}+R_L)^2 - 2R_L(R_{TH}+R_L)}{(R_{TH}+R_L)^4}\right]_0$$

$$= V_{TH}^2\left[\frac{(R_{TH}+R_L-2R_L)}{(R_{TH}+R_L)^3}\right] = 0$$

$\Rightarrow 0 = (R_{TH} + R_L - 2R_L) \Rightarrow (R_{TH} - R_L) = 0$

$\Rightarrow$ $\boxed{R_{TH} = R_L}$

$\Rightarrow$ The maximum power transferred is obtained by putting $R_{TH} = R_L$, we get

$$\boxed{P_{max} = \frac{V_{TH}^2}{4.R_{TH}}}$$

Now total power supplied by the voltage source is

$$P = \frac{V_{TH}^2}{R_{TH}+R_L} = \frac{V_{TH}^2}{2R_{TH}} \text{ at Max. Power transfer}$$

→ Efficiency η is

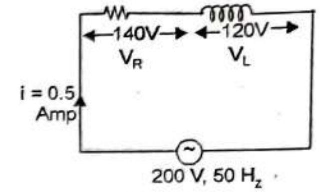
$$\eta(\%) = \frac{P_{max}}{P} \times 100$$

$$\Rightarrow \quad \eta(\%) = \frac{V_{TH}^2/4.R_{TH}}{V_{TH}^2/2R_{TH}} \times 100 = 50\%$$

$\boxed{\eta = 50\%}$ **Ans.**

Q.2. (b) A coil and a non inductive resistor are connected in series across a 200V, 50Hz supply. The voltage across the coil and resistor are 120V and 140V respectively. If the supply current in 0.5A then calculate the resistance and inductance of the coil. Also calculate the power factor of the circuit and power dissipated in the coil. (5)

Ans.



R = ?
L = ?
P = ?
cos ϕ – ?
P = ?

$\Rightarrow$ $V_R = 140$ V, $V_L = 120$ V, I = 0.05 Amp, $V_S = 200$V,

→ $V_R = I.R, R = \frac{V_R}{I} = \frac{140}{0.5} = 280\Omega$

→ $V_L = I.X_L, X_L = \frac{V_L}{I} = \frac{120}{0.5} = 240\Omega$

→ $X_L = 2\pi f_L \Rightarrow L = \frac{X_L}{2\Omega f} = \frac{240}{2\pi \times 50} = 0.382H$

→ Impedance $\Rightarrow Z = R + jx_L = (280 + j\,240)\Omega$

→ $\text{Cos}\,\phi = \frac{R}{Z} = \frac{280}{(280+j240)} = 0.807$ lagging

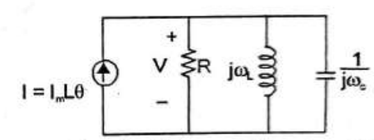
Power dissipated, $P = I^2.Z$

$P = (0.5)^2.(280 + j\,240)$

P = 10.7 Watt **Ans.**

Q.3. (a) If an inductive coil having resistance (R) and inductance (L) is connected in parallel with a capacitor (C) then derive the expression of resonance frequency in terms of R, L and C. (6.5)

Ans.



$\Rightarrow$ At Parallel Resonance, the admittance of the circuit is given by

$$Y = \frac{I}{V} = \frac{I}{R} + j\omega_c + \frac{i}{J\omega_L}$$

$$\Rightarrow \quad \boxed{Y = \frac{1}{R} + j\left(\omega_c - \frac{1}{\omega_L}\right)}$$

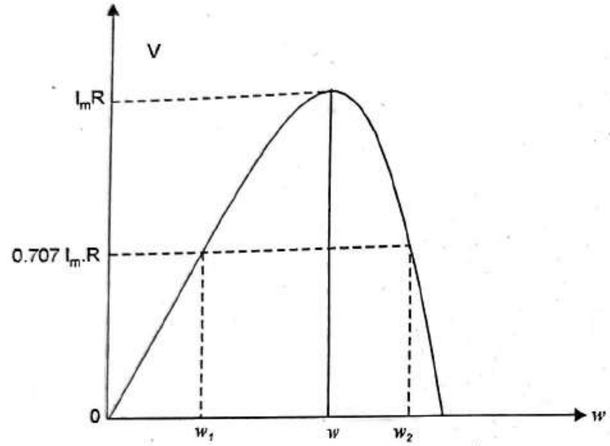
$\Rightarrow$ At Resonance, imaginary part should be zero.

i.e $\quad j\left(\omega_c - \frac{1}{\omega_L}\right) = 0$

$$\Rightarrow \qquad \omega_c - \frac{1}{\omega_L} = 0$$

$$\Rightarrow \qquad \boxed{\omega = \frac{1}{\sqrt{LC}}} \text{ rad/sec.}$$

→ At resonance the combination L-C acts like open circuit.



→ From the above graph the frequencies ω_1 and ω_2 are given as–

$$\omega_1 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$

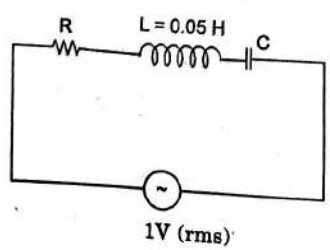
$$\omega_2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$

→ Bandwidth, $B = \omega_2 - \omega_1 = \dfrac{1}{RC}$

→ Quality factor, $Q = \dfrac{\omega}{\beta} = \dfrac{R}{\omega_L} = \omega.RC$

Q.3. (b) In a Series Resonance Circuit, AC supply voltage is 1V (rms) and L=0.05H. If bandwidth of series resonance circuit is 100 rad/s and voltage across L at resonance is 70.71V (rms) then find the value of R, C and resonance frequency. power at resenace is 0.1 W. **(6)**

Ans.



Bandwidth $B = w_2 - w_1 = 100$ rad/sec $P = 0.1$ Watt $V_L = 70.71$ (rms), $R = ?$ $C = ?$

⇒ At resonance, $\boxed{X_L = X_C}$

$$\Rightarrow \qquad X_L = 2\pi f.L = 2\pi \times 50 \times 0.05$$
$$= 15.7\Omega$$

Now we know

$$X_L = X_C$$
$$\Rightarrow \qquad 2\pi fC = 15.7$$
$$C = \frac{15.7}{2\pi f} = \frac{15.7}{314}$$
$$\boxed{C = 0.05F}$$

⇒ At the time of Resonance, the power is only dissipated by resistance.

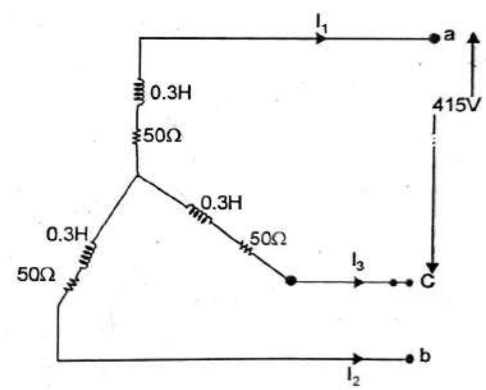
$$P = I^2.R \Rightarrow \boxed{R = \frac{P}{I^2}}$$

⇒ Now

$$V_L = I.X_L$$
$$\Rightarrow \qquad I = \frac{V_L}{X_L} = \frac{70.71}{15.7} = 4.5038.\text{ Amp.}$$
$$\Rightarrow \qquad R = \frac{0.1}{(4.50)^2} = \frac{0.1}{20.25} = 0.0049\Omega \textbf{ Ans.}$$

Q.4. (a) A three phase Delta connected load consists of three similar inductive coils each of resistance 50 Ohm and reductance 0.3H. Three phase supply is 415 V, 50 Hz. Calculate the line current, phase, line voltage, load phase voltage and total power consumed by the load.

Ans. Line Current - ?
Line Voltage – ?
Phase Current – ?
Phase Voltage – ?
Power – ?



In star connected system

Line current = Phase current

$$\boxed{I_L = I_{Ph}}$$

and line voltage = $\sqrt{3}$ × phase voltage

$$\boxed{V_L = \sqrt{3} \times V_{Ph}}$$

⇒ Now

$$V_L = 415\text{ V (given)}$$

$$V_{Ph} = VL/\sqrt{3} = \frac{415}{\sqrt{3}} = 239.607V$$

Phase voltage $\boxed{V_{Ph} = 239.60V}$

⇒ Impedance

$$Z = R + jX_L$$

$$Z = (50 + j0.3)\ \Omega$$

⇒ line current

$$I_L = \frac{V_L}{Z} = \frac{415}{(50+j0.3)} = \frac{415}{50.0008\underline{|.343}}$$

$$I_L = 8.299\underline{|-0.343}$$

Now

$$I_L = I_{Ph} = \text{Amp.}$$

$$= 8.299\underline{|-0.343}$$

→ Power in star connected system

$$P = 3.V_{ph}.I_{ph}\cos\phi$$

$$\cos\phi = \frac{R}{Z} = \frac{50}{(50+j0.3)} = 0.999\underline{|-0.343°}$$

$$P = 5.959\text{ kW}$$

Q.4. (b) A magnetic core, in the form of a closed ring, has a mean length of 20 cm and a cross-section of 1cm. sq. permeability of rings is 2400. What direct current will be needed in the coil of 2000 turns uniformly wound round to create a flux of 0.2m Wb in the ring?

Ans.

Mean length = 20 Cm = 0.2 m

Cross-section = 1 cm² = 10^{-4} m²

Permeability = 2400, = 2400 μr

N = 2000 turns I = ?

φ = 0.2m wb

Reluctance,

$$S = \frac{1}{\mu_0\mu_r.a} = \frac{0.2}{4\pi\times10^{-7}\times2400\times10^{-4}} = 6.63\times10^5$$

$$\rightarrow \quad F = S\phi, \Rightarrow IN = S\phi,\ I = \frac{S\phi}{N}$$

$$\Rightarrow \quad I = \frac{6.63\times10^5\times0.2\times10^{-3}}{2000}$$

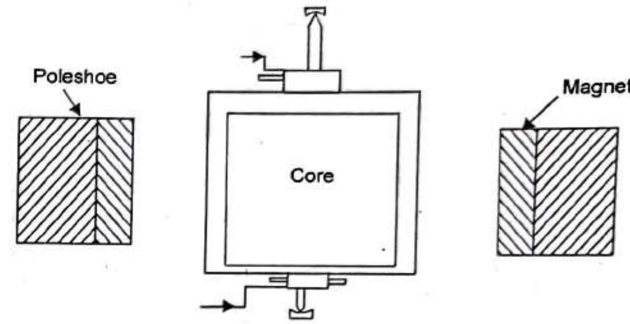
$$I = 66.3\times10^{-3}\text{ Amp}$$

$$\boxed{I = 66.3\text{m Amp}}\ \textbf{Ans.}$$

Q.5. (a) Explain the construction and working principle of PMMC instrument. Also derive the expression of deflection torque. Give its merits and demerits over other types of measuring instruments. **(8)**

Ans. Construction of moving coil instruments: A PMMC type moving instruments consits of permanent powerful magnet with soft iron pole piece.

A cylindrical iron core is mounted between the two poles of the magnet giving very narrow air gap in which sides of a pivoted light reactangular coil lies.



The reactangular coil is wound of many turns from wire on light aluminium or copper former and act as moving element.

→ The purpose of using core is to make the field uniform and to reduce the reluctance of the magnetic circuit. A low reluctance helps to retain permanence of the magnet for a longer period.

→ The current is led into and out of the coil by means of phosphor bronze hair springs provided at both ends. The springs also provide the controlling torque.

→ At Balance condition the controlling torque and deflecting torque become equal.

$$\boxed{T_c = T_d}$$

→ $\boxed{T_c = K\theta}$ and $\boxed{T_d \alpha I}$

i.e. at balance $\boxed{Q\alpha I}$

Hence the scale of PMMC is uniform.

Merits of PMMC instruments:

(1) Uniform Scale

(2) Low power consumption because of small driving power.

(3) No Hysteresis loss as the former is of copper or aluminium.

Demerits

(1) These instruments can not be used for AC measurements.

(2) They are costlier in comparisen to moving iron instruments.

Q.5. (b) Draw and explain the block diagram of Electronic Energy Meter. **(4)**

Ans. Electrometers are an integrating instruments, and takes into account both the equatiblies i.e. the power and time.

→ The product of which gives the energy. An energy meter keeps a record of total energy consumed in a circuit during a particular period but it does not give any idea about the variation in the rate of energy consumption during the period.

→ Energy meters are generally of three types

(1) Electrolytic Meters (2) Motor meters (3) Clock meters

→ In Electronic energy meter, we use some electronic device for the measurement of energy.

→ Eletronic Energy meter takes very less power to operate and very accurate as well.

→ Electronic Energy meter consists of Rectifier, Memory, Counter circuit to evaluate the energy.

Q.6. (a) A moving coil instrument of resistance 5 ohm, requires a potential difference of 75mV to give a full scale deflection. Convert this measuring instrument into:

(i) Ammeter of range (0-30A) **(7)**

(ii) Voltmeter of range (0-250V)

Ans. Current through the instrument for full scale deflection is

$$I_m = \frac{75\times10^{-3}}{5} = 0.015 \text{ Amp.}$$

(a) Current through the shunt when the instrument reads 30 Amp is

$$I_s = I - I_m = 30 - 0.015$$

$$I_s = 29.935 \text{ Amp.}$$

$$I_s.R_s = I_m.R_m$$

$$\Rightarrow \quad 29.935.\ R_s = 0.015 \times 5$$

$$\Rightarrow \quad \boxed{R_s = 0.0025\Omega}$$

(b) From equation

$$V = I_m (R_m + R_{se})$$

$$\Rightarrow \quad R_m + R_{se} = V/I_m$$

$$R_{se} = \frac{V}{I_m} - R_m$$

$$R_{se} = \frac{250}{0.015} - 5 = 1661.7\Omega$$

$$\boxed{R_{se} = 16661.7\Omega} \textbf{ Ans.}$$

Q.6. (b) Power in a 3 phase circuit is measured by two wattmeters and the readings of the wattmeters are 5 KW and 0.5 KW, the latter reading being obtained after reversal of the current coil connections. Find the total power and power factor of the circuit. **(5.5)**

Ans.

$$W_1 = 5 \text{ KW}$$

$$W_2 = 0.5 \text{ KW}$$

Reading is obtained after reversal of current coil so, one wattmeter should show negative reading, because the angle changes so

$$W_1 = V_L I_L \cos(30 - \phi)$$

$$W_2 = V_L I_L (30 + \phi)$$

Active power

$$P = W_1 + W_2$$

$$P = V_L I_L \cos(30 - \phi) + V_L I_L \cos(30 + \phi)$$

$$P = V_L I_L [\cos(30 - \phi) + \cos(30 + \phi)]$$

$$\boxed{P = \sqrt{3} V_L I_L \cos\phi} \Rightarrow P = 5 + (-0.5)$$

$$\boxed{P = 4.5 \text{ kW}}$$

Now

$$\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

due to reversal,

$$\tan\phi = \frac{\sqrt{3}(W_1 + W_2)}{W_1 - W_2} = \frac{\sqrt{3}[5 + 0.5]}{5 - 0.5}$$

$$\tan\phi = \frac{9.526}{2.1168} = 4.501$$

$$\phi = \tan^{-1}[4.501]$$

Now

$$\cos\phi = 0.4271 \textbf{ Ans.}$$

Q.7. (a) Derive the expression of rms value of emf induced in the primary and secondary of a Transformer. **(6)**

Ans. EMF Equation of Transformer

→ Main flux ϕ established in the core is alternating in nature.

→ An emf is induced in the primary winding of the transformer, which is given by

$$e_1 = -N_1 \frac{d\phi}{dt} \quad ...(1)$$

N_1 = Nomber of turns in the primary

The main flux 'ϕ' can be expressed as

$$\phi = \phi_m \cos wt \quad ...(2)$$

$$\phi_m = \text{maximum value of the main flux}$$

$$e_1 = -N_1 \frac{d}{dt}[\phi_m \cos wt]$$

$$\boxed{e_1 = -N_1 w.\phi_m \sin wt} \quad ...(3)$$

→ The induced Emf e_1 is maximum, when $\sin wt = 1$

$$\boxed{E_{1\max} = N_1 w \phi_m} \quad ...(4)$$

→ Rms value of a induced Emf in the primary is given by

$$E_{1\text{rms}} = \frac{E_1 \max}{\sqrt{2}} = \frac{N_1 w \phi_m}{\sqrt{2}} = \frac{N_1.2\pi f.\phi_m}{\sqrt{2}} \quad ...(5)$$

$$\boxed{E_{1rms} = 4.44 f \phi_m N_1} \text{ volts} \quad ...(6)$$

→ Emf induced in the secondary winding with N_2 turns is given by

$$E_{2\text{ rms}} = 4.44 f \phi_m N_2 \quad ...(7)$$

→ The induced Emf in primary winding E_1 as well as in secondary winding E_2 lags the main flux ϕ by 90°.

→ On dividing equation (7) and (6), we get

$$\Rightarrow \quad \boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = K}$$

Q.7. (b) Give the features of an Ideal Transformer. Draw and explain the equivalent circuit diagram of a practical tranformer.

Ans. Features of Ideal Transformer:

(1) Its primary and secondary winding resistance are negligible.

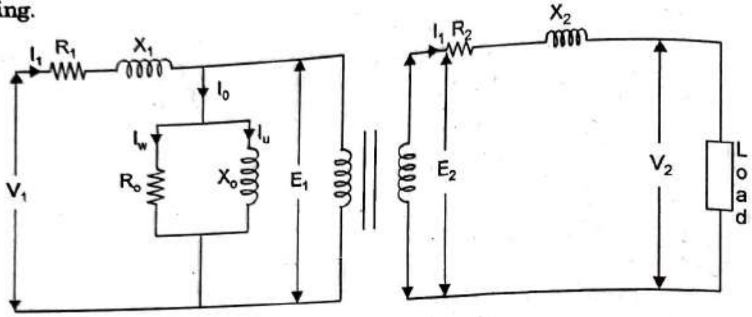
(2) The core has infinite permeability (μ) so that negligible mmf is required to establish the flux in the core.

(3) Its leakage flux and leakage inductances are zero. The entire flux is confined to the core and links both windings.

(4) There are no losses due to resistance, hysteresis, and eddy currents. Hence efficiency is 100%.

Equivalent circuit of Practical Transformer:

→ The transformer can be resolved in to an equivalent circuit in which the resistance and leakage reactances of both side of transformer are imagined to be external to the winding.

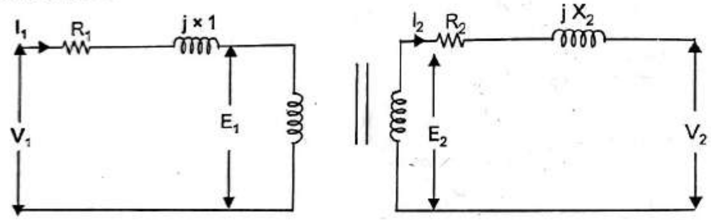


Applying K.V.L, we get

$$E_2 = I_2 R_2 + j\, I_2 X_2 + V_2 \qquad \text{...(1)}$$

$$V_1 = I_1 R_1 + j I_1 X_1 + (-E_1) \qquad \text{...(2)}$$

On Neglecting the I_o, because it is 2 to 5% of full-load current, so equivalent circuit can be converted in to-



$$\overrightarrow{E_2} = \overrightarrow{V_2} + \overrightarrow{I_2} R_2 + j \overrightarrow{I_2} X_2$$

$$\overrightarrow{E_2} = \overrightarrow{V_2} + \overrightarrow{I_2}(R_2 + jX_2)$$

$$\overrightarrow{E_2} = \overrightarrow{V_2} + \overrightarrow{I_2 Z_2} \qquad \text{...(1)}$$

where $\qquad \overrightarrow{Z_2} = R_2 + jX_2$ = Secondary leakage impedance

$$Z_2 = \sqrt{R_2^2 + X_2^2} \;\Big|\tan^{-1}\frac{X_2}{R_2}$$

→ $$\overrightarrow{V_1} = \overrightarrow{E_1} + \overrightarrow{I_1} R_1 + j \overrightarrow{I_1} X_1$$

$$\overrightarrow{V_1} = \overrightarrow{E_1} + \overrightarrow{I_1}(R_1 + jX_1) = \overrightarrow{E_1} + \overrightarrow{I_1 Z_1} \qquad \text{...(2)}$$

Q.8. (a) Explain the construction and working principle of a DC motor. **(6.5)**

Ans. Basic Structure of DC Motor: A dc motor has two main parts, stator and rotor.

→ Stator and rotor, separated by the air gap. Stator of dc motor does not move and normally is the outer frame of the machine. The rotor is free to move and normally is the inner part of the machine.

→ Both stator and rotor are made of ferromagnetic materials. Slots are cut on the inner periphery of the rotor.

→ The conductors are placed in the slots of the stator or rotor, and they are connected in the form of windings.

→ The winding in which voltage is induced is called armature winding and in which main flux is produced called Field winding.

Working Principle of DC Motor:

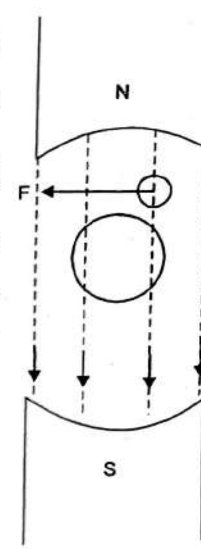
When a conductor carrying current is put in magnetic Field, a force is produced on it.

The effect of placing a current carrying conductor in a magnetic Field is shown in figure.

→ Suppose conductor acted upon by the magnetic field from a north pole of the motor. By applying left- hand rule, it is found the conductor has a tendency to move to the left side.

→ Since the conductor is in a slot on the circumference of the rotor, the force F acts in a tangential direction to the rotor.

→ Thus torque is developed on the rotor. Now rotor is free to move, so it starts rotating in the anticlock wise direction.



Q.8. (b) Write a short note on any two: **(6)**

(i) Stepper Motor:

Ans. Stepper or stepping motor has a rotor movement is discrete steps. The angular rotation is determined by the number of pulses fed into the control circuit.

→ Each input pulse initiates the drive circuit which produces one step of angular movement.

→ The device may be considered as a digital to analog converter. The drive circuit has inbuilt logic which causes appropriate windings to be energized and de-energized by solid-state switches in the required sequential manner.

→ There are three most popular types of rotor arrangements.

(1) Variable reluctance (VR) type.

(2) Permanent Magnet (PM) type

(3) Hybrid type, a combination of VR and VM.

→ The angle by which the rotor of stepper motor moves, when one pulse is applied to the stator is called step angle.

→ $$\text{Revolution} = \frac{\text{No. of steps}}{\text{No. of revolutions of the rotor}}$$

Q.8. (*ii*) Moving Iron type Measuring instrument :

Ans. There are two types of moving from instruments.

(1) Attraction type moving iron

(2) Repulsion type moving iron

→ The iron is made of sheet metal specially shaped to give a scale a nearly uniform as possible.

→ The moving iron is drawn into the field of solenoid when current flow through it. The movement of the iron is always from weaker magnetic field outside the coil into the stronger magnetic field inside the coil regardless the direction of the flow of current.

→ When the current to be measured is passed through a solenoid, a magnetic field is setup inside the solenoid, which inturn magnetizes the iron.

→ Thus iron is attracted in to the coil causing the spindle and the pointer to rotate. Such instruments normally have spring control pheumatic and damping.

Such an instrument has a scale crmped at the lower end and greatly expanded at the upper end, as the iron torque is quite low.

Q.8. (*iii*) Starting methods of Single phase induction motor.

Ans.

→ For starting 1-phase induction motor, we are doing following steps.

→ The single- phase winding on the stator is split into two windings, which are 90° electrical apart from each other. It means the two windings or coil have current 90° out of phase with each other.

→ The two windings are connected in parallel.

→ Impedance is connected in series with one of these windings.

→ By proper selection of such impedance the current may be made to differ by as much as 90° in the two coils.

→ This arrangement produce a rotating Magnatic field similar to 2-phase motor.

→ This method of achieving such an arrangement is known as split phase method.

→ This phase splitting is achieve by-

(1) Resistance start

(2) Capacitor start

(3) Capacitor start, capacitor run

(4) Permanent capacitor

(5) Shaded pole.

END TERM EXAMINATION [DEC. 2015]
FIRST SEMESTER (B.TECH)
ELECTIRCAL TECHNOLOGY [ETEE-107]

Time : 3 hrs. **M.M. : 75**

Note: *Attempt any five questions including Q.no.1 which is compulsory. Select one question from each unit. Assume missing data if any.*

Q.1. (a) State and explain reciprocity theorem?

(5×5=25)

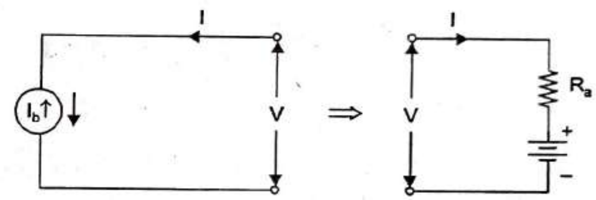
Ans. If the source voltage and zero- resistance ammeter are interchanged the magnitude of the current through the ammeter will be the same, no matter how complicated the network.

This is higly useful relation. In a linear passive network, supply voltage V, and current I are mutually transferable. The ratio of V and I is called the transfer resistance.

→ The circuits having this property are called reciprocal ones and obey.

Q.1. (*b*) What is the significance of back emf in DC motor?

Ans. When the motor armature carrying current rotates in the magnetic field, the armature conductor also rotate and hence cut the flux.



→ Rotating armature generating the back emf, E_b is like a battery of Emf E_b, put in opposition to the mains of 'V volts.

$$\boxed{V = E_a + I_a R_a}$$

Q.1. (*c*) Explain working of electronic energy meter?

Ans. Electronic energy meter is based on digital microtechnology (DMT) and uses no moving parts so it is also knwown as Static Energy meter. In EEM the accurate functioning is controlled by specially design *Ic* called ASIC.

→ The input data i.e. voltage is compared with programmed reference data and finally a voltage rate p_s given to the output

→ This output p_s then converted into digital data by A/D converters.

→ The digital data is then converted into an average value.

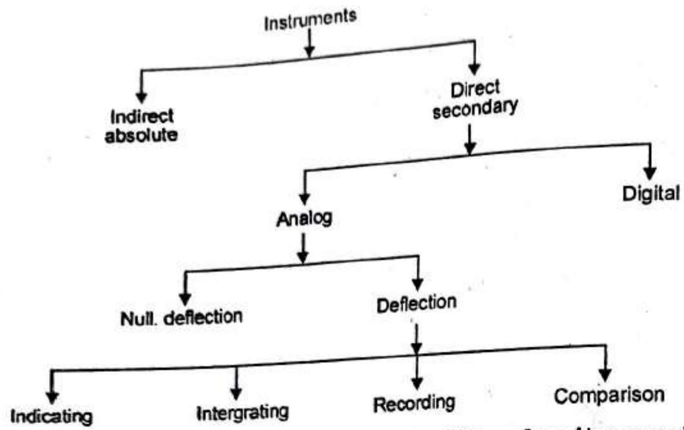
→ It improves the cost and quality of electicity distributions.

Q.1. (*d*) Classify instruments and clearly differentiate between absolute and secondary instruments?

Ans. Instruments are broadlly classify as

(1) Primary Instruments

(2) Secondary Instruments.



Q.1. (e) What is slip of an induction motor? How does it vary with load?

Ans. The Rotor runs at a speed which is always less than the speed of stator field i.e. synchronous speed.

→ let the synchronous speed denoted by N_s and rotor speed is denoted by N_r.

→ The difference between the synchronous speed and actual speed rotor is known as "Slip Speed."

$$\boxed{\text{Slip Speed} = N_s - N_r}$$

Or
$$S = \left[\frac{N_s - N_r}{N_s}\right] \times 100$$

Case I. When S = 0, means there is no relative motion motor is not rotating $0 = N_s - N_r$

$\Rightarrow \boxed{N_s = N_r}$ → Motor will not rotate.

Case II. $S = 1$ motor is in stand still current

$$S = \frac{N_s - N_r}{Ns}$$

$$\Rightarrow \quad 1 = \frac{N_s - N_r}{N_s} \Rightarrow \cancel{N}s = \cancel{N}s - Nr$$

$\Rightarrow \boxed{N_r = 0}$, motor is at stand still condition

UNIT I

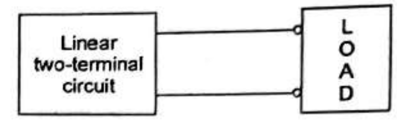
Q.2. (a) State and explain Thevenin's theorem. **(6.5)**

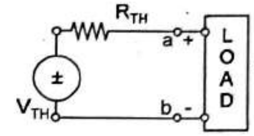
Ans. A linear two-terminal circuit can be replaced by an equivalent circuit consisting of voltage source V_{TH} in series with resistor R_{TH}

V_{TH} = Open circuit voltage at the terminals

R_{TH} = input or equivalent resistor the terminal

$$I_L = \frac{V_{TH}}{R_{TH} + R_L}$$





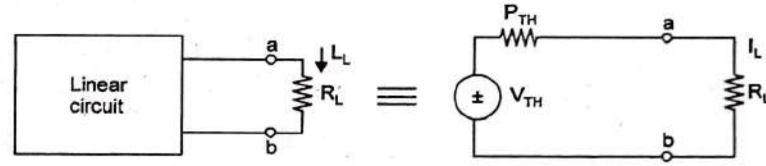
$\Longrightarrow V_L = I_L \cdot R_L$

$$V_L = R_L\left(\frac{V_{TH}}{R_{TH} + R_L}\right)$$

The terminals a - b are made open-ciruited to current flows, so that open circuit voltage across the terminals a-b must be V_{TH}

$$\boxed{V_{TH} = V_{OC}}$$

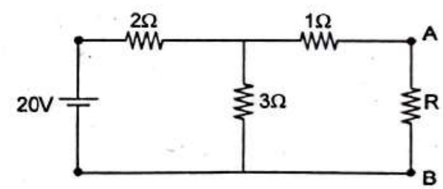
Generalised Form



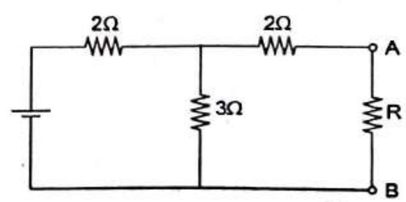
$$I_L = \frac{V_{TH}}{R_{TH} + R_L},$$

$$V_L = I_L R_L = \left[\frac{R_L}{R_{TH} + R_L}\right] V_{TH}$$

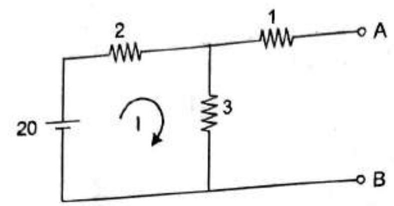
Q.2. (b) Calculate the value of load resistance in branch AB, so that the maximum power is transferred to the load of the circuit shown along side. (6)



Ans.



For V_{TH}:

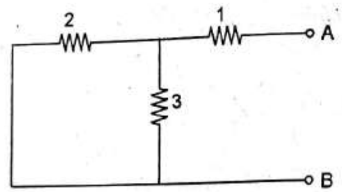


$$2I + 3I = 20$$

$$\Rightarrow \quad \boxed{I = 4 \text{ amp}}$$

$$V_{AB} = V_{TH} = V_{OC} = 3.I = 3.4$$
$$= 12 \text{ Volt}$$

For R_{TH}:



$$R_{AB} = R_{TH} = (3 \,||\, 2) + 1 = \frac{6}{5} + 1 = 11/_5 = 2.2\Omega$$

For maximum power transfer

$$R_L = R_{TH}$$

$$\Rightarrow \quad \boxed{R_L = R_{TH} = 2.2\Omega}$$

Maximum power

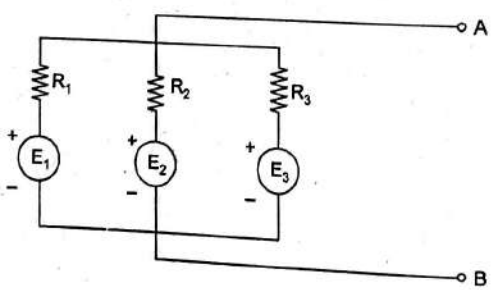
$$P_{max} = \frac{V_{TH}^2}{4R_{TH}}$$

$$P_{max} = \frac{(|2|^2)}{4 \times 2.2} = \frac{144}{8.8}$$

$$\boxed{P_{max} = 16.3 \text{ watt}} \quad \textbf{Ans.}$$

Q.3. (*a*) State and explain Millman's theorem. (6.5

Ans. This theorem enables a number of voltage or current sources to be combine into a single voltage and current sources.



$$V_{AB} = \frac{\frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{E_1G_1 + E_2G_2 = E_3G_3}{G_1 + G_2 + G_3}$$

$$= \frac{\Sigma EG}{\Sigma G}$$

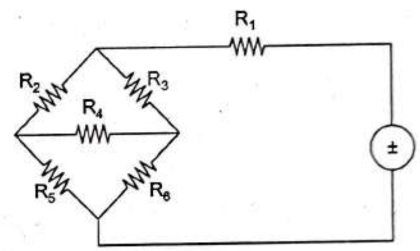
$$R_{AB} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{G_1 + G_2 = G_3} = \frac{1}{G}$$

$$\rightarrow \quad I_L = \frac{V_T}{R_T = R_L}$$

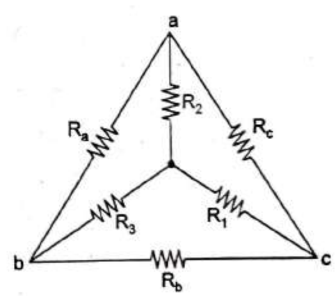
Q.3. (*b*) Drive expression for converting a star network to a delta equivalent networks. **(6)**

Ans. γ-Δ Transformation:

→ In circuit Analysis when the resistors are neither in parallel nor in series then we use γ – Δ transformation.



(1) Δ–γ Conversion: It is more convenient to work with γ - Network as compare to Δ- Network.



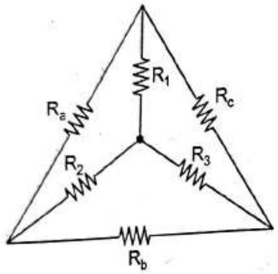
$$R_1 = \frac{R_bR_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_cR_a}{R_a + R_b + R_c}$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$

(2) γ – Δ Conversion:

$$R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$$



$$R_b = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$$

$$R_c = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

→ For Balanced system

→ $R_1 = R_2 = R_3 = R\gamma$

→ $R_a = R_b = R_c = R\Delta$

$$\boxed{R\gamma = \frac{R\Delta}{3}}$$

or

$$\boxed{R_\Delta = 3R\gamma}$$

UNIT II

Q.4. (a) Explain the term RMS value, Average value and form factor w.r.t. alternating quantity. Deduce the value of form factor of a sinusoidal voltage. (6.5)

Ans. Rms Value:

→ Rms value is defined based on heating effect of the wave form.

→ The voltage (A.C) at which heat dissipation in AC circuit is equal to heat dissipation in DC circuit is called V_{rms}.

→ $$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V^2 d\omega t}$$

→ $$V_{rms} = \sqrt{\frac{1}{T}\int_0^{T} V^2\, dt}$$

Average Value: Average value is defined based on charge transfer in a circuit.

→ The voltage (A.C) at which charge transfer in AC is equal to charge transfer in DC circuit, called the Average value.

$$\boxed{V_{ag} = \frac{1}{\pi}\int_0^{\pi} V d\omega t}$$

→ **Form factor:** Form factor is the ratio of Rms value of wave form to average value of wave form.

$$\boxed{\text{Form factor} = \frac{V_{rms}}{V_{av}} = \frac{I_{rms}}{I_{ag}}}$$

Average Value for sinusoidal current or voltage.

$$i = I_m \sin \omega t$$

→ Half cycle i.e. when wt varies from o to π.

$$I_{av} = \frac{\text{Area of first half cycle}}{\pi}$$

$$= \frac{1}{\pi}\int_o^{\pi} i d(\omega t) = \frac{1}{\pi}\int_o^{\pi p} I_{max} \sin \omega t\, d\omega t$$

$$I_{av} = \frac{I_{max}}{\pi}[-\cos \omega t]_0^{\pi} = \frac{2}{\pi} I_{max} = 0.63 I_{max}$$

$$\boxed{I_{av} = 0.637 I_{max}}$$

Rms of effective value for sinusoidal current:

$$i = I_{max} \sin wt$$

$$= \frac{\text{Area of I}^{st}\text{half cycle of } i^2}{\pi}$$

$$= \frac{i}{\pi}\int_0^{\pi} i^2 d\omega t = \frac{1}{\pi}\int_0^{\pi} I_{max}{}^2 \sin^2 \omega t\, d\omega t$$

$$= \frac{I_{max}{}^2}{2\pi}\int_0^{\pi}[1 - \cos 2\omega t]d\omega t$$

$$= \frac{I_{max}{}^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}$$

$$= \frac{I_{max}{}^2}{2\pi} \times \pi = \frac{I^2_{max}}{2}$$

$$I_{rms} = I_{max}/\sqrt{2}$$

$$\text{Form factor} = \frac{I_{rms}}{I_{avg}}$$

$$= \frac{I_m/\sqrt{2}}{2I_m/\pi}$$

$\boxed{\text{Form factor} = 1.11}$ **Ans.**

Q.4. (b) Explain the concept of bandwidth and quality factor for a series RLC circuit. Drive their expression. **(6)**

Ans. Bandwidth: The difference between the two half power frequency

i.e.
$$\boxed{B = \omega_2 - \omega_1}$$

where
$$\omega_2 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

$$\omega_1 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

$$\boxed{\omega_0 = \sqrt{\omega_1\omega_2}\ \text{rad/sec}}$$

→ 'B' is a half power Bandwidth, because it is the width of frequency band between the half frequencies.

Quality factor: The "sharpness" of the resonance in a resonant is measured quantitatively by the quality factor 'Q'.

→ At resonance the reactive energy in the circuit oscillate between the inductor and the capacitor

→ Quality factor

$$Q = 2\pi\left[\frac{\text{Peak energy stored in the circuit}}{\text{Energy dissipated by the circuit in one period at resonance}}\right]$$

$$\Rightarrow \quad Q = 2\pi\frac{\frac{1}{2}LI^2}{\frac{1}{2}I^2R\left(\frac{1}{f_o}\right)} = \frac{2\pi f_o L}{R}$$

$$\rightarrow \quad Q = \frac{\omega_o L}{R} = \frac{1}{\omega_o CR}$$

$$\rightarrow \quad \boxed{B = \frac{R}{L} = \frac{\omega_o}{Q}} \text{ Or } \boxed{B = \omega_0^2 CR}$$

→ The quality factor of a resonant circuit is the ratio of its resonant frequency to its bandwidth.

Q.5. (a) State the advantages of three phase system over single over single phase system. **(4.5)**

Ans. (1) Primary advantage of a 3-phase system over a poly phase or single phase is the inter connection is possible i.e. windings can be connected either in the form of star or delta.

(2) Nearly all electric power is generated and distributed in three phase system at frequency 50 Hz when are phase or two phase system is required they are taken it separately instead of generating it separetaly.

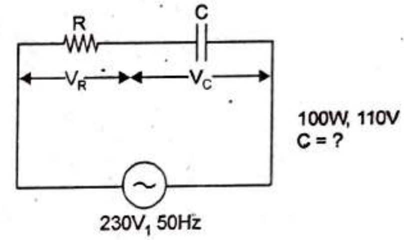
(3) When more than 3- phares are needed such as in aluminium company where 48 phases are required then we use the manipulating of 3-phase system.

(4) The instantaneous power in a 3-phase system can be constant (not pulsating). This results in uniform power transmission and less vibration, of 3-phase machine.

(5) For the same amount of power, the three phase system is more economical than the single phase. The amount of wire required for a-3- phase system is less than that required for an equivalent signle-phase system.

Q.5. (b) Find the capacitance which must be connected in series with a 100 W, 110 V lamp in order that the lamp may draw its normal current when the combination is connected to a 230 V 50 Hz supply. **(8)**

Ans.



$$\Rightarrow \quad P = V.i \Rightarrow i = \frac{P}{V} = \frac{100}{110} = 0.909$$

$$\Rightarrow \quad V = \sqrt{V_R^2 + V_C^2} \Rightarrow V_C^2 = V^2 - V_R^2$$

$$V_C^2 = (230)^2 - (110)^2 = (52900)^2 - (12100)^2$$

$$V_C^2 = 40800$$

$$\boxed{V_c = 20.19} \text{ Volt}$$

$$\Rightarrow \quad V_C = \text{I.2}\,X_c$$

$$\Rightarrow \quad X_C = \frac{V_c}{I} = \frac{20.19}{0.909} = 22.21$$

$$\rightarrow \quad Z = R + jx_c$$

$$\rightarrow \quad X_C = \frac{1}{2\pi fc} = 22.21 = \frac{1}{2\times 3.14\times 50\times C}$$

$$C = \frac{1}{6977.477}$$

$$\boxed{C = 1.4331\times 10^{-4}\ \text{Farad.}}$$

UNIT III

Q.6. (a) Describe deflecting torque, controlling torque and damping torque in case of indicating type instruments giving the significance of each one of them. (6.5)

Ans. Deflecting Torque: It is produced by the parameter under measurement it self when it undergoes one of the effect of electric current. The utility of this torque is to deflect the pointer away from 'o' position and the deflecting torque is proportional to the parameter under measurement.

Controlling Torque: The controlling torque has the 2 field utility.

(1) It contains the deflection by making the pointer, come to rest at steady-state position.

(2) It brings the pointer back to zero position when the parameter of measurement is removed from the terminal of instrument

Damping Torque:

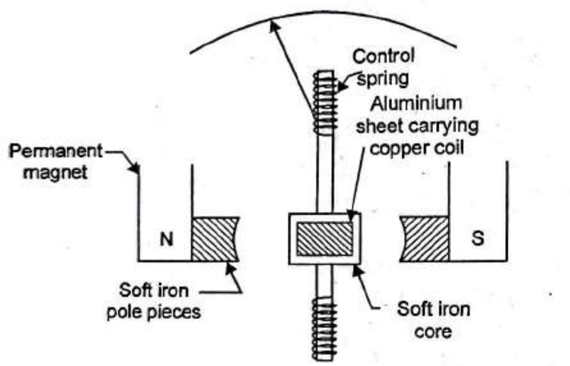
→ is produced in the parameter under measurement when it is connected for it.

→ When it is connected with supply then pointer is move from zero position. In the presence of damping torque it provide stability in the pointer.

→ Damping torque produce friction in the pointer because of that vibration has been reduced and pointer show an accurate or exact reading.

Q.6. (b) Explain the construction and working of permanent magnet moving coil (PMMC) instruments. (6)

Ans. Permanent Magnent Moving Coil Type:



Principle and operation: The permanent magnet moving coil instrument based its operation on magnetic field of electric current.

Construction:

→ The fixed system of this instrument consists of a permanent magnet with iron pole pieces drilled on to its poles.

→ The utility of these poles pieces is to focus the entire magnetic field in the air gap between the magnet.

→ The moving system consists of a spindle to which a pointer, a control spring, a soft iron core and an aluminium sheet carrying the coil, which carries the current to be measured in wound.

Working: When the current to be measure is pass through moving coil, it would experience a force which tends to push the coil away from the field of permanent magnet.

→ This force is angular in nature, and makes pointer away from zero position

→ The deflecting torque T_d acting on the pointer is given by

$$\boxed{T_d = NBAI \text{ Nm}}$$

$$\text{or } \boxed{T_d \, \alpha \, I}$$

N = No. of turns of coil
B = Flux density of permanent magnet
A = Area of coil in m_2

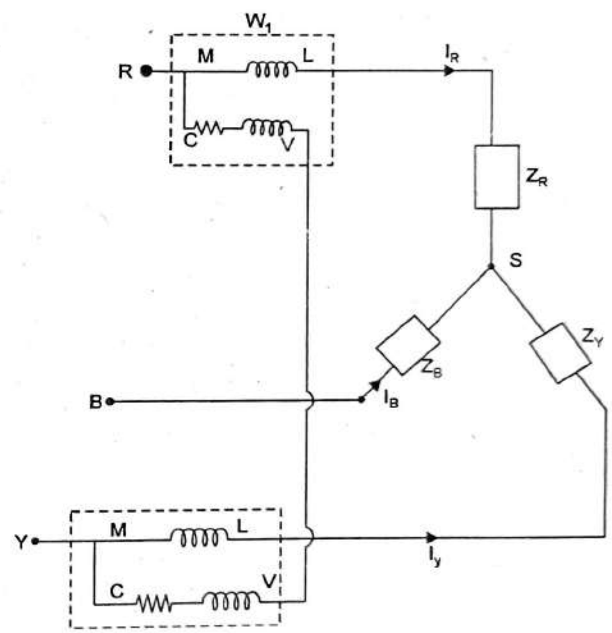
Advantages: Low power consumption (25-200 μw)

High torque to weight ratio due to strong magnetic field.

→ It is not easily effected by stray magnetic field due to strong magnetic field produced in it.

Q.7. (a) Explain 2 wattmeter method of measuring power in a three phase AC circuit with the help of suitable circuit diagram. (6.5)

Ans. Two wattmeter method

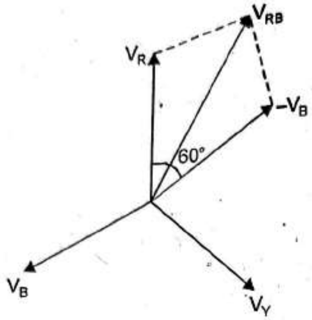


For wattmeter:

→ Current-Measured by current coil of wattmeter –1 = I_R

→ Voltage measured by potential coil of w_1.

$$w_1 = V_{RB} = V_R - V_B$$



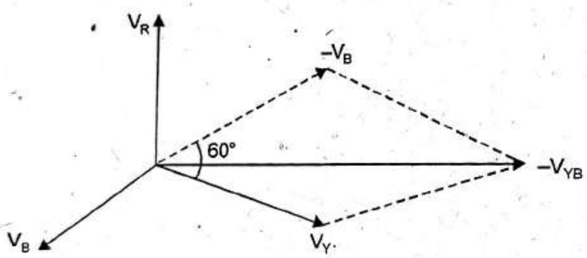
$\rightarrow$ $$W_1 = I_L V_L \cos(30 - \phi) \quad ...(1)$$

For wattmeter -2:

(1) Current measure by current coil of $W_2 = I_Y$.

(2) Voltage measured by potential coil $W_2 = V_{YB}$

$$W_2 = V_{YB} = V_Y - V_B$$



$\rightarrow$ $$\boxed{W_2 = V_L I_L \cos(30 + \phi)}$$

$\rightarrow$ Total power $= w_1 + w_2$ (Active power)

$$P = V_L I_L [\cos(30 - \phi) + \cos(30 + \phi)]$$

$$\boxed{w_T = \sqrt{3} V_L I_L \cos\phi}$$

or.

$$W_1 - W_2 = V_L I_L [\cos/30 - \phi] - \cos/30 + \phi)]$$

$\Rightarrow$ $$\boxed{W_1 - W_2 = V_L I_L \sin\phi} \text{ (Reactive power)}$$

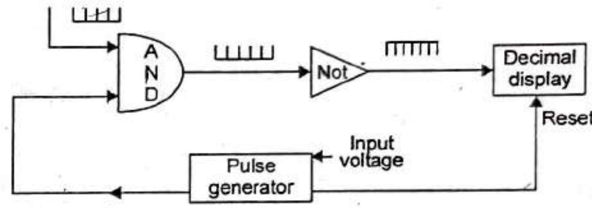
$$Q = \sqrt{3}(W_1 - W_2)$$

$\Rightarrow$ $$\frac{Q}{w_T} = \frac{\sqrt{3} V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi} = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

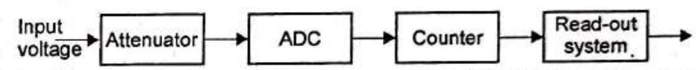
$$\boxed{\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}} \text{ Ans.}$$

Q.7. (*b*) Discuss digital voltmeter and its applications. **(6)**

Ans. DVM displays measurement of ac or dc voltages as discrete numerals instead of a pointer deflection on a continuous scale. The unknwn voltage signal is feel to the pulse generator which generates a pulse whose width is directly proportional to the input unknown voltage. The output of the pulse generator is applied to one leg of an AND gate. The input signal to the other leg of AND gate is train of pulses. Output of AND gate is, thus a positive trigger train of duration t seconds & the inverter converts it in to a negative trigger train. The counter, counts the no. of tiggers in t seconds while is propotional to the voltage under measurement. Thus counter can be calibrated to indicate the voltage in volts directly.



(Block diagram of DVM)



Digital volt meter can be made by using any one of A/D conversion method.

DVM application:

$\rightarrow$ It is used in industries for remp input application

$\rightarrow$ DVM used with electronic circuit where the power consumption is low.

$\rightarrow$ DVM is used where the accuracy and precision is required at highest level.

UNIT IV

Q.8. (*a*) What are the factors that affect the speed of DC motor? Also explain how the speed can be controlled above and below the normal spped. **(6.5)**

Ans. Speed of a DC Motor

$\rightarrow$ $$E_b = V - I_a R_a$$

$\rightarrow$ $$E_b = \frac{\phi ZNP}{60A}$$

$\rightarrow$ $$\frac{\phi ZNP}{60A} = V - I_a R_a$$

$\rightarrow$ $$N = \frac{V - I_a R_a}{\phi}\left[\frac{60A}{ZP}\right]$$

$\rightarrow$ $$N = K\left[\frac{V - I_a R_a}{\phi}\right]$$

$\rightarrow$ $$K = \frac{60A}{ZP}$$

$$\boxed{N = \frac{KE_b}{\phi}} \quad or \quad \boxed{N \alpha \frac{1}{\phi}}$$

→

→ For DC Motor speed can be vary as following equations.

→ $N \alpha \frac{1}{\phi}$, if we increase the flux of the motor than speed of motor is reduced.

→ $N \alpha \frac{1}{I}$, if the value of current is increases, then value of spped will reduce.

→ Speed of the motor can be controlled by two methods.

(1) Field control method

(2) Armature control method.

→ These two methods are can control the speed of motor above and below th normal spped.

→ Armature control method gives speed control below the base speed.

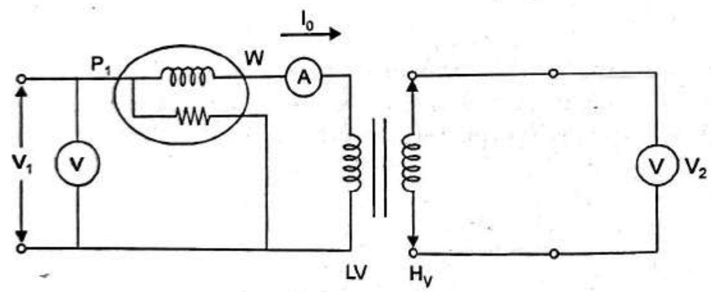
→ Field control method gives, speed control above the base speed.

→ Base speed or normal speed is the of speed the motor when there is no extern resistance in the field circuit as well as a armature circuit.

Q.8. (b) Explain the open circuit and short circuit test as performed f single phase transformer and why it is performed.

Ans. Open circuit and short circuit tests are performed to determine the circu constants, efficiency and regulation without actually loading the transforme.

Open Circuit Test:



Armature reading = no-load current I_o

Voltmeter reading = Primary rated voltage V_1

Wattmeter reading = iron or core loss p_i

→ $$P_i = V_I I_o \cos\phi_o$$

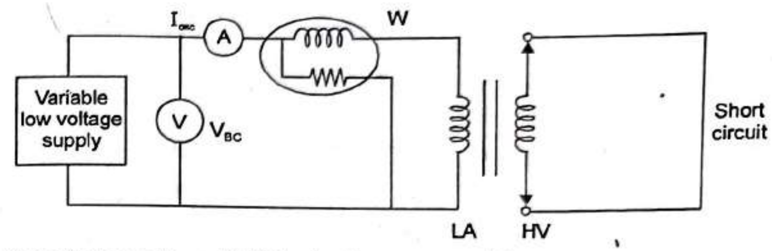
→ No- load power factor

$$\text{Cos}\,\phi_o = \frac{P_i}{V_1 I_o}$$

→ $$I_W = I_o \cos\phi_o, I\mu = I_o \sin\phi_o$$

→ $$Ro = \frac{V_1}{Iw}, X_o = \frac{V_1}{I\mu}$$

Short Circuit Test:



→ Armature reading = Full-load primary current I,sc

→ Voltmeter reading = Short circuit voltage V_{isc}

→ Wattmeter reading = Full load copper loss of the conductance

→ Equivalent resistance of the X'mer referred to primary

$$R_{e1} = \frac{P_{efl}}{I^2\,\text{sec}}$$

→ Equivalent impedance referred to primary

$$Z_{e1} = \frac{V_{isc}}{I_{isc}}$$

→ Equivalent reactance referred to primary

$$e_1 = \sqrt{Z_{e1}^2 - P_{e1}^2}$$

→ $$\cos\phi = \frac{R_{e1}}{z_{e1}}$$

Q.9. (a) Drive the emf equation of a transformer. **(6.5)**

Ans. The main flux ϕ established in the core is alternating in nature.

→ An emf is induced in the primary winding of the X'$_{mer}$ which is given by

$$e_1 = -\frac{N_1 d\phi}{dt} \qquad \text{...(1)}$$

N_1 = Number of turns in the primary

→ The main flux 'ϕ' can be expressed as

$$\phi = \phi_m \cos wt \qquad \text{...(2)}$$

where ϕ_m = Maximum value of the main flux

$$e_1 = -N_1 \frac{d}{dt}[\phi_m \cos wt]$$

$$\boxed{e_1 = -N_1 w \phi_m \sin wt} \qquad \text{...(3)}$$

The induced emf e_1 is maximum, when

$$\sin wt = 1$$

$$\boxed{E_{1max} = N_1 w \phi_m} \qquad \text{...(4)}$$

→ RMS value of induced emf in the primary is given by

$$E_{1rms} = \frac{E_{1max}}{\sqrt{2}} = \frac{N_1 w \phi_m}{\sqrt{2}}$$

$$E_{1rms} = \frac{N_1 2\pi f \phi m}{\sqrt{2}}$$

$$\boxed{E_{1rms} = 4.44 f \phi_m N_1}$$

→ emf induced in the secondary of X'mer is

$$\boxed{E_{2rms} = 4.44 f \phi_m N_2}$$

→ Generalised emf eqⁿ for Xmer is

$$\boxed{E_{rms} = 4.44 f \phi_m N}$$

Q.9. (b) Explain hysteresis and eddy current losses. How they are minimi[zed] in three phase induction motor.

Ans. Separation of Hysteresis and eddy current losses:

Hysternesis loss: The core of a Induction motor is subjected to an alternati[ng] magntizing force and for each cycle of emf a hysteresis loop is traced out.

Hysteresis loss, $P_h = \eta (B_{max})^2 f_v$ Joules

Eddycurrent loss: If the magnetic circuit is made up of iron and if the flux in t[he] circuit is variable current will be induced by induction in the iron circuit itself.

Eddy current loss is given by

$$\boxed{P = Ke(B_{max})^2 f^2 t^2 V \text{ watts}}$$

- Hysteresis and eddy current losses depend upon the maximum flux density in t[he] core and supply frequency.

FIRST TERM EXAMINATION [SEPT. 2016]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

Time : 1½ hrs. **M.M. : 30**

Note: *Q.No. 1 is compulsory. Attempt any two more Questions from rest.*

Q.1. (a) What are limitations of Ohm's law? **(5x2)**

Ans. The limitation of Ohm's law are as follow:

1. This law can not be applied to unilateral networks, like diode transistors etc, which do not have same voltage-current relation for both directions of current.

2. It is not applicable for Non-linear elements or systems.

Q.1. (b) If the length of a wire of resistance R is uniformly stretched to 'n' times its original value, what will be its new resistance?

Ans. Wire resistance = R

length = l

stretched length = n.l

$$R = \frac{\rho l}{A} \Rightarrow R \propto l$$

$$= \boxed{R \propto n.l}$$

New resistance $\Rightarrow$ R = n.l Ohms

Q.1. (c) What is rms value of an alternating current?

Ans. Rms value is defined as the heating of the quantity or parameter in AC as well DC system.

- Rms value for Alternating current is

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

Where I_m is the maximum value of current.

Q.1. (d) What is the significance of peak factor?

Ans. Peak factor is defined as the ratio of maximum value to the Rms value of Alternating quantity.

- The alternating quantities can be voltage or current.
- Maximum value is the peak value of the voltage or current and the root mean square value is the amount of heat produced by the alternating current.

$$\text{Peak factor} = \frac{I_m}{I_{rms}} \text{ or } \frac{E_m}{E_{rms}}$$

Q.1. (e) What do you mean by phase and phase difference?

Ans. Phase: It is a definition of the position of a point in time (instant) on a wave form cycle.

Phase difference: It is the difference in phase angle between two sinusoids or phasors.

Example: In 3-Phase system, Phase difference is 120°

Q.2. (a) State and derive Maximum power transfer theorem? **(4)**

Ans. Maximum Power Transfer Theorem

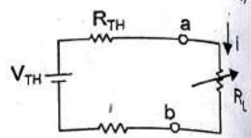
Maximum Power is transferred to the load when the load resistance is equal to the thevenin's resistance *i.e.*

$$\boxed{R_L = R_{TH}}$$

→ Thevenin's equivalent is useful in finding the maximum power a linear circuit can deliver to a load.

→ If Entire circuit is replaced by its thevenin's equivalent except for the load then,

$$P = i^2.R_L\left(\frac{V_{TH}}{R_{TH}+R_L}\right)^2.R_L \quad \text{...(1)}$$



$$\Rightarrow \quad P = \left(\frac{V_{TH}}{R_{TH}+R_L}\right)^2.R_L$$

$$\frac{dP}{dR_L} = V_{TH}^2\left[\frac{(R_{TH}+R_L)^2-2R_L(R_{TH}+R_L)}{(R_{TH}+R_L)^4}\right]$$

$$V_{TH}^2\frac{[R_{TH}+R_L-2R_L]}{(R_{TH}+R_L)^3} = 0$$

$$\Rightarrow \quad \boxed{R_{TH}=R_L} \text{ Proved.}$$

Q.2. (b) Find the value of R in the ckt of fig (1) such that maximum power transfer takes place. And how much maximum power delivered to load, also indicate in graph? (6)

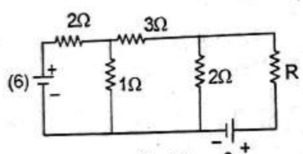
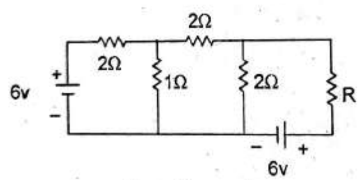


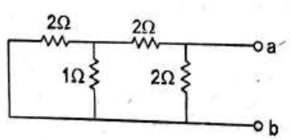
Fig. (1)

Ans.



$$R = ?$$

⇒ For 'R'

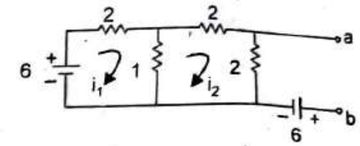


$$R_{ab} = R_{TH} = (2\Omega \,||\, 1\Omega)+2\Omega+2\Omega$$

$$= \frac{2}{3}+4 = \frac{14}{3}\Omega$$

For maximum Power, $\boxed{R_L = R_{TH} = \frac{14}{3}\Omega}$

Maximum Power $\quad P_{max} = \dfrac{V_{TH}^2}{4R_{TH}}$



For V_{TH}

$$= 2i_1 + (i_1 - i_2) = 6$$

$$= 3i_1 - i_2 = 6 \quad \text{...(1)}$$

$$= 2i_2 + 2i_2 + i_2 - i_1 = 0$$

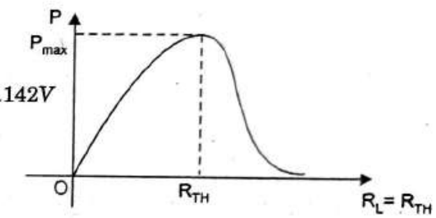
$$5i_2 = i_1 \quad \text{...(2)}$$

Put value of i_1 in equation (1), we get $3.5\, i_2 - i_2 = 6$

$$14\, i_2 = 6 \Rightarrow i_2 = \frac{6}{14} Amp$$

Vab = $\quad V_{ab} = V_{TH} = 2.i_2 - 6$

$$= \frac{2.6}{14} - 6 = \frac{12}{14} - 6 = -5.142V$$



$$P_{max} = \frac{V_{TH}^2}{4.R_{TH}}$$

$$= \frac{(-5.142)^2}{4\times 4.666} = \frac{26.440}{18.664}$$

$$\boxed{P_{max} = 1.416\, Watt} \text{ Ans.}$$

Q.3. (a) State thevenin theorem. Find thevenin equivalent voltage and thevenin equivalent resistance shown in fig. (2) and draw Norton equivalent circuit? (6)

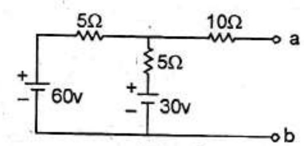
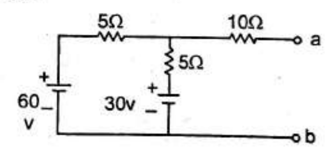


Fig. 2.

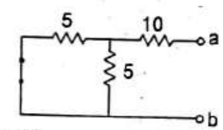
Ans. A linear two-terminal circuit can be replaced by an equivalent circuit consisting of voltage source V_{TH} is series with resistor R_{TH}.

Where R_{TH} = Equivalent Resistance

V_{TH} = Equivalent Voltage.



$$R_{ab} = R_{TH} \quad \Rightarrow$$



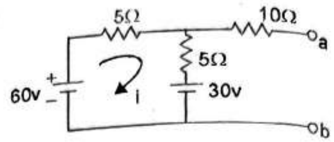
$$R_{ab} = R_{TH} = (5\,||\,5) + 10$$

$$= 12.5\ \Omega$$

For V_{TH}

$= 5i + 5i + 30 = 60$

$10i = 30$



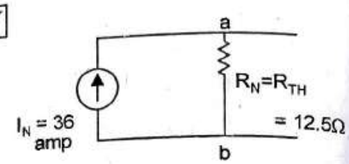
$$\boxed{i = 3\,amp}$$

$V_{ab} = V_{TH} = 10 \times 0 + 5.i + 30$

$= 0 + 5 \times 3 + 30$

$$\boxed{V_{ab} = V_{TH} = 45V}$$

For Norton's Equivalent



⇒
$$I_N = \frac{V_{TH}}{R_{TH}}$$

$$I_N = \frac{45}{12.5} = 36\,amp \text{ Ans.}$$

Q.3. (b) A supply voltage of 230V, 50 Hz is fed to a residential building. Write down its equation for instantaneous value? (4)

Ans. $V_m = 230V$, F = 50Hz instantaneous equation-?

Instantaneous equation of Alternating voltage

$$V = V_m(\sin wt + \phi)$$

Phase difference $\phi = 0$

Now $w = 2\pi f$

$= 2\pi \times 50 = 100\pi$

$$\boxed{w = 314}$$

Equation is given by

$$\boxed{V = 230 \sin 314t} \text{ Ans.}$$

Q.4. (a) The equation of an alternating current is i=42.42 Sin 628t. Determine (*i*) its maximum value (*ii*) frequency (*iii*) rms value (*iv*) average value (*v*) Form factor (*vi*) Peak factor. (6)

Ans. $i = 42.42 \sin 628t$

(*i*) Compare the equation with

$$i = I_m \sin wt$$

$$\boxed{I_m = 42.42} \text{ amp}$$

(ii). $wt = 628t$

$$w = 2\pi f = 628$$

$$f = \frac{628}{2\pi} = \frac{314}{\pi}$$

$$\boxed{f = 100\,Hz}$$

(iii). Rms value

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I^2\, dwt} = I_m/\sqrt{2}$$

$$I_{rms} = \frac{42.42}{\sqrt{2}} = 29.99\,Amp$$

(iv). Average value

$$I_{avg} = \frac{2I_m}{\pi} = 0.637 \times 42.42$$

$$= 27.02 \text{ Amp}$$

(v) Form factor

$$\text{Form factor} = \frac{I_{rms}}{I_{avg}} = \frac{29.99}{27.02}$$

$$= 1.11$$

(*vi*). Peak factor

$$= \frac{I_m}{I_{rms}} = \frac{42.42}{29.99} = 1.414 \text{ Ans.}$$

Q.4. (*b*) Find the current I in the network shown in fig (3) using star-delta transformation. (4)

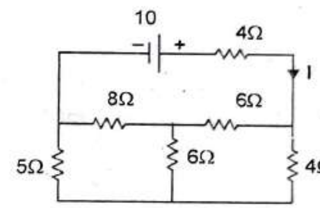
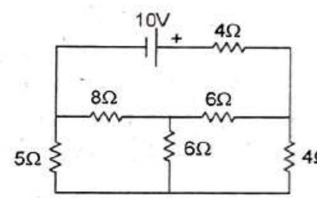


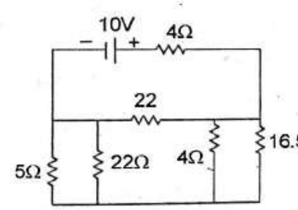
Fig. 3.

Ans.

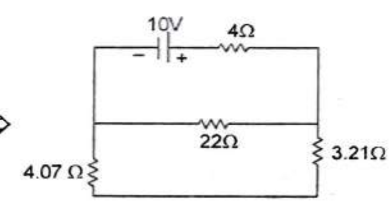


Converting star in to delta

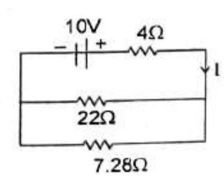
$$\Rightarrow R_{12} = \frac{8+6+\frac{8\times6}{6}}{} = 22\Omega;\quad R_{23} = 6+6+\frac{6\times6}{8} = 16.5\Omega;\quad R_{31} = 8+6+\frac{8\times6}{6} = 22\Omega$$



⇒



⇒



$$\Rightarrow I = \frac{10}{4+4.69} = 1.150\,Amp \text{ Ans.}$$

END TERM EXAMINATION [SEPT. 2016]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

Time : 3 hrs. **M.M. : 75**

Note: *Attempt any five questions including Q.no.1 which is compulsory. Select one question from each Unit. Assume missing data if any.*

Q.1. (a) Find the equivalent resistance across AB in the Fig. 1, all the resistances are equal and 5 ohm. **(5)**

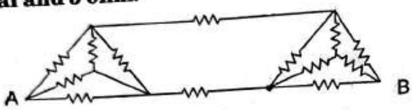
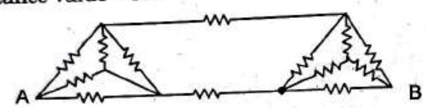


Fig. 1.

Ans. Each resistance value = 5Ω



Converting from star to delta

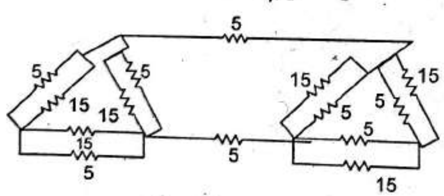
$$\Rightarrow \qquad R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

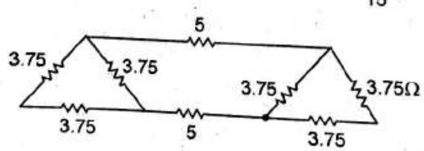
$$\Rightarrow \qquad = \frac{5\times5+5\times5+5\times5}{5} = \frac{75}{5} = 15\Omega$$

$$R_b = 15\Omega, R_c = 15\Omega$$

Now

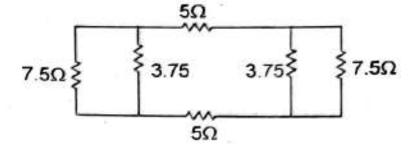
$$15 \,||\, 15 \Rightarrow \frac{15\times\cancel{5}}{2\cancel{0}4} = \frac{15}{4} = 3.75\Omega$$





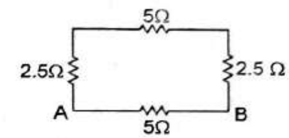
$\Rightarrow 3.75 + 3.75 = 7.50\ \Omega$

$\Rightarrow$



$$\Rightarrow \qquad 7.5\,||\,3.75 \Rightarrow \frac{7.5\times3.75}{7.5+3.75} = \frac{28.125}{11.25} = 2.5\Omega$$

Now



$$\Rightarrow \qquad R_{AB} = 2.5 + 2.5 + 5 + 5 = 15\Omega \textbf{ Ans.}$$

Q.1. (b) Explain the physical significance of power factor in AC system. (5)

Ans. Physical significance of power factor

⇒ Power factor is defined as the ratio of real power to Apparent power

i.e
$$\cos\phi = \frac{\text{Real Power}}{\text{Apparent Power.}}$$

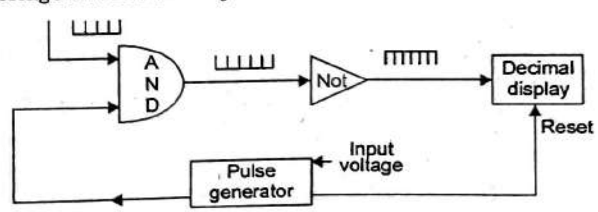
⇒ Power factor is the factor, which should be multiply by the apparent power to achive Real Power.

⇒ If the value of Power factor is high *i.e.* around unity that means $\boxed{\text{Real Power = Apparent Power}}$ at this time losses will be minimum or zero in ideal condition.

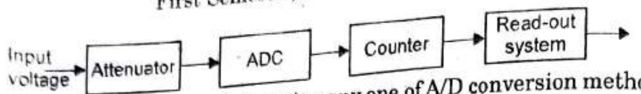
⇒ Power factor can be lagging or leading, according to the load i.e. inductive or capacitive.

Q.1. (c) Explain working of digital voltmeter.

Ans. DVM displays measurement of ac or dc voltages as discrete numerals instead of a pointer deflection on a continuous scale. The unknown voltage signal is feel to the pulse generator which generates a pulse whose width is directly proportional to the input unknown voltage. The output of the pulse generator is applied to one leg of an AND gate. The input signal to the other leg of AND gate is train of pulses. Output of AND gate is, thus a positive trigger train of duration *t* seconds & the inverter converts it in to a negative trigger train. The counter, counts the no. of tiggers in t seconds while is propotional to the voltage under measurement. Thus counter can be calibrated to indicate the voltage in volts directly.



(Block diagram of DVM)



Digital volt meter can be made by using any one of A/D conversion method.

DVM application:

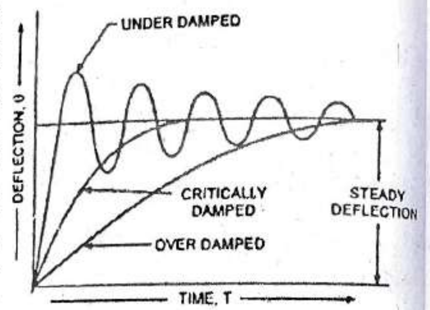
→ It is used in industries for remp input application

→ DVM used with electronic circuit where the power consumption is low.

→ DVM is used where the accuracy and precision is required at highest level.

Q.1. (d) Describe controlling torque in indicating type instruments. (5)

Ans. Controlling Torque: The magnitude of the movement of the moving system would be somewhat indefinite under the influence of deflecting torque and increases with the increase in deflection of the moving system, thus limits the movement and ensures that the magnitude of the deflection is always the same for a given value of quantity to be measured. Under the influence of the controlling torque the pointer (or moving system) will return to its zero position on removing the source producing the deflecting torque. Without controlling system, the pointer would swing over its maximum deflected position irrespective of magnitude of current and moreover, once deflected it would not return to its zero position on removing the current. The controlling torque in indicating instruments is created either by a spring or by a gravity.



Q.1. (e) Explain the effect of variation in load on the magnitude of flux in the core of single phase transformer. (5)

Ans. Effect of load variation of Flux

→ When Electrical load is connected to secondary winding of a transformer and the transformer loading is greater than zero.

→ The secondary current I_s, which is determined by the characterstics of the load, creates a self-induced secondary magnetic field ϕ_2 in the transformer core which flows in the exact opposite direction to the main primary field.

→ These two magnetic field oppose each other resulting in a combined magnetic field of less magnetic strength than the single field produced by primary winding.

→ This combined magnetic field reduced the back EMF of the primary winding causing the primary current.

→ The primary current countinues to increase untill the cores magnetic field is back at its original strength.

UNIT-I

Q.2. Find the current through, 2 ohm resistor using nodal analysis and Thevenin's theorem for the circuit shown in fig 2. (12.5)

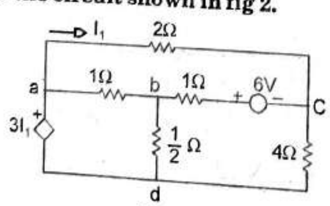
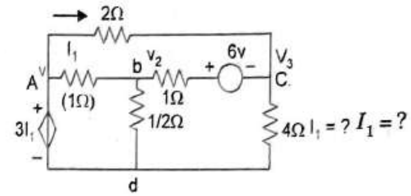


Fig. 2

Ans.



Nodal Analysis

$$V_1 = 3I_1$$

$$\Rightarrow \quad \frac{V_2-V_1}{1}+\frac{V_2-6-V_3}{1}+\frac{2V_2}{1} = 0$$

$$4V_2-V_1-V_3 = 6 \qquad ...(1)$$

Now,

$$\frac{V_1-V_3}{2} = I_1$$

$$\Rightarrow \quad 2I_1 = V_1-V_3$$

$$V_1 = \frac{3(V_1-V_3)}{2}$$

$$\Rightarrow \quad \boxed{3V_3 = V_1} \qquad ...(2)$$

$$\Rightarrow \quad \frac{V_3}{4}+\frac{V_3+6-V_2}{1}+\frac{V_3-V_1}{2} = 0$$

$$V_3+4V_3+24-4V_2+2V_3-2V_1 = 0$$

$$7V_3-6V_2 = 24 \qquad ...(3)$$

After solving

$$V_1 = 99 \text{ volt}, V_3 = 33 \text{ volt}$$

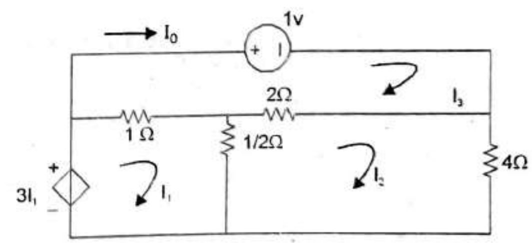
$$I_1 = \frac{V_1-V_3}{2} = \frac{99-33}{2} = \frac{66}{2}$$

$$\boxed{I_1 = 33\ Amp} \textbf{ Ans.}$$

Thevenin's Equivalent–

For R_{TH}

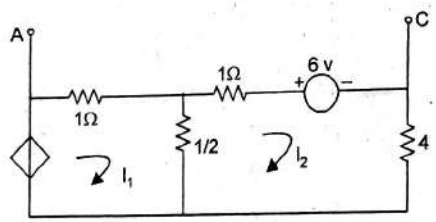
$$R_{TH} = \frac{1}{I_0}$$



$$3I_1+(I_1-I_3)+\frac{1}{2}(I_1-I_2) = 0$$

$$\Rightarrow \quad 4I_1 - I_3 + \frac{1}{2}I_1 - \frac{1}{2}I_2 = 0$$
$$\Rightarrow \quad 3.5\,I_1 - 0.5\,I_2 - I_3 = 0 \qquad \ldots(1)$$
$$2(I_2 - I_3) + 4I_2 + 1/2\,(I_2 - I_1) = 0$$
$$2I_2 - 2I_3 + 4I_2 + 0.5\,I_2 - 0.5\,I_1 = 0$$
$$\Rightarrow \quad -0.5I_1 + 6.5\,I_2 - 2I_3 = 0$$
$$0.5I_1 - 6.5I_2 + 2I_3 = 0 \qquad \ldots(2)$$
$$(I_3 - I_1) + 1 + 2\,(I_3 - I_2) = 0$$
$$I_3 - I_1 + 1 + 2I_3 - 2I_2 = 0$$
$$\Rightarrow \quad -I_1 - 2I_2 + 3I_3 = -1$$
$$\Rightarrow \quad I_1 + 2I_2 - 3I_3 = 1 \qquad \ldots(3)$$
$$I_1 = 0.166 \text{ Amp}$$
$$I_2 = 0.166 \text{ Amp}$$
$$\boxed{I_3 = -0.5} \text{ Amp}$$
$$R_{TH} = \frac{1}{0.5} = 2\Omega$$
$$\boxed{R_{TH} = 2\Omega}$$

for $V_{TH} = V_{ac}$



$$\Rightarrow \quad I_1 + 1/2\,(I_1 - I_2) = 0$$
$$0.5I_1 - 0.5\,I_2 = 0 \qquad \ldots(1)$$
$$I_2 + 6 + 4I_2 + 1/2\,(I_2 - I_1) = 0 \quad I_1 = 1 \text{ amp.}$$
$$I_2 + 6 + 4I_2 + 1/2\,I_2 - 0.5\,I_1 = 0 \quad I_2 = -1 \text{ amp}$$
$$-0.5I_1 + 5.5\,I_2 = -6 \qquad \ldots(2)$$
$$V_{ac} = V_{TH}$$
$$\Rightarrow \quad 1 \times I_1 + 1I_2 + 6$$
$$= \cancel{1} - \cancel{1} + 6$$
$$= 6\text{V}$$
$$\boxed{V_{TH} = 6V} \textbf{ Ans.}$$

Q.3. (*a*) Verify the reciprocity theorem in the circuit shown in fig. 3, w.r.t. the voltage source and the current I. (6.5)

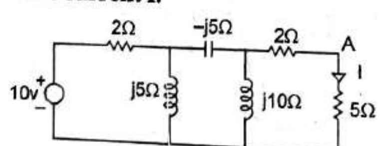
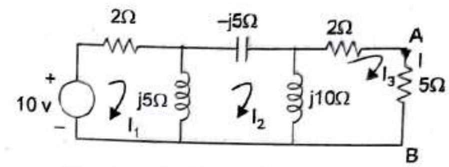


Fig. 3.

Ans.



$$\Rightarrow \quad 2I_1 + (I_1 - I_2)\,j5 = 10$$
$$2I_1 + j5\,I_1 - j5I_2 = 10$$
$$I_1\,(2 + j5) - j5\,I_2 = 10 \qquad \ldots(1)$$
$$\Rightarrow \quad -j5I_2 + j10\,(I_2 - I_3) + j5\,(I_2 - I_1) = 0$$
$$\Rightarrow \quad -j5I_2 + j10\,I_2 - j10I_3 + j5I_2 - j5I_1 = 0$$
$$\Rightarrow \quad -j5\,I_1 + j10\,I_2 - j10\,I_3 = 0$$
$$j5\,I_1 - j10\,I_2 + j10\,I_3 = 0 \qquad \ldots(2)$$
$$\Rightarrow \quad 2I_3 + 5I_3 + j10\,(I_3 - I_2) = 0$$
$$\Rightarrow \quad 5I_3 + j10\,I_3 - j10I_2 = 0$$
$$I_2 = \frac{(5 + j10)I_3}{j10} \qquad \ldots(3)$$

From eq^n 1 ... (1)

$$I_1 = \frac{10 + j5\,I_2}{(2 + j5)}$$

Now put value of I_1 and I_2 in eq^n (2)

$$\Rightarrow j5\left(\frac{10 + j5I_2}{(2 + j5)}\right) - j1\cancel{0}\left[\frac{(5 + j10)I_3}{j10}\right] + j10I_3 = 0$$

$$\Rightarrow \quad \frac{j5}{(2 + j5)}\left[10 + \frac{j5.(5 + j10)I_3}{j10}\right] - I_3(5 + j10) + j10I_3 = 0$$

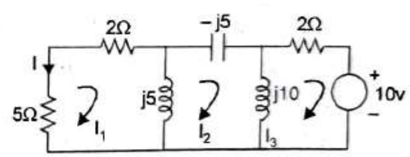
$$\Rightarrow \quad \frac{j50}{(2 + j5)} + (0.431 + j5.172)I_3 - 5I_3 - j10\,I_3 + j10\,I_3 = 0$$

$$\Rightarrow \quad (-4.56 + j5.\,5.172)\,I_3 = -(8.620 + j\,3.44)$$

$$I_3 = \frac{(8.620 + j3.44)}{(-4.56 + j5.172)}$$

$$\boxed{I = I_3 = 0.453 + j1.266 = 1.344\angle 70.29}$$

Now,



$$\Rightarrow \quad 5I_1 + 2I_1 + j5\,(I_1 - I_2) = 0$$
$$\Rightarrow \quad 7I_1 + j5I_1 - j5\,I_2 = 0$$
$$\Rightarrow \quad I_1\,(7 + j5) - j5\,I_2 = 0 \qquad \ldots(1)$$
$$\Rightarrow \quad -j5\,I_2 + j10\,(I_2 - I_3) + j5\,(I_2 - I_1) = 0$$

$\Rightarrow -j\cancel{5}I_2 + j10I_2 - j10I_3 + j\cancel{5}I_2 - j5I_1 = 0$

$\Rightarrow \quad -j5I_1 + j10I_2 - j10I_3 = 0$

$j5I_1 - j10I_2 + j10I_3 = 0$ ...(2)

$2I_3 + 10 + j10(I_3 - I_2) = 0$

$(2I_3 + j10I_3) - j10I_2 = -10$

$\Rightarrow \quad I_3(2 + j10) - j10I_2 = -10$ ...(3)

Now, I_1, I_2, I_3 is given as

$$\Rightarrow \quad I_3 = \frac{-10 + j10I_2}{(2 + j10)} \quad ...(4)$$

$j5I_1 = j10I_2 - j10I_3$ ...(5)

$I_1(7 + j5) = j5I_2$ ...(6)

from ... (5)

$j10I_2 - j10I_3 = j5I_1$

$j10I_2 = j5I_1 + j10I_3$

$$I_2 = \frac{j5I_1 + j10I_3}{j10} \quad ...(7)$$

Now put value of I_3 in (7)

$$I_2 = \frac{j5I_1}{j10} + \frac{(-10 + j10I_2)}{(2 + j10)}$$

$= 0.5I_1 - 0.192 + 0.96j + (0.96 + j0.192)I_2$

$I_2 - (0.96 + j0.192)I_2 = 0.5I_1 - (0.192 - j0.96)$

$I_2(0.038 - j0.192) = 0.5I_1 - (0.192 - j0.96)$

$$I_2 = \frac{0.5I_1}{(0.038 - j0.192)} - \frac{(0.192 - j0.96)}{(0.038 - j0.192)}$$

$I_2 = (0.495 + j2.50)I_1 - (14.19 - j18.09)$

Now put this value in Eq^n– (6)

$$I_1 = \frac{j5I_2}{(7 + j5)}$$

$= (0.337 + j0.472)I_2$

$I_1 = (0.337 + j0.472)[(0.495 + j2.50)I_1 - [14.19 - j18.09)]$

$I_1 = (-1.01 + j1.07)I_1 - (13.32 + j0.601)$

$\boxed{I_1 = 1.334\angle 70.29}$ Amp.

Q.3. (*b*) Using superposition theorem determines the current through the branch AB, for the circuit shown in fig. 4. (6)

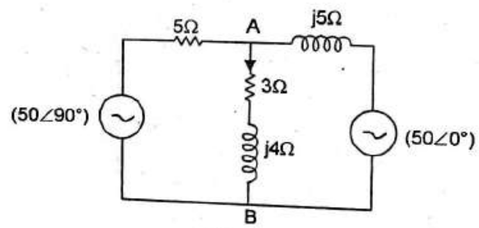
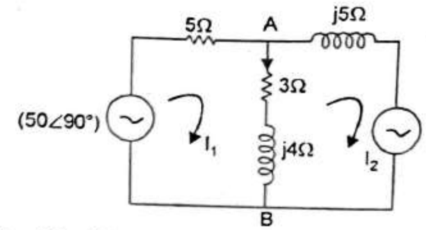


Fig. 4.

Ans. For source 50 ∠ 90°



$\Rightarrow \quad 5I_1 + (3 + j4)(I_1 - I_2) = 50\angle 90°$

$\Rightarrow \quad 5I_1 + 3I_1 + j4I_1 - 3I_2 - j4I_2 = 50\angle 90°$

$\Rightarrow \quad 8I_1 + j4I_1 - I_2 - (3 + j4) = 50\angle 90°$

$\Rightarrow \quad (8 + j4)I_1 - I_2(3 + j4) = 50\angle 90°$ ...(1)

$\Rightarrow \quad J5I_2 + (3 + J4)(I_2 - I_1) = 0$

$\Rightarrow \quad -J5I_2 + 3I_2 + J4I_2 - 3I_1 - J4I_1 = 0$

$\Rightarrow \quad -(3 + j4)I_1 + I_2(3 - j) = 0$ ...(2)

$\Rightarrow \quad 8.94\angle 26.56° I_1 - 5\angle 53.13 I_2 = 50\angle 90°$ ...(3)

$-5\angle 53.13 I_1 + 3.16\angle -18.43° I_2 = 0$ ...(4)

$5\angle 53.13 I_1 = +3.16\angle -18.43° I_2$

$$I_1 = \frac{3.16\angle -18.43°}{5\angle 53.13} I_2 = 0.632 I_2$$

$I_1 = \boxed{I_1 = 0.632\angle -71.56° I_2}$ ...(5)

Put the above eq4 in eqn No. (3)

i.e. $8.94\angle 26.56° I_1 - 5\angle 53.1_3 I_2 = 50\angle 90°$

$I_1 = 0.632\angle .71.56° I_2$

$\Rightarrow \quad 8.94\angle 26.56° \times 0.632\angle -71.56° I_2 - 5\angle 53.13 I_2 = 50\angle 90°$

$\Rightarrow \quad 5.650\angle -45° I_2 - 5\angle 53.13 I_2 = 50\angle 90°$

$\Rightarrow \quad 8.056\angle -82.90 I_2 = 50\angle 90°$

$$I_2 = \frac{50\angle 90°}{0.65\angle 8.13} = 6.206\angle 172.9° \text{ Amp}$$

$I_1 = 0.632\angle -71.56° \times 6.206\angle 172.9°$

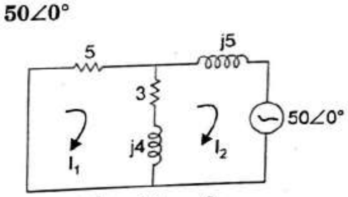
$I_1 = 3.922\angle 101.34°$ Amp.

Current in AB Branch $\Rightarrow I_2 - I_1$

$6.206\angle 172.9° - 3.922\angle 101.34°$

$= 6.20\angle -150.25°$ Amp.

Now From source 50∠0°



$\Rightarrow \quad 5I_1 + (3 + j4)(I_1 - I_2) = 0$

$$\Rightarrow \quad 5I_1 + 3I_1 - 3I_2 + j4I_1 - j4I_2 = 0$$

$$\Rightarrow \quad I_1(8+j4) - I_2(3+j4) = 0 \quad \ldots(1)$$

$$\Rightarrow \quad j5I_2 + 50\angle 0^\circ + (3+j4)(I_2 - I_1) = 0$$

$$\Rightarrow \quad j5I_2 + 3I_2 - 3I_1 + j4I_2 - j4I_1 = -50\angle 0^\circ$$

$$\Rightarrow \quad -(3+j_4)I_1 + I_2(3+j9) = -50\angle 0^\circ \quad \ldots(2)$$

$$\Rightarrow \text{ from eqn} - (1) \Rightarrow I_1 = \frac{(3+j4)}{(8+j4)} I_2 = 0.559\angle 26.56^\circ \, I_2$$

$\Rightarrow$ Eqn. (2) can be written in polar form.

$$\Rightarrow \quad -5\angle 53.13^\circ I_1 + 9.4\angle 71.56\, I_2 = -50\angle 0^\circ \quad \ldots(3)$$

$$\Rightarrow \quad -(3+j4)I_1 + (3+j9)I_2 = -50\angle 0^\circ$$

$$I_1 = (3+4.5j)I_2$$

$$\Rightarrow \quad -(3+j4)(3+j4.5)I_2 + (3+j9)I_2 = -50\angle 0^\circ$$

$$\Rightarrow \quad (9-j25.5)I_2 + (3+j9)I_2 = -50\angle 0^\circ$$

$$\Rightarrow \quad (I2 - j16.5)I_2 = -50\angle 0^\circ$$

$$I_2 = \frac{-50\angle 0^\circ}{20.40\angle -53.97^\circ} = 2.45\angle 53.97^\circ \text{ Amp.}$$

$$I_1 = (3+j4.5).(1.44+j1.982)$$

$$= -4.599 + j12.426 = 13.249\angle 110.31 \text{ Amp.}$$

Branch in AB Branch–

$$= I_1 - I_2$$

$$= 13.249\angle 110.31 + (-1.44 - j1.98)$$

$$= (-4.599 + j12{,}426) - (1.44 + j1.98)$$

$$= -6.039 + j10.446 = 12.066\angle 120.03^\circ \text{ Amp.}$$

Final current in AB Branch

$$= 6.20\angle -150.25^\circ + 12.066\angle 120.03$$

$$= 13.59\angle 147.16^\circ \text{ Amp.}$$

UNIT-II

Q.4. (a) In the circuit shown in Fig. 5, $I_s = \cos 1000\,t$. Determine the frequency domain circuit and determine the phasors I_1 and I_2. Draw the phasor diagram for V_1, V_2, V_3 and V_4 in the same figure. **(6.5)**

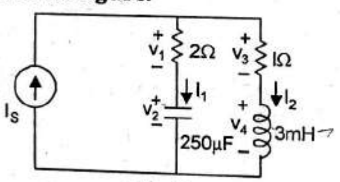


Fig. 5.

Ans.

Comparing with reference equation–

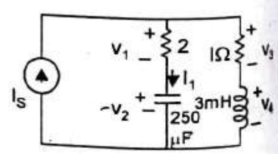
$$I_s = \cos 1000\,t$$

$$I_s = \cos wt \Rightarrow w = 1000$$

$$= 2\pi f = 1000$$

$$f = \frac{1000}{2\pi}$$

$$\boxed{f = 159.15\, Hz}$$



Now
$$C = 250\,\mu F, X_c = \frac{1}{2\pi fc}$$

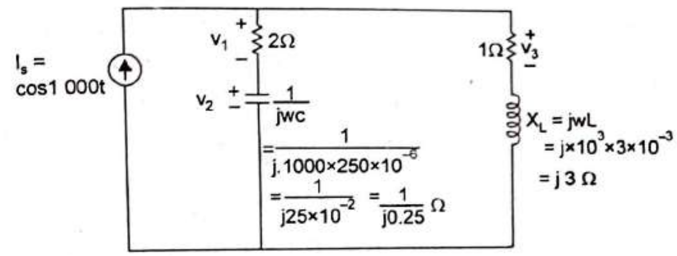
$$= \frac{1}{2\pi \times 159.15 \times 250 \times 10^{-6}}$$

$$= \boxed{X_c = 4.00\Omega}$$

$$L = 3\text{mH } X_L = 2\pi fl = 2\pi \times 159.15 \times 3 \times 10^{-3}$$

$$\boxed{X_L = 0.333\Omega}$$

Frequency domain circuit



$$\Rightarrow \quad Zeq = Z_1 \,||\, Z_2$$

$$= \left(2 + \frac{1}{jwc}\right) \| (1 + jwL)$$

$$= \frac{\left(2 + \frac{1}{j0.25}\right) \times (1+j3)}{\left(2 + \frac{1}{j0.25}\right) + (1+j3)} = \frac{(2-j4)(1+j3)}{(2-j4)+(1+j3)}$$

$$\text{Zeq.} = \frac{(14+j2)}{(3-j)} = (4+j2)\Omega$$

$$\text{Veq.} = I_m \times \text{Zeq} = 1 \times (4+j2), \; \boxed{I_m = 1}$$

$$= (4+j2) \text{ volt}$$

$\Rightarrow$ Now

$$I_1 = \frac{V_{eq}}{Z_1} = \frac{(4+j2)}{(2-j4)} = 1\angle 90^\circ$$

$$I_2 = \frac{Veq}{Z_2} = \frac{(4+j2)}{(1+j3)} = 1.414\angle -45^\circ \; amp$$

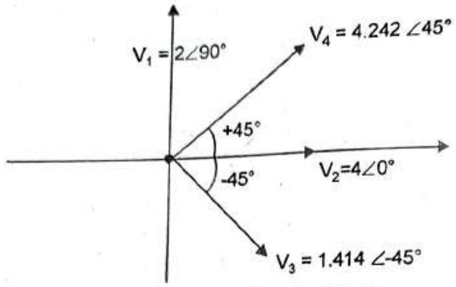
$$V_1 = I_1 \times 2 = 1\angle 90^\circ \times 2 = 2\angle 90^\circ$$

$$V_2 = I_1 \times (-j4) = 1\angle 90^\circ \times (j4) = 4\angle 0^\circ$$

$$V_3 = I_2 \times 1 = 1.414\angle -45^\circ \times 1 = 1.414\angle -45^\circ$$

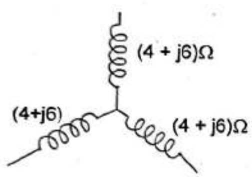
$$V_4 = I_2 \times j3 = 1.414\angle -45^\circ \times j3 = 4.242\angle 45^\circ$$

Phasor diagram



Q.4. (b) A balanced star connected load of (4 + j6) ohm per phase is connected to a balanced 3-phase, 400v supply. Find the line current, power factor and total power. (6)

Ans.



$$V_L = 400\text{V}, Z = (4 + j6)\ \Omega/\text{phase}$$

$$I_L = ?\ \text{P.F}=?\ P = ?$$

$$I_L = \frac{V_L}{Z} = \frac{400}{3(4+j6)} = \frac{400}{12+j18}$$

$$I_L = 10.25 - j15.38$$

$$\boxed{I_L = 18.49\angle -56.30°\ \text{amp}}$$

In star connection, $I_L = I_{ph} = 18.49\ \angle -56.30°$ amp

P.F → Angle between voltage and current

$$\phi = -56.30°$$

$$\Rightarrow \quad \text{P.F} = \cos(\phi) = 0.554$$

Power in three phase system is given by

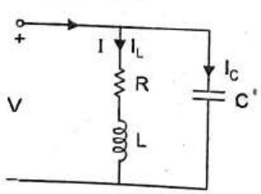
$$P = \sqrt{3} V_L . I_L \cos\phi$$

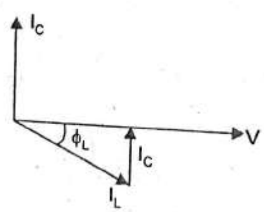
$$= \sqrt{3} \times 400 \times 18.49\angle -56.30° \times 0.554$$

$$\boxed{P = 3.937\ watt}\ \textbf{Ans.}$$

Q.5. For a parallel RLC circuit define resonant frequency, damped resonant frequency and Q. Obtain exact expressions for half power frequencies in terms of resonant frequency and Q. (12.5)

Ans. Parallel Resonant





⇒ The admittance of the circuit is

$$Y = jwc + \frac{1}{R + jwL} = jwc + \frac{R - jwl}{R^2 - w^2L^2}$$

$$\frac{R}{R^2 + w^2L^2} + jw\left(C - \frac{L}{R^2 + w^2L^2}\right)$$

At resonance the j term is zero, and $w = w_\theta$,

so

$$\Rightarrow \quad C - \frac{L}{R^2 + u_\theta^2 L^2} = 0$$

$$\Rightarrow \quad R^2 + w_\theta^2 L^2 = \frac{L}{C}$$

$$\Rightarrow \quad w_\theta^2 L^2 = \frac{L}{C} - R^2 \Rightarrow \boxed{w_0 = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}}\ \text{rad/sec}$$

Resonant frequency in Hz $\boxed{f_0 = \frac{w_0}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}}$ rad/sec

if 'R' is small than

$$\boxed{F_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}}\ \text{Hz}$$

Bandwidth

At f_1, susceptance = $B_{L1} - B_{CL} = G$

f_2, susceptance, $B_{C2} - B_{L2} = G$

$$Y = \sqrt{(G^2 + B^2)} = \sqrt{2}G$$

and phase angle $\phi = \tan^{-1}\frac{B}{G}$

$$= \tan^{-1}1 = 45° \text{ or } \frac{\pi}{4} \text{ radian.}$$

Quality factor

$$\text{Q–factor} = \frac{\text{Circulating current between Land C}}{\text{Line current}}$$

$$I_C = 2\pi f_r CV$$

line current,

$$I = \frac{V}{L/CR} = VcR/L$$

$$\text{Q–factor} = \frac{I_C}{I} = \frac{2\pi fL}{R}$$

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

$$\text{Q–factor} = 2\pi \times \frac{1}{2\pi}\sqrt{\frac{1}{LC}} \times \frac{L}{R}$$

$$\boxed{Q = \frac{1}{R}\sqrt{\frac{L}{C}}}\ \textbf{Ans.}$$

UNIT-III

Q.6. (a) Derive an expression for the deflecting of a moving iron movement in terms of the rate of change of inductance with position of the movement. **(6.5)**

Ans. Consider a moving iron instrument in a steady state deflected position.

→ In order to affect an increase in current dI in the instrument there must be increase in the applied voltage given by

$$e = \frac{d}{dt}(LI) = I\frac{dL}{dt} + L\frac{dI}{dt}$$

The electrical Energy supplied = eIdt

$$= I^2dL + ILdI$$

⇒ The stored energy change form

$$\frac{1}{2}LI^2 \text{ to } \frac{1}{2}(I+dI)^2(L+dL)$$

so stored Energy is given as

$$dE = \frac{1}{2}(I+dI)^2(L+dL) - \frac{1}{2}I^2L$$

$$= \frac{1}{2}(I^2 + dI^2 + 2IdI)(L+dL) - \frac{1}{2}I^2L$$

$$dE = \frac{1}{2}I^2dL + IL\,dI$$

The change in potential Energy of the spring or order control system

$$= T_d\,d\theta$$

From principle of conversion energy
Electrical Energy supplied

= Increase in stored Energy + Increase in potential Energy of control system

$$\Rightarrow \quad I^2dL + IL\,dI = \frac{1}{2}I^2dL + IL\,dI + T_d d\theta$$

$$\Rightarrow \quad Td = \frac{1}{2}I^2\frac{dL}{d\theta}N - m$$

θ includes the initial displacement α,

hence $\boxed{T_d = \frac{1}{2}I^2\frac{dL}{d(\theta+\alpha)}}N - m$

Q.6. (b) A moving coil instrument has a resistance of 3 ohm and gives full scale reading of 25 mA.

(i) The shunt resistance for full scale deflection corresponding to 125 amp.
(ii) The resistance for full scale reading with 625v.
Also find power consumption in the shunt and multiplier. **(6)**

Ans.
(i) Meter resistance $R_m = 3\Omega$, full scale current $I_m = 25$ mA

$$R_m = \frac{125\times10^{-3}}{25\times10^{-3}} = 5\Omega$$

⇒ Shunt multiplying factor, $\frac{I}{I_m} = \frac{125}{25\times10^{-3}} = 5000$

Shunt Resistance, $R_{sh} = \frac{5}{5000-1} = \frac{5}{4999}$

$$\boxed{R_{sh} = 1m\Omega}$$

Power, $P = V.I = 75\times10^{-3}\times125$
$= 9.375$ watt

(ii) Voltage multiplying factor

$$m = \frac{V}{v} = \frac{625}{75\times10^{-3}} = 8333.33$$

multiplier resistance

$$R_s = (m-1)R_m$$
$$= (8333.33-1)\times5$$
$$\boxed{R_s = 41661.66\Omega}$$

Power dissipation = V.Im
$= 625\times25\times10^{-3}$
$= 15.625$ watt **Ans.**

UNIT-IV

Q.7. (a) A 250v, 10A dynamometer type wattmeter has resistance of current and pressure coil are 0.5 ohm and 12500 ohm respectively. Find the percentage error when:

(i) The pressure coil is connected on the supply side, (ii) The pressure coil on the load side. **(7)**

Assume unity power factor load at 250v, 4A.

Ans. $V = 250$V, I = 10 Amp,
P.C = 0.5 Ω C.C = 12500Ω

(1) Pressure coil or supply side

$P = VI\cos\phi$
$= 250\times10\times1 = 2500$ watt
$\cos\phi = 1$
$\phi = 0°$

⇒ current, $I = 10(\cos 0° - j\sin\theta°)$

$$\boxed{I = 10Amp}$$

⇒ Voltage drop across C.C $= 10(0.5 + j12500)$
$= 5 + j\,125000$

voltage across P.C V_p $= 250 + 5 + j\,12500$
$= 255 + j\,12500$
$= 125\times10^3\angle 89.88°$ V

Power indicated by wattmeter $= 125\times10^3\times10\times\cos(-89.88°)$
$= 125\times10^4\times2.094\times10^{-3}$
$= 2617.5$ watt

$$\text{Error} = \frac{2617.5-2500}{2500} = 4.7\%$$

$$\frac{\text{When connected to load side}}{\text{Power lost in pressure coil}} = \frac{(250)^2}{12500} = 5 \text{ watt}$$

Power indicated by wattmeter

$$= 2500 + 5 = 2505 \text{ watt}$$

$$\text{Error} = \frac{2505 - 2500}{2500} = 0.2\% \textbf{ Ans.}$$

Q.7. (b) Discuss working of electronic energy meter. **(5.5)**

Ans. Electrometers are an integrating instruments, and takes into account both the equatlatiblies *i.e.* the power and time.

→ The product of which gives the energy. An energy meter keeps a record of total energy consumed in a circuit during a particular period but it does not give any idea about the variation in the rate of energy consumption during the period.

→ Energy meters are generally of three types

(1) Electrolytic Meters (2) Motor meters (3) Clock meters

→ In Electronic energy meter, we use some electronic device for the measurement of energy.

→ Eletronic Energy meter takes very less power to operate and very accurate as well.

→ Electronic Energy meter consists of Rectifier, Memory, Counter circuit to evaluates the energy.

UNIT-IV

Q.8. (a) Prove that single phase induction motor is not self starting. **(4.5)**

Ans. Double Revolving-Field Theory–

"Stationary pulsating magnetic field can be resolved into two rotating magnetic fields, each of equal magnitude but rotating in opposite direction".

→ The induction motor responds to each magnetic field separately and the torque in the motor is equal to the sum of torques.

i.e.

$$b(\alpha) = \beta_{max} \sin \omega t \cos \alpha \quad ...(1)$$

$\beta_{max} \rightarrow$ maximum air gap flux density

Since

$$\sin A \cos B = \frac{1}{2}\sin(A-B) + \frac{1}{2}\sin(A+B)$$

so

$$b(\alpha) = \frac{1}{2}\beta_{max} \sin(\omega t - \alpha) + \frac{1}{2}\beta_{max} \sin(\omega t + \alpha)$$

⇒ The first term of revolving theory is in positive direction and second term is in negative direction.

⇒ $\frac{1}{2}$ βmax sin $(\omega t - \alpha)$ is the forward field

$\frac{1}{2}$ βmax sin $(\omega t + \alpha)$ is the backward field.

⇒ Both are moving in opposite directions. So the Net torque produced is zero.

Q.8. (b) Describe phasor diagram on no load and on load of a transformer. **(8)**

Ans. (*i*) No load

where

V_1 = Primary voltage (volt)

E_1 = Primary side induced emf (volt)

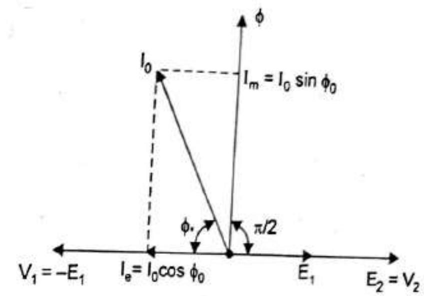
I_0 = no load current at primary side

I_e = active current = $I_0 \cos \phi_0$

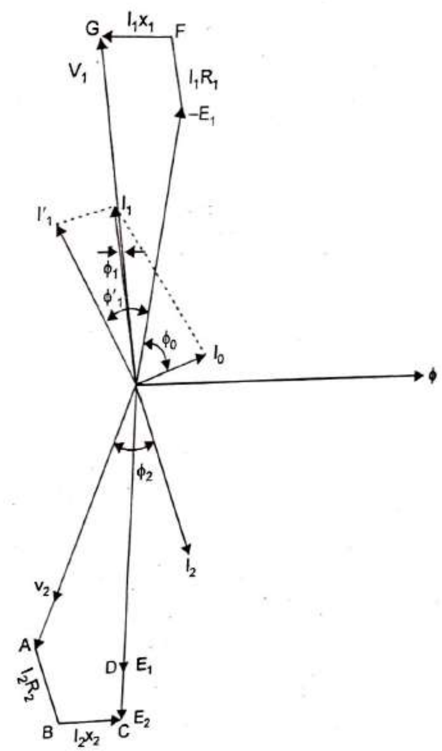
I_m = magnetising current = $I_0 \sin \phi_0$

V_2 = secondary side voltage (volt)

E_2 = Secondary side induced emf (volt)



(*ii*) **Capacitive load with practical trnsformer.**



Q.9. (a) Explain types of DC motors. **(6.5)**

Ans.

Self-Excited Motor-

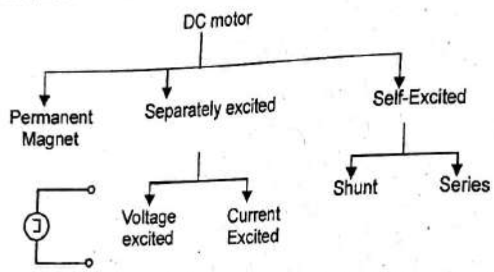
→ Field winding have electrical contact with armature winding.

→ **Separately Excited–**

Field winding does not connect electrically to armature winding.

→ Permanent magnet does not require any field winding

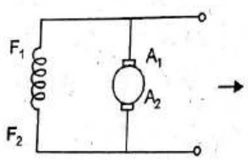
→ It may further classified as



(1) Voltage Excited- Field winding is directly connected to voltage source

(2) Current Excited- Field winding is energised by current source

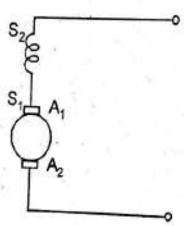
→ **Shunt Excited**



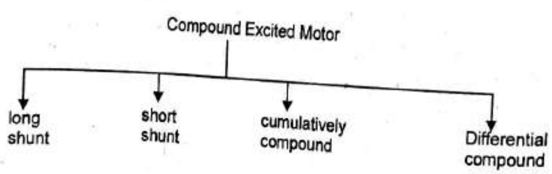
→ Voltage Excited, used as a shunt Excited.

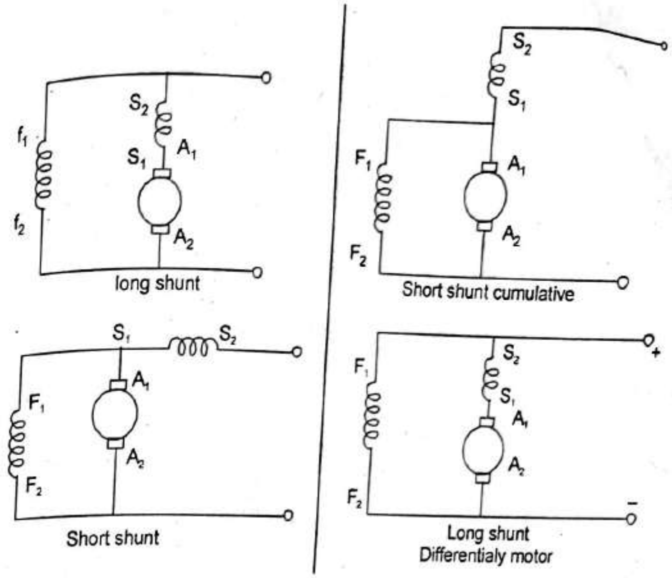
→ **Series Excited**

→ Armature and field winding is in series



→ conductor used is thick.





Q.9. (b) Explain voltage regulation and efficiency of single phase transformer. **(6)**

Ans. Voltage regulation of a transformer :

(*i*) It is defined a the ratio of change in voltage from no load to full load.

(*ii*) For a good transformer the voltage change across the load from no load to full load should be minimum.

(*iii*) If E_2 is the voltage across the load at no load condition and V_2 is the full load voltage across the load

so voltage regulation $= \dfrac{E_2 - V_2}{V_2}$

$$\% \quad V.R = \frac{E_2 - V_2}{V_2} \times 100$$

or % V. R. = (% resistive drop) cos $\phi \pm$ (% reactive drop) sin ϕ

$$= \left(\frac{I_2 R_2}{N_2} \times 100\right) \cos\phi \pm \left(\frac{I_2 x_2}{V_2} \times 100\right)$$

Where, '+' sign is used for lagging power factor

'–' sign is used for leading power factor

R_2 : Secondary side resistance of transformer

x_2 : Secondary side reactance of transformer

I_2 : Secondary side current.

Transformer efficiency : (η)

$$\eta = \frac{o/p}{i/p} \times \frac{i/p - losses}{i/p} \times 100$$

$$= \frac{o/p}{o/p + losses} \times 100$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + P_{cupper}(x)^2} \times 100$$

For full loud $x = 1$

$$\Rightarrow \quad \eta_{full} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + P_{cu}} \times 100$$

where

$V_2 I_2 \cos\phi_2$ = total active power in watt

$V_2 I_2$ = apparent power in volt ampere

P_{cu} = Cupper loss (watt)

P_e = core loss (watt)

Total losses $= P_e + x^2 P_{cu}$

$$\text{where } x = \frac{\text{load current}}{\text{full load current}}$$

$$\text{or } \%\eta = \frac{\text{KVA rating} \times \cos\phi}{\text{KVA rating} \times \cos\phi + p_e + x^2 P_c} \times 100$$

for full load $x = 1$

for half load $x = 1/2$

$$\%\eta = \left[\frac{\frac{1}{2} \times KVA\,\text{rating} \times \cos\phi}{\frac{1}{2} \times KVA\,\text{rating} \times \cos\phi + P_e + \left(\frac{1}{2}\right)^2 P_c}\right] \times 100$$

for $\left(\frac{1}{3}\right)^{rd}$ load

$$\%\eta = \left[\frac{\frac{1}{3} \times KVA\,\text{rating} \times \cos\phi}{\frac{1}{3} KVA\,\text{rating} \times \cos\phi + P_e + \left(\frac{1}{3}\right)^2 P_{cu}}\right] \times 100$$

→ condition for maximum efficiency:

$$\frac{d\eta}{dx} = \frac{d}{dx}\left(\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_e + x^2 P_c}\right) = 0$$

$$\Rightarrow \quad x^2 P_c = P_e$$

$$\Rightarrow \quad x = \sqrt{P_e / P_c}$$

$$\Rightarrow \quad x = \sqrt{P_e / I_2^2 R_{02}}$$

$[\because P_{cu} = I_1^2 R_{01} \text{ or } I_2^2 R_{02}]$

FIRST TERM EXAMINATION [SEPT. 2017]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE–107]

Time : 1½ hrs. **M.M. : 30**

Note: Q.No 1 is compulsory. Attempt any two more questions from the rest.

Q.1. (a) What are the limitation of Ohm's law? **(2)**

Ans. Limitation of Ohm's law are

(i) Ohm's law is applicable only to bilateral elements.

(ii) It can not be applied to circuits consisting of non-linear elements such as powdered carbon, thyrite etc.

Q.1. (b) Write down the difference between Active and Passive elements. **(2)**

Ans.

Active Elements	Passive Elements
(i) Elements which supply energy to the network are known as active elements	(i) Components that dissipate energy are known as passive components.
(ii) Examples Batteries, DC generators, AC generators photoelectric cell etc.	(ii) Examples are Resistor, Inductor, capacitor etc.

Q.1. (c) Difference between Form factor and Peak factor. **(2)**

Ans. Form factor: The ratio of effective value to the average or mean value of periodic wave is known as form factor

$$\text{Mathematically, form factor} = \frac{\text{Effective value}}{\text{Average value}}$$

$$\text{For sinusoidal wave } K_f = \frac{E_{rms}}{E_{av}} = \frac{E_{max}/\sqrt{2}}{E_{max}/\pi/2} = 1.11$$

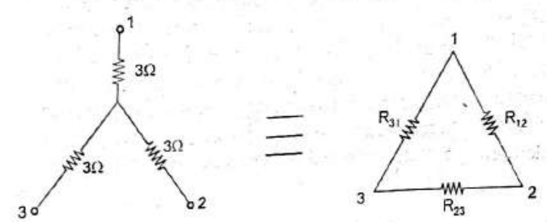
Peak factor: Peak/crest/amplitude factor of a periodic wave is defined as the ratio of maximum or peak of the effective or rms value of the wave

$$K_p = \frac{\text{Maximum value}}{\text{Effective value}}$$

For sinusoidal wave $K_p = \frac{E_{max}}{E_{rms}} = \sqrt{2} \cong 1.414$

Q.1. (d) Three equal resistance of 3 ohm are connected in star. What is the resistance in one of the arms in an equivalent delta circuit? **(2)**

Ans.



$$R_{31} = R_{23} = R_{12} = 3 + 3 + \frac{3 \times 3}{3} = 9\,\Omega$$

Q.1. (e) For 100 volts RMS value Triangular-Wave. What is the peak voltage? (2)

Ans. For triangular wave

$$I_{rms} = \frac{I_{max}}{\sqrt{3}}$$

$$\Rightarrow \quad I_{max} = \sqrt{3}\, I_{rms} = \sqrt{3} \times 100 = 100\sqrt{3}\ V$$

Q.2. (a) Find the Thevenin's and Norton's Equivalents for the circuit as shown in fig 1 with respect to terminals *ab*. (5)

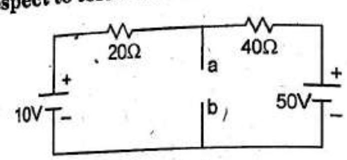


Fig 1.

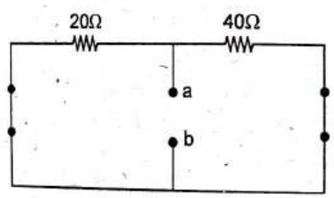
Ans. (a) Thevenin's Equivalent circuit

Step (*i*)

$$i = \frac{50-10}{20+40} = \frac{40}{60} = \frac{2}{3}\,A$$

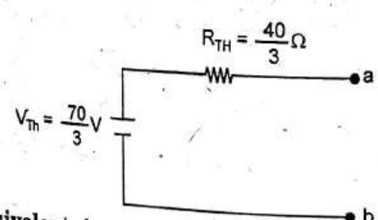
$$V_{th} = V_{ab} = 50 - 40 \times \frac{2}{3} = \frac{70}{3}\,V$$

Step (*ii*) For R_{Th}



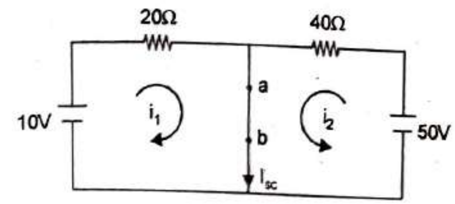
$$R_{Th} = 20\,\Omega \parallel 40\,\Omega = \left(\frac{1}{20} + \frac{1}{40}\right)^{-1} = \frac{40}{3}\,\Omega$$

Step (*iii*) Thevenin equivalent circuit



(*b*) Norton's Equivalent circuit:

Step (*i*) For finding I_{SC}



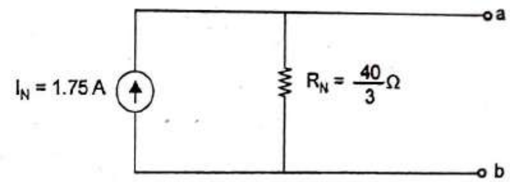
$$i_1 = \frac{10}{20} = 0.5\,A;\ i_2 = \frac{50}{40} = 1.25\,A$$

$$I_{SC} = i_1 + i_2 = 0.5 + 1.25 = 1.75\,A$$

Step (*ii*) For finding R_N

$$R_N = R_{th} = \frac{40}{3}\,\Omega$$

Step (*iii*) Norton's Equivalent circuit



Q.2. (*b*) Find the current I in the circuit as shown in fig 2 by using Super position Theorem. (5)

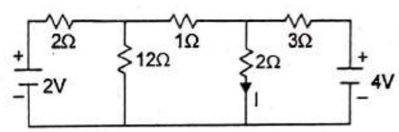
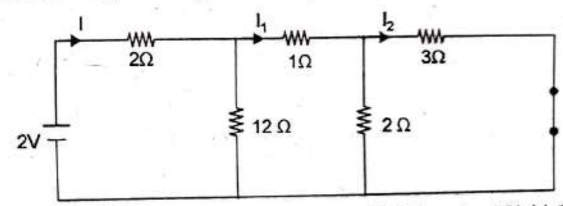


Fig. 2

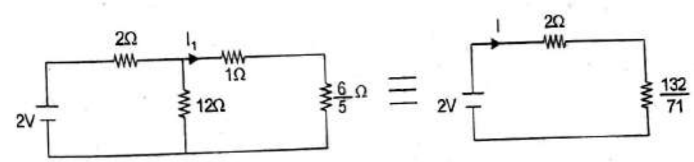
Ans.

Step (*i*) Considering 2*V* voltage source



$$R_{eq} = (((3\Omega \parallel 2\Omega) \text{ series } 1\Omega) \parallel 12\Omega) \text{ series } 2\Omega$$

$$= \frac{274}{71}\,\Omega$$

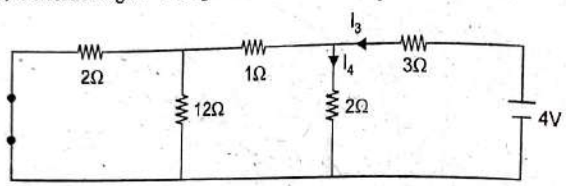


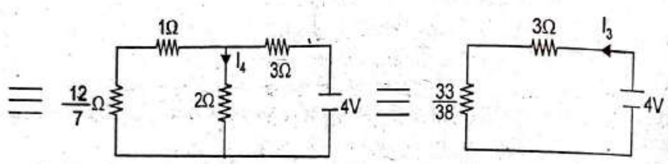
$$I = \frac{V}{R_{eq}} = \frac{2}{\frac{274}{71}} = \frac{71}{137}$$

$$I_1 = \frac{71}{137}\times\frac{12}{12+\frac{11}{5}} = \frac{60}{137}\,A$$

$$I_2 = \frac{60}{137}\times\frac{3}{3+2} = \frac{36}{137}\,A = 0.263\,A$$

Step (*ii*) Considering 4*V* voltage source





$$I_3 = \frac{4}{\frac{33}{38}+3} = \frac{4\times 38}{33+3\times 38} = \frac{152}{147}$$

$$I_4 = \frac{152}{147}\times\frac{\frac{19}{7}}{\frac{19}{7}+2}$$

$$= \frac{152}{147}\times\frac{19}{\cancel{7}}\times\frac{\cancel{7}}{33} = 0.595\,A$$

$$I_1' = I_2 + I_4 = 0.263 + 0.595 = 0.858\,A$$

Q.3. (*a*) Determine the maximum power delivered to the Load Resistance in the circuit as shown in figure. (5)

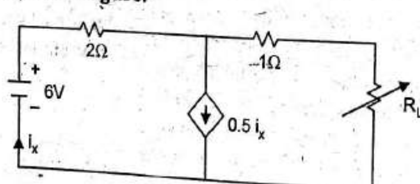
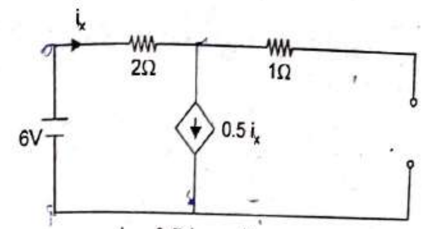


Fig 3

Ans.

For finding V_{Th}

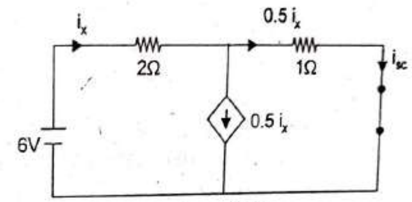


$$i_x - 0.5\,i_x = 0$$

$$\Rightarrow \quad i_x = 0$$

$$V_{Th} = V = 6V$$

For finding I_{SC}



$$i_{sc} = 0.5\,i_x$$

$$6 - 2i_x - 0.5\,i_x = 0$$

$$\Rightarrow \quad i_x = \frac{6}{2.5} = 2.4\,A$$

$$\Rightarrow \quad I_{SC} = 2.4\times 0.5 = 1.2\,A$$

$$R_{Th} = \frac{V_{OC}}{I_{SC}} = \frac{6}{1.2} = 5\,\Omega$$

For maximum power transfer $R_{Th} = R_L = 5\Omega$

$$I_L = \frac{V_{Th}}{R_{Th}+R_L} = \frac{6}{5+5} = 0.6\,A$$

$$\text{Power} = I_L^2 R_L = 0.6^2\times 5 = 1.8\,W.$$

Q.3. (*b*) A current of (15 + *j*8) A flows in a circuit which has a supply voltage of (20 + *j*10), find out the circuit parameters, impedance, power-factor, active power, reactive power, apparent power? (5)

Ans. Circuit Voltage $V = (20 + j10)V = 22.36\angle 26.56°$

Circuit current $I = (15 + j8)A = 17\angle 28°$

Circuit impendance $Z = \frac{V}{I} = \frac{22.36\angle 26.56}{17\angle 28°} = 1.32\angle -1.44°$

Power factor $\cos\phi = \cos(1.44) = 0.99$ (leading)

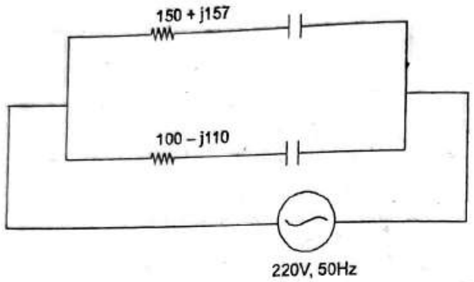
$P = VI\cos\phi = 22.36\times 17\times 0.99 = 376.32$ W

$Q = VI\sin\phi = 22.36\times 17\times 0.02 = 7.60$ VAr

Apparent power
$$S = \sqrt{P^2+Q^2}$$
$$= \sqrt{376.32^2+7.6^2} = 376.4\text{ W}$$

Q.4. (a) Two impedances (150+j 157) ohm and (100–j 110) ohm connected in parallel across a 220volt, 50 Hz AC supply. Find out the equivalent impedance, total current and power factor. (5)

Ans.



$$Z_1 = 150 + j157 = 217.17\angle 46.31$$
$$Z_2 = 100 - j110 = 148.66\angle -47.73$$

$$Z = \left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)^{-1} = \left(\frac{1}{(150 + j157)} + \frac{1}{(100 - j110)}\right)^{-1}$$
$$= 124.09 - j\,26.53 = 126.9\angle -12.07\ \Omega$$

$$\text{Current } I_1 = \frac{V}{Z_1} = \frac{200\angle 0}{217.14\angle 46.31}$$
$$= 0.92\angle -46.31\text{A}$$

$$\text{Current } I_2 = \frac{V}{Z_2} = \frac{200\angle 0}{148.66\angle -47.73} = 1.345\angle 47.73\text{ A}$$

$$I = I_1 + I_2$$
$$= 0.92\angle -46.31 + 1.345\angle 47.73$$
$$= 0.6355 - j\,0.6652 + 0.9047 + j\,0.9953$$
$$= 1.5402 + j\,0.33 = 1.575\angle 11.83\text{ A}$$

Power factor $= \cos\phi = \cos(11.83) = 0.979.$

Q.4. (b) A series R-C circuit takes a power of 7000watt, when connected to 200 volt, 50Hz supply. The voltage across the resistor is 130volt. Calculate the value of R, I, C, Z, Power factor? (5)

Ans.

$$\text{Supply Voltage } V = 200\text{ V}$$
$$\text{Voltage across resistor, } V_R = 130\text{ V}$$

$$\text{Pour factor, } \cos\phi = \frac{R}{Z} = \frac{I \times R}{I \times Z} = \frac{V_R}{V_z}$$
$$= \frac{130}{200} = 0.65\text{ (leading)}$$

$$\text{Current } I = \frac{P}{V\cos\phi} = \frac{7000}{200 \times 0.65} = 53.846\text{ A}$$

$$\text{Resistance } R = \frac{V_R}{I} = \frac{130}{53.846} = 2.41\ \Omega$$

$$\text{Impedance } Z = \frac{V}{I} = \frac{200}{53.846} = 3.714\ \Omega$$

$$\text{Capacitive Reactance } X_C = \sqrt{Z^2 - R^2}$$
$$= \sqrt{(3.714)^2 - (2.41)^2} = 2.826\ \Omega$$

$$\text{Capacitance, } C = \frac{1}{2\pi f X_C} = \frac{1}{2 \times \pi \times 50 \times 2.826} = 1126\ \mu F.$$

END TERM EXAMINATION [NOV-DEC. 2017]
FIRST SEMESTER [B.TECH]
ELECTRICAL TECHNOLOGY [ETEE-107]

Time : 3 hrs. **M.M. : 75**

Note: *Attempt any five questions including Q.No. 1 which is compulsory. Select one question from each unit.*

Q.1. (a) What are dependent and independent sources? Explain. (4)

Ans. (1) Dependent source : A dependent source is one whose value depends on some other variable in the circuit. The voltage or current values is proportional to some other voltage or current in the circuit. for example, in modelling the behavior of amplifiers. E.g. A BJT or an Opamp.

An operational amplifier can be described as a voltage source dependent on the differential input voltage between its input terminals.

Classification:

Dependent sources can be classified as follows:

Voltage-controlled voltage source: The source delivers the voltage as per the voltage of the dependent element. $V=av_x$

Voltage-controlled current source: The source delivers the current as per the voltage of the dependent element. $I=bv_x$

Current-controlled current source: The source delivers the current as per the current of the dependent element. $I=ci_x$

Current-controlled voltage source: The source delivers the voltage as per the current of the dependent element. $V=di_x$

(2) Independent sources: Ideal Independent Source maintains same voltage or current regardless of the other elements present in the circuit. Its value is either constant (DC) or sinusoidal (AC). The strength of voltage or current is not changed by any variation in connected network.

Example: a Copper resistance along the circuit

Classification:

(i) *Ideal Independent Voltage Sources:* An ideal independent voltage source is a two-terminal circuit element where the voltage across it

(a) is independent of the current through it

(b) can be specified independently of any other variable in a circuit.

In a circuit, voltage across elements which are parallel with voltage sources are equal to the voltage of the corresponding voltage sources

(ii) *Ideal Independent Current Sources:* In contrast to ideal independent voltage sources, an ideal independent current source is a two-terminal circuit element where the current passing through it

(a) is independent of the voltage across it

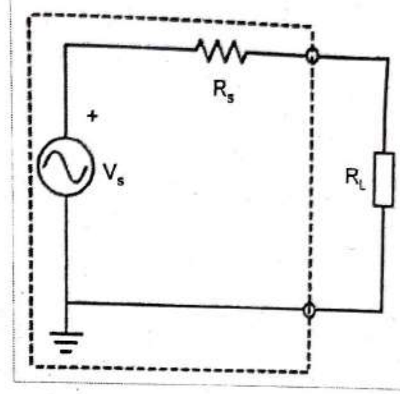
(b) can be specified independently of any other variable in a circuit.

Q.1. (b) State and prove maximum power transformer theorem. (5)

Ans. Maximum Power Transfer Theorem Statement

The maximum power transfer theorem states that in a linear , bilateral DC network, maximum power is delivered to the load when the load resistance is equal to the internal resistance of a source.

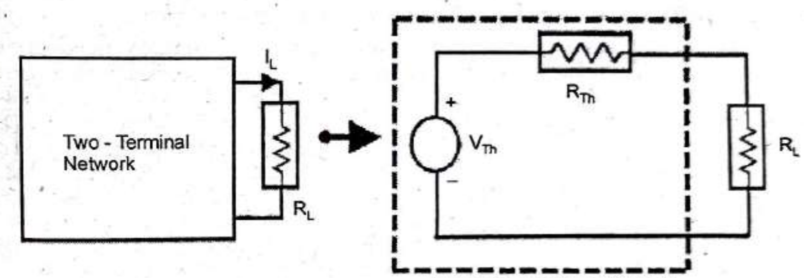
If it is an independent voltage source, then its series resistance (internal resistance R_s) or if it is independent current source, then its parallel resistance (internal resistance R_s) must equal to the load resistance R_L to deliver maximum power to the load.



Proof of Maximum Power Transfer Theorem

The maximum power transfer theorem ensures the value of the load resistance , at which the maximum power is transferred to the load.

Consider the below DC two terminal network (left side circuit) , to which the condition for maximum power is determined , by obtaining the expression of power absorbed by load with use of mesh or nodal current methods and then derivating the resulting expression with respect to load resistance R_L.



Thevenin's Equivalent Circuit

The original two terminal circuit is replaced with a Thevenin's equivalent circuit across the variable load resistance. The current through the load for any value of load resistance is

$$I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

The power absorbed by the load is

$$P_L = I_L^2 \times R_L$$

$$P_L = \left[\frac{V_{Th}}{R_{Th} + R_L}\right]^2 \times R_L \quad ...(1)$$

Form the above expression the power delivered depends on the values of R_{TH} and R_L. However the Thevenin's equivalent is constant, the power delivered from this equivalent source to the load entirely depends on the load resistance R_L. To find the exact value of R_L, we apply differentiation to P_L with respect to R_L and equating it to zero as

$$\frac{dP(R_L)}{dR_L} = V_{Th}^2\left[\frac{(R_{Th}+R_L)^2 - 2R_L \times (R_{Th}+R_L)}{(R_{Th}+R_L)^4}\right] = 0$$

$$\Rightarrow \quad (R_{Th}+R_L) - 2R_L = 0$$

$$\Rightarrow \quad R_L = R_{Th}$$

Therefore, this is the condition of matching the load where the maximum power transfer occurs when the load resistance is equal to the Thevenin's resistance of the circuit. By substituting the $R_{th} = R_L$ in equation (1) we get

The maximum power delivered to the load is,

$$P_{max} = \left[\frac{V_{Th}}{R_{Th}+R_L}\right]^2 \times R_L\Bigg|_{R_L=R_{Th}} = \frac{V_{Th}^2}{4R_{Th}}$$

Total power transferred from source is

$$P_T = I_L^2(R_{Th}+R_L)$$
$$= 2\,I_L^2 R_L \qquad ...(2)$$

Hence, the maximum power transfer theorem expresses the state at which maximum power is delivered to the load, that is, when the load resistance is equal to the Thevenin's equivalent resistance of the circuit. Below figure shows a curve of power delivered to the load with respect to the load resistance.

Q.1. (c) Differentiate among real, reactive and apparent power. **(4)**

Ans. The reactive loads such as inductors and capacitors dissipate zero power, yet the fact that they drop voltage and draw current gives the deceptive impression that they actually *do* dissipate power. This "phantom power" is called *reactive power*, and it is measured in a unit called *Volt-Amps-Reactive* (VAR), rather than watts. The mathematical symbol for reactive power is (unfortunately) the capital letter Q. The actual amount of power being used, or dissipated, in a circuit is called *true power*, and it is measured in watts (symbolized by the capital letter P, as always). 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.

As a rule, true power is a function of a circuit's dissipative elements, usually resistances (R). Reactive power is a function of a circuit's reactance (X). Apparent power is a function of a circuit's total impedance (Z).

There are several power equations relating the three types of power to resistance, reactance, and impedance (all using scalar quantities):

P = true power $\quad P = I^2R \quad P = \frac{E^2}{R}$

Measured in units of Watts

Q = reactive power $\quad Q = I^2X \quad Q = \frac{E^2}{X}$

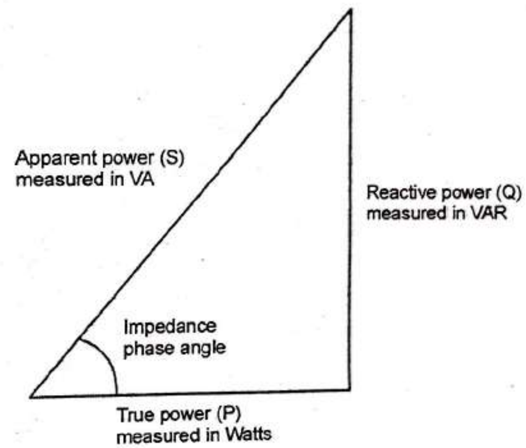
Measured in units of Volt-Amps-Reactive (VAR)

S = apparent power $\quad S = I^2Z \quad S = \frac{E^2}{Z} \quad S = IE$

Measured in units of Volt-Amps (VA)

These three types of power–true, reactive, and apparent: – relate to one another in trigonometric form. We call this the power triangle:

The "Power Triangle"



Q.1. (d) Define voltage regulation of transformer. **(4)**

Ans. The voltage regulation is the percentage of voltage difference between no load and full load voltages of a transformer with respect to its full load voltage.

Explanation of Voltage Regulation of Transformer

Say an electrical power transformer is open circuited, means load is not connected with secondary terminals. In this situation, the secondary terminal voltage of the transformer will be its secondary induced emf E_2. Whenever full load is connected to the secondary terminals of the transformer, rated current I_2 flows through the secondary circuit and voltage drop comes into picture. At this situation, primary winding will also draw equivalent full load current from source. The voltage drop in the secondary is I_2Z_2 where Z_2 is the secondary impedance of transformer.

Now if at this loading condition, any one measures the voltage between secondary terminals, he or she will get voltage V_2 across load terminals which is obviously less than no load secondary voltage E_2 and this is because of I_2Z_2 voltage drop in the transformer.

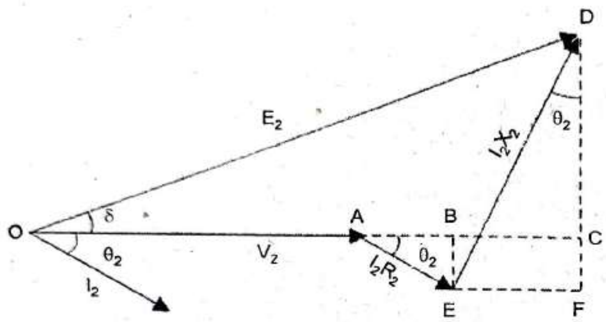
Expression of Voltage Regulation of Transformer

Expression of **Voltage Regulation of Transformer**, represented in percentage, is

$$\text{Voltage regulation (\%)} = \frac{E_2 - V_2}{V_2} \times 100\%$$

Voltage Regulation of Transformer for Lagging Power Factor

Now we will derive the expression of voltage regulation in detail. Say lagging power factor of the load is $\cos\theta_2$, that means angle between secondary current and voltage is θ_2.



Voltage Regulation at Lagging Power Factor

Here, from the above diagram,

$$OC = OA + AB + BC$$

Here, $OA = V_2$

Here $AB = AE\cos\theta_2 = I_2R_2\cos\theta_2$

and, $BC = DE\sin\theta_2 = I_2X_2\sin\theta_2$

Angle between OC and OD may be very small, so it can be neglected and OD is considered nearly equal to OC i.e,

$$E_2 = OC = OA + AB + BC$$
$$E_2 = OC = V_2 + I_2R_2\cos\theta_2 + I_2X_2\sin\theta_2$$

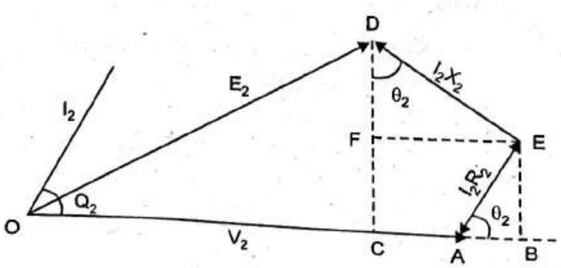
Voltage regulation of transformer at lagging power factor,

$$\text{Voltage regulation (\%)} = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2R_2\cos\theta_2 + I_2X_2\sin\theta_2}{V_2} \times 100(\%)$$

Voltage Regulation of Transformer for Leading Power factor

Let's derive the expression of voltage regulatipn with leading current, say leading power of the load is $\cos\theta_2$, that means angle between secondary current and voltage is θ_2.



Here, from the above diagram,

$$OC = OA + AB - BC$$

Here, $OA = V_2$

Here $AB = AE\cos\theta_2 = I_2R_2\cos\theta_2$

and, $BC = DE\sin\theta_2 = I_2X_2\sin\theta_2$

Angle between OC and OD may be very small, so it can be neglected and OD is considered nearly equal to OC i.e.,

$$E_2 = OC = OA + AB - BC$$
$$E_2 = OC = V_2 + I_2R_2\cos\theta_2 - I_2X_2\sin\theta_2$$

Voltage regulation of transformer at leading power factor,

$$\text{Voltage regulation (\%)} = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2R_2\cos\theta_2 - I_2X_2\sin\theta_2}{V_2} \times 100(\%)$$

Q.1. (e) What are the advantages and disadvantages of PMMC instruments? (4)

Ans. There are some advantages of PMMC (permanent magnet moving coil) are given below,

- The PMMC has uniformly divided scale. The scale may be very long, over about 250 degree.
- It has a very high torque to weight ratio.
- The PMMC consumes low power.
- The PMMC has a very high accuracy.
- The PMMC is free from hysteresis error.
- The PMMC has efficient damping characteristics and is not affected by stray magnetic field.
- Extension of instrument range is possible with the help of shunt and series resistances.

There are some disadvantages of PMMC (permanent magnet moving coil) are given below,

- It has comparatively high cost.
- The PMMC is only suitable for D.C. measurements.
- Aging of permanent magnets and control springs introduces errors.

Q.1. (f) Single phase induction motor is not self starting? Give reasons. (4)

Ans. Single phase induction motor has *distributed stator winding* and a *squirrel cage rotor*. When fed from a single-phase supply, its stator winding produces a flux (or field) which is only alternating i.e. one which alternates along one space axis only. It is not a synchronously revolving (or rotating) flux as in the case of a two or a three phase stator winding fed from a 2 or 3 phase supply. Now, an alternating or pulsating flux acting on a stationary squirrel-cage rotor cannot produce rotation (only a revolving flux can produce rotation). **That is why a single phase motor is not self-starting.**

• However, if the rotor of such a machine is given an *initial start* by hand (or small motor) or otherwise in either direction, then immediately a torque arises and the motor accelerates to its final speed (unless the applied torque is too high).

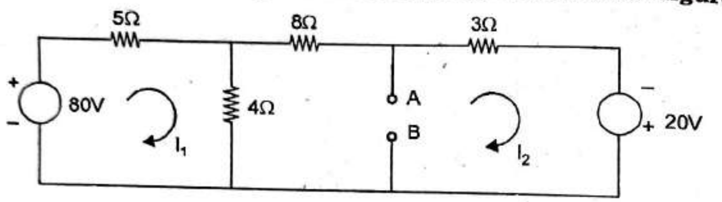
This peculiar behaviour of the motor has been explained in two ways

(i) by two-field or **double-field revolving theory** and

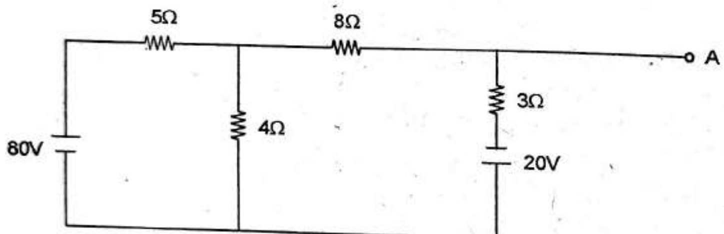
(ii) by **cross-field theory**.

UNIT–I

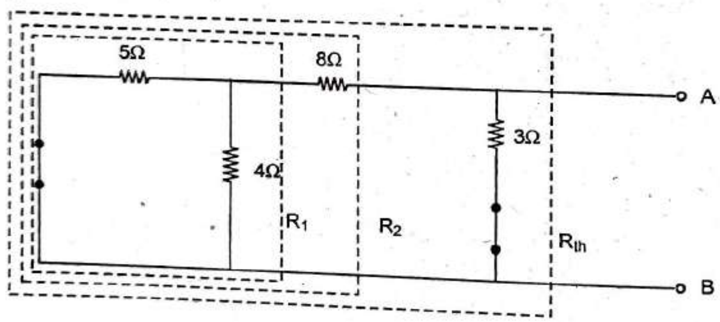
Q.2. (a) Obtain Thevenin equivalent circuit at AB as shown in figure. (6.5)



Ans.



for R_{th},



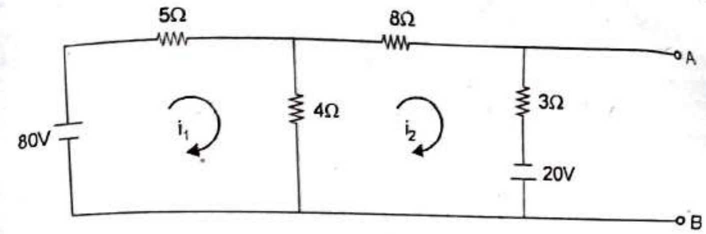
$$R_1 = 5\Omega \,\|\, 4\,\Omega$$

$$= \left(\frac{1}{5}+\frac{1}{4}\right)^{-1} = \frac{20}{9}\Omega$$

$$R_2 = \left(\frac{20}{9}\Omega\right) + 8\Omega = \frac{92}{9}\Omega$$

$$R_{th} = R_2 \,\|\, 3\Omega = \left(\frac{9}{92}+\frac{1}{3}\right)^{-1} = \frac{276}{119}\Omega$$

for V_{th},



Apply KVL,

$$80 - 5i_1 - 4(i_1 - i_2) = 0$$

$$9i_1 - 4i_2 = 80 \quad \text{...(1)}$$

$$4(i_2 - i_1) + 8i_2 + 3i_2 + 20 = 0$$

$$4i_1 - 15i_2 = 20 \quad \text{...(2)}$$

equation (2) × 9 – eq. (1) × 4

$$119\, i_2 = 140$$

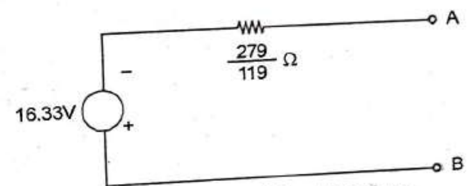
$$i_2 = \frac{140}{119}$$

$$V_{th} = 3i_2 - 20$$

$$= 3\times\frac{140}{119} - 20 = \frac{420-2380}{119} = \frac{-1960}{119}$$

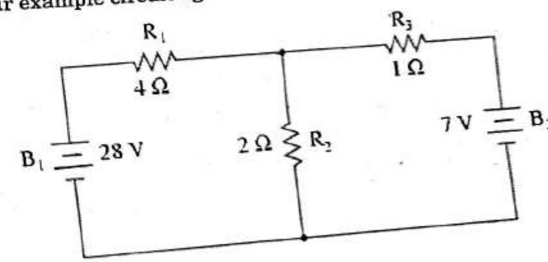
$$= -16.33\text{V}$$

Equivalent circuit

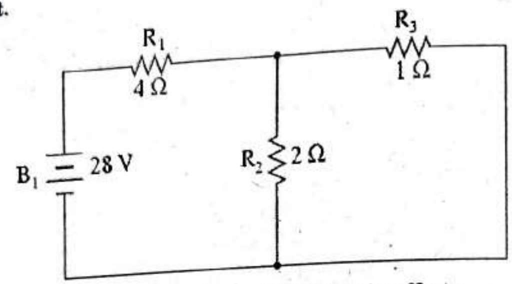


Q.2. (b) State and prove the superposition theorem. (6)

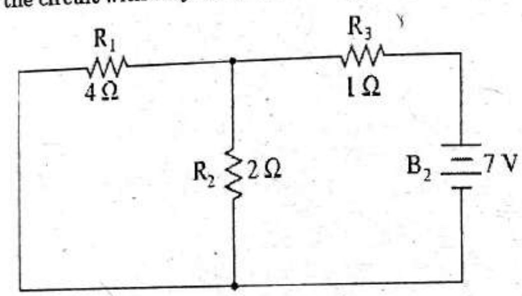
Ans. The strategy used in the Superposition Theorem is to eliminate all but one source of power within a network at a time, using series/parallel analysis to determine voltage drops (and/or currents) within the modified network for each power source separately. Then, once voltage drops and/or currents have been determined for each power source working separately, the values are all "superimposed" on top of each other (added algebraically) to find the 4actual voltage drops/currents with all sources active. Let's look at our example circuit again and apply Superposition Theorem to it:



Since we have two sources of power in this circuit, we will have to calculate two sets of values for voltage drops and/or currents, one for the circuit with only the 28 volt battery in effect.



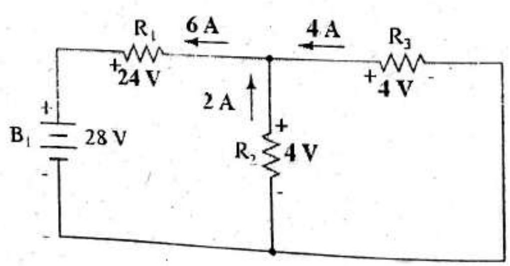
and one for the circuit with only the 7 volt battery in effect:



When re-drawing the circuit for series/parallel analysis with one source, all other voltage sources are replaced by wires (shorts), and all current sources with open circuits (breaks). Since we only have voltage sources (batteries) in our example circuit, we will replace every inactive source during analysis with a wire.

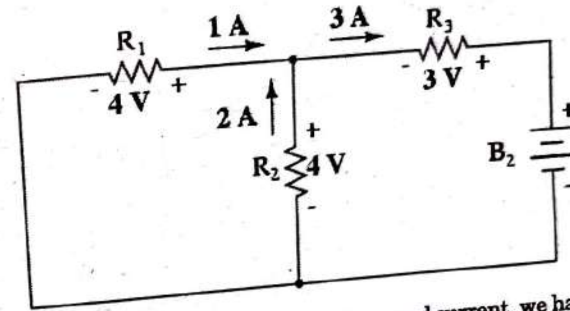
Analyzing the circuit with only the 28 volt battery, we obtain the following values for voltage and current:

	R_1	R_2	R_3	$R_2//R_3$	$R_1 + R_2//R_3$ Total	
E	24	4	4	4	28	Volts
I	6	2	4	6	6	Amps
R	4	2	1	0.667	4.667	Ohms



Analyzing the circuit with only the 7 volt battery, we obtain another set of values for voltage and current:

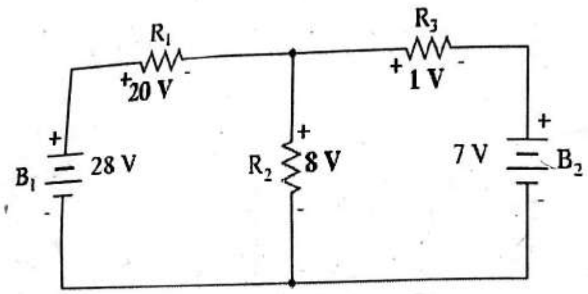
	R_1	R_2	R_3	$R_1//R_2$	$R_3 + R_1//R_2$ Total	
E	4	4	3	4	7	Volts
I	1	2	3	3	3	Amps
R	4	2	1	1.333	2.333	Ohms



When superimposing these values of voltage and current, we have to be very careful to consider polarity (voltage drop) and direction (electron flow), as the values have to be added *algebraically*.

With 28 V battery	With 7 V battery	With both batteries
24 V + − E_{R_1}	4 V − + E_{R_1}	20 V E_{R_1} + − 24V − 4V = 20V
E_{R_2} + 4 V −	E_{R_2} + 4 V −	E_{R_2} + 8 V − 4V + 4V = 8V
4 V + − E_{R_3}	3 V − + E_{R_3}	1V E_{R_3} + − 4V − 3V = 1V

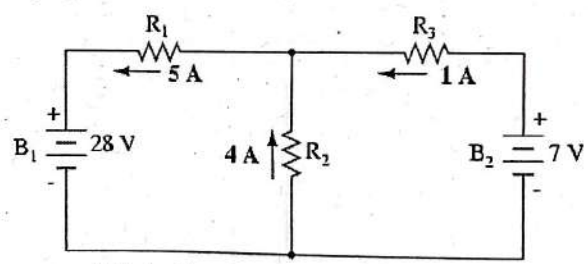
Applying these superimposed voltage figures to the circuit, the end result looks something like this:



Currents add up algebraically as well, and can either be superimposed as done with the resistor voltage drops, or simply calculated from the final voltage drops and respective resistances (I=E/R). Either way, the answers will be the same. Here I will show the superposition method applied to current:

With 28 V battery	With 7 V battery	With both batteries
I_{R_1} 6 A (←)	I_{R_1} 1 A (→)	I_{R_1} 5 A (←) 6A – 1A = 5A
I_{R_2} 2 A (↑)	I_{R_2} 2 A (↑)	I_{R_2} 4 A (↑) 2A + 2A = 4A
I_{R_3} 4 A (←)	I_{R_3} 3 A (→)	I_{R_3} 1 A (←) 4A – 2A = 1 A

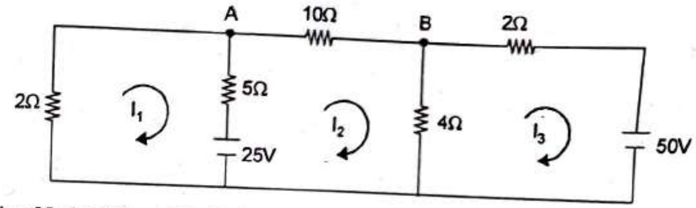
Once again applying these superimposed figures to our circuit:



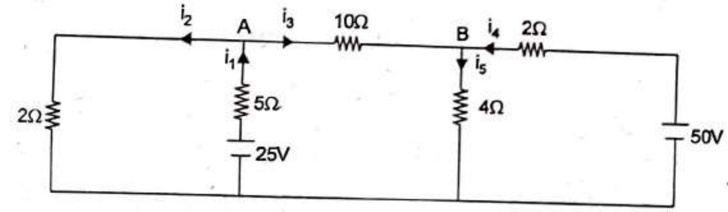
Another prerequisite for Superposition Theorem is that all components must be "bilateral," meaning that they behave the same with electrons flowing either direction through them. Resistors have no polarity-specific behavior, and so the circuits we've been studying so far all meet this criterion.

Q.3. (a) Use node voltage method to solve the mesh currents in the network shown in the fig. **(6.5)**

Ans.



Using Node Voltage Method,



At node A,

$$i_1 = i_2 + i_3$$

$$\frac{25 - V_A}{5} = \frac{V_A - 0}{2} + \frac{V_A - V_B}{10}$$

$$50 - 2V_A = 5V_A + V_A - V_B$$

$$8V_A - V_B = 50 \quad ...(1)$$

At node B,

$$i_3 + i_4 = i_5$$

$$\frac{V_A - V_B}{10} + \frac{50 - V_B}{2} = \frac{V_B - 0}{4}$$

$$2V_A - 2V_B + 500 - 10V_B = 5V_B$$

$$2V_A - 17V_B = -500 \quad ...(2)$$

equation (1) – (2) × 4

$$67V_B = 2050$$

$$V_B = \frac{2050}{67} V$$

in equation (1)

$$8V_A = 50 + \frac{2050}{67}$$

$$V_A = \frac{5400}{8 \times 67} = \frac{675}{67} V$$

$$i_2 = \frac{V_A}{2} = \frac{675}{67 \times 2} = \frac{675}{134} A$$

Current $I_1 = -i_2 = \dfrac{-675}{134}$ A

Current $I_2 = i_3 = \dfrac{V_A - V_B}{10} = \dfrac{675}{67} - \dfrac{2050}{67}$

$= \dfrac{-1375}{67}$ A

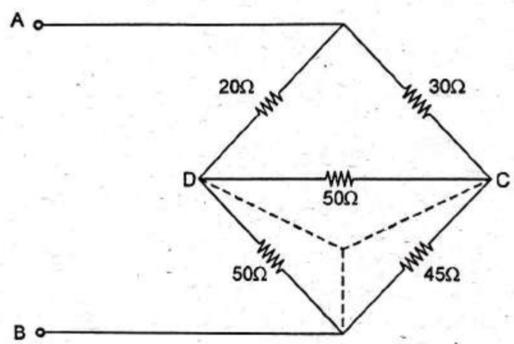
Current $I_3 = -i_4 = \dfrac{V_B - 50}{2}$

$= \dfrac{\frac{2050}{67} - 50}{2} = -\dfrac{1300}{134}$

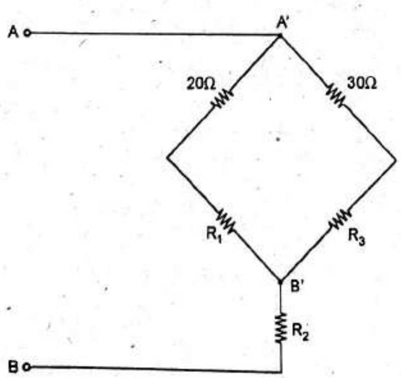
$I_3 = \dfrac{-650}{67}$ A

Q.3. (*b*) Find the resistance at *A-B* terminals in the electric circuit as shown using star- delta transformation. (6)

Ans.



Using Star-Delta conversion



$$R_1 = \frac{50 \times 50}{50 + 50 + 45} = \frac{2500}{145} = \frac{500}{29}\,\Omega$$

$$R_2 = \frac{50 \times 45}{50 + 50 + 45} = \frac{2250}{145} = \frac{450}{29}\,\Omega$$

$$R_3 = \frac{50 \times 45}{50 + 50 + 45} = \frac{450}{29}\,\Omega$$

$$R_{A'B'} = \left(20 + \frac{500}{29}\right) || \left(30 + \frac{450}{29}\right)$$

$$= \left(\frac{29}{1080} + \frac{29}{1320}\right)^{-1} = \frac{120}{29}\left(\frac{1}{9} + \frac{1}{11}\right)^{-1} = \frac{594}{29}\,\Omega$$

$$R_{AB} = R_{A'B'} + \frac{450}{29} = \frac{594}{29} + \frac{450}{29} = \frac{1044}{29} = 36\Omega$$

UNIT-II

Q.4. (*a*) A 240 V, 50 Hz voltage is applied across a circuit consisting of resistance of 40 ohms. Find (6)

(*i*) Current flowing through the circuit

(*ii*) Power observed by the resister

(*iii*) Write expression for voltage and current

(*iv*) Show phasor diagram voltage and current.

Ans. (i) Current flowing throught the circuit $= I = \dfrac{V}{R} = \dfrac{250}{20} = 12.5$A

(ii) Power observed $P = VI = 250 \times 12.5$

$= 3125$ W or 3.125 kW

(iii) Peak value $V_{max} = \sqrt{2}\,V_{rms} = \sqrt{2} \times 250 = 353.6$ V

$I_{max} = \sqrt{2}\,I_{rms} = \sqrt{2} \times 12.5 = 17.68$ A

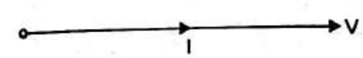
Expression for voltage, $V = V_{max} \sin 2\pi ft$

$= 353.6 \sin 2\pi \times 50t = 353.6 \sin 314\,t$

Expression for current $i = I_{max} \sin 2\pi ft$

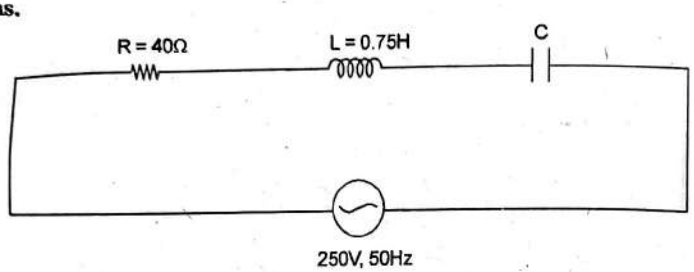
$i = 1768 \sin 314t$

(iv) Phasor,



Q.4. (*b*) A coil of resistance 40 Ω and inductance 0.75 H forms port of a series circuit for which resonant frequency is 55 Hz. If the supply is 250 V, 50 Hz find (*i*) Line current (*ii*) Power factor (*iii*) Power consumed (*iv*) Voltage across the coil. **(6.5)**

Ans.



Resonant frequency $f_r = 55$ Hz

At resonance,

$$X_L = X_C$$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$C = \frac{1}{(2\pi f_r)^2 L} = \frac{1}{(2\pi \times 55)^2 \times .75} = 11.165\ \mu F$$

At 250V, 50Hz

Reactance of circuit, $X = \omega L \frac{1}{\omega C}$

$$X = 2\pi \times 50 \times .75 - \frac{1}{2\pi \times 50 \times 11.165 \times 10^{-6}}$$

$$= 235.62 - 285.1 = -49.48\ \Omega$$

Impedance $Z = \sqrt{R^2 + X^2} = \sqrt{40^2 + (49.48)^2}$

$$= 63.63\ \Omega$$

(i) Line current $I = \frac{V}{Z} = \frac{250}{63.63} = 3.93A$

(ii) Power factor $\cos\phi = \frac{R}{Z} = \frac{40}{63.63} = .629$ (leading)

(iii) $P = I^2R = (3.93)^2 \times 40 = 618$ W

(iv) $V_{RL} = IZ_{R\text{-}L}$

$$= 3.93\sqrt{40^2 + (2\pi \times 50 \times .75)^2}$$

$$= 939.2\ V$$

Q.5. (*a*) Compare between the voltage and current resonance. **(6)**

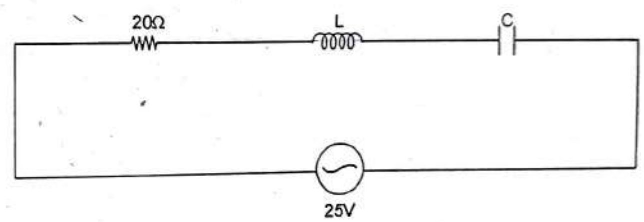
Ans.

	Particulars	Series Resonance	Parallel Resonance
Difference	Circuit impedance at resonance	Minimum	Maximum
	Circuit Admittance at resonance	Maximum	Minimum
	Current in the circuit at resonance	Maximum	Minimum
	Circuit for f > f_0	Inductive	Capacitive
	Circuit for f < $0f_0$	Capacitive	Inductive
	Amplification of	Voltage	Current
	Q-factor	$\frac{\omega_0 L}{R}$ or $\frac{1}{\omega_0 RC}$ or $\frac{1}{R}\sqrt{\frac{L}{C}}$	$\frac{R}{\omega_0 L}$ or $\omega_0 RC$ or $R\sqrt{\frac{C}{L}}$

Similarities	Power factor of the circuit at resonance	Unity	Unity
	Resonant frequency	$\omega_0 = \frac{1}{\sqrt{LC}}$	$\omega_0 = \frac{1}{\sqrt{LC}}$
	Bandwidth	$BW = \frac{f_0}{Q}$	$BW = \frac{f_0}{Q}$
	Half-power frequencies	$\omega_0 = \sqrt{\omega_1\omega_2}$	$\omega_0 = \sqrt{\omega_1\omega_2}$

Q.5. (*b*) A 20Ω resistor is connected in series with inductor and capacitor across a variable frequency 25 V supply. When the frequency is 400 Hz, the current is at its maximum value of 0.5 A and the potential difference across the capacitor is 150 V. Calculate the resistance and inductance of the inductor. **(6.5)**

Ans.



For max current

$$Z = R$$

i.e.

$$X_L = X_C \text{ at } f = 400 \text{ Hz}$$

$$i = .5A \text{ and } V_L = 150 \text{ V(given)}$$

$$\frac{V}{I} = R_L + 20$$

$$\frac{25}{0.5} = R_L + 20 \Rightarrow R_L = 30\ \Omega$$

$$X_L = X_C = \frac{V_C}{I} = \frac{150}{0.5} = 300\Omega$$

$$2\pi f L = 300\ \Omega$$

$$\Rightarrow \quad L = \frac{3\times 7}{2\times 22\times 4} = 0.119\text{H}$$

UNIT–III

Q.6. (a) Compare merits and demerits of moving coil and moving iron instruments. **(6.5)**

Ans. Comparison between MC and MI Instruments

S.No.	M.C Instruments	M.I Instruments
1.	More accurate	Less accurate
2.	Costly	Cheap
3.	Uniform scale	Non-uniform scale (scale cramped at beginning and finishing)
4.	Very sensitive	Robust in construction
5.	Low power consumption	Slightly high power consumption
6.	Eddy current damping is used	Air friction damping is used
7.	Can be used only for D.C	Can be used on A.C as well as on D.C
8.	Controlling torque is provided by spring	Controlling torque is provided by gravity or spring
9.	$\theta \propto I$	$\theta \propto I^2$
10.	Errors are set due to aging of control springs, permanent magnet (*i.e.* No Hysteresis loss)	Errors are set due to hysteresis and stray fields (*i.e.* hysteresis loss takes place).

Advantages and Disadvantages of Moving Coil Instruments

Advantages:

1. Uniform scale.
2. High sensitivity
3. Low power consumption.
4. No hysteresis loss.
5. Not much affected by stray magnetic fields.
6. Very effective and efficient eddy current damping.
7. High torque / weight ratio.
8. Very accurate and reliable.
9. Can be used in vertical and horizontal position due to spring control and
10. Can be designed to cover a wide range of currents and voltages by using shunt and series resistances respectively

Disadvantages:

1. Can be used only for D.C measurements.
2. More costly than moving iron instruments.
3. Develop errors due to ageing of control springs and permanent magnets, and
4. Develop also errors due to friction, mechanical unbalance, resistance temperature coefficient, etc.

Advantages and Disadvantages of Moving-Iron Instruments

Advantages:

1. Can be used both in D.C. as well as in A.C. circuits.
2. Robust and simple in construction.
3. Possess high operating torque.
4. Can withstand overload momentarily.
5. Since the stationary parts and the moving parts of the instrument are simple so they are cheapest.
6. Suitable for low frequency and high power circuits.
7. Capable of giving an accuracy within limits of both precision and industrial grades.

Disadvantages:

1. Scales not uniform.
2. For low voltage range the power consumption is higher.
3. The errors are caused due to hysteresis in the iron of the operating system and due to stray magnetic field.
4. In case of A.C. measurements, change in frequency causes serious error.
5. With the increase in temperature the stiffness of the spring decreases.

Q.6. (b) Derive the expression for torque produced in a moving coil type of instruments and explain briefly its working. **(6)**

Ans. Torque Equation for PMMC

The equation for the delevoped torque of the PMMC can be obtained from the basic law of electromagnetic torque.

The deflecting torque is given by,

$$T_d = NBAI$$

Where,

T_d = deflecting torque in N-m

B = flux density in air gap, Wb/m^2

N = Number of turns of the coils

A = effective area of coil m^2

I = current in the moving coil, amperes

Therefore, $T_d = GI$

Where, $G = NBA = \text{constant}$

The controlling torque is provided by the springs and is proportional to the angular deflection of the pointer.

$$T_c = K\text{Ø}$$

Where,

T_c = Controlling Torque

K = Spring Constant Nm/rad or Nm/deg

Ø = angular deflection

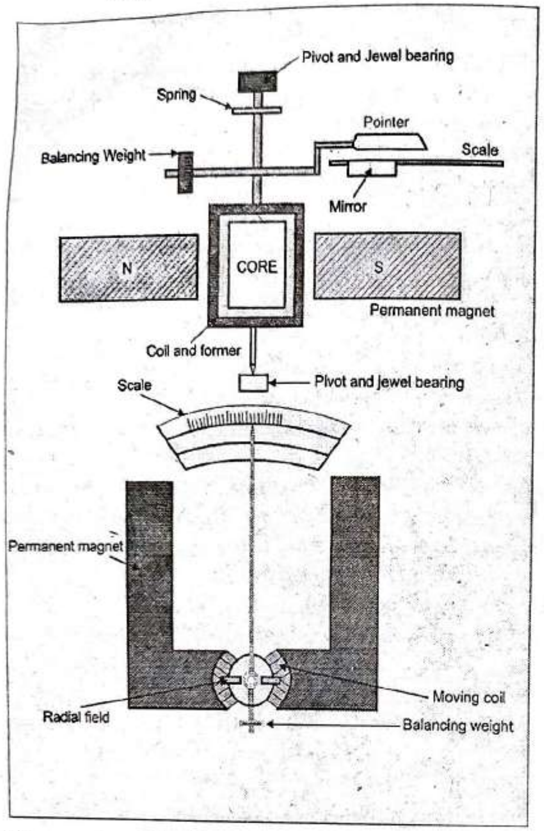
For the final steady state position,

$$T_d = T_c$$

Therefore $GI = K\text{Ø}$

So, $\text{Ø} = (G/K)I \text{ or } I = (K/G)\text{Ø}$

Thus the deflection is directly proportional to the current passing through the coil. The pointer deflection can therefore be used to measure current.



Working: When a current flow through the coil, it generates a magnetic field which is proportional to the current in case of an ammeter. The deflecting torque is produced by the electromagnetic action of the current in the coil and the magnetic field.

When the torques are balanced the moving coil will stop and its angular deflection represents the amount of electrical current to be measured against a fixed reference, called a scale. If the permanent magnet field is uniform and the spring linear, then the pointer deflection is also linear.

The controlling torque is provided by two phosphorous bronze flat coiled helical springs. These springs serve as a flexible connection to the coil conductors.

Damping is caused by the eddy current set up in the aluminum coil which prevents the oscillation of the coil.

Q.7. (a) Describe the construction of single phase induction energy meter. (6.5)

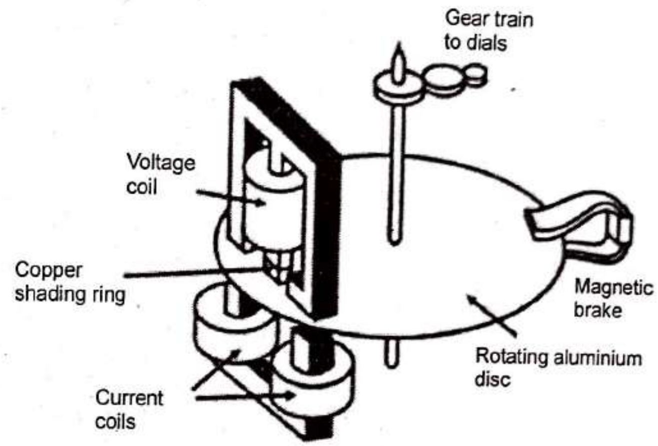
Ans. Single phase induction type energy meter is also popularly known as ***watt-hour meter***. Induction type energy meter essentially consists of following components:

1. Driving system
2. Moving system
3. Braking system and
4. Registering system

Driving system: It consists of two electromagnets, called "shunt" magnet and "series" magnet, of laminated construction. A coil having large number of turns of fine wire is wound on the middle limb of the shunt magnet.

This coil is known as "pressure or voltage" coil and is connected across the supply mains. This voltage coil has many turns and is arranged to be as highly inductive as possible. In other words, the voltage coil produces a high ratio of inductance to resistance.

This causes the current and therefore the flux, to lag the supply voltage by nearly 90 degree.



Watt-hour meter.

Single-phase induction kilowatt hour meter - Construction

An adjustable copper shading rings are provided on the central limb of the shunt magnet to make the phase angle displacement between magnetic field set up by shunt magnet and supply voltage is approximately 90 degree.

The copper shading bands are also called the power factor compensator or compensating loop. The series electromagnet is energized by a coil, known as ***"current" coil*** which is connected in series with the load so that it carry the load current. The flux produced by this magnet is proportional to, and in phase with the load current.

Moving system: The moving system essentially consists of a light rotating aluminium disk mounted on a vertical spindle or shaft. The shaft that supports the aluminium disk is connected by a gear arrangement to the clock mechanism on the front of the meter to provide information that consumed energy by the load.

The time varying (sinusoidal) fluxes produced by shunt and series magnet induce eddy currents in the aluminium disc.

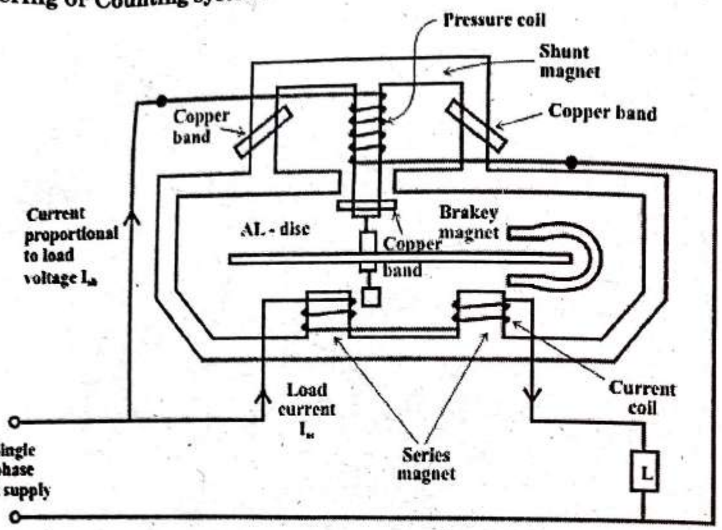
The interaction between these two magnetic fields and eddy currents set up a driving torque in the disc.

The number of rotations of the disk is therefore proportional to the energy consumed by the load in a certain time interval and is commonly measured in kilowatt-hours (kwh).

Braking system: Damping of the disk is provided by a ***small permanent magnet***, located diametrically opposite to the a.c magnets. The disk passes between the magnet gaps. The movement of rotating disc through the magnetic field crossing the air gap sets up eddy currents in the disc that reacts with the magnetic field and exerts a braking torque.

By changing the position of the brake magnet or diverting some of the flux there form, the speed of the rotating disc can be controlled.

Registering or Counting system



Single-phase induction kilowatt hour meter scheme

The registering or counting system essentially consists of gear train, driven either by worm or pinion gear on the disc shaft, which turns pointers that indicate on dials the number of times the disc has turned.

The energy meter thus determines and adds together or integrates all the instantaneous power values so that total energy used over a period is thus known.

Q.7. (b) Explain the operating principle and an electrodynamic type wattmeter. **(6)**

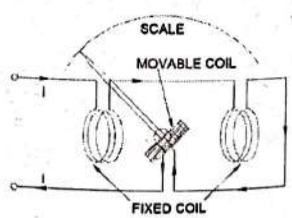
Ans. Electrodynamic types of instrument are used for the measurement of AC and DC quantities unlike PMMC instrument which can only be used for the measurement of DC quantity. This type of instrument is known as Electrodynamometer type instrument.

Construction of Electrodynamic Type instrument

An electrodynamic type instrument consists of two fixed coil, a moving coil, control spring, damping device and magnetic shielding arrangement.

Fixed Coil: Fixed coil is provided for the sake of production of magnetic field. This fixed coil is divided into two sections so that a uniform magnetic field may be achieved at the centre. Further, splitting up fixed coil in two section facilities passage of instrument's moving shaft.

Moving Coil: Moving coil serves the purpose of converting the actuating quantity into readable value of the scale. It is generally wound on a non magnetic metallic former. Metallic former shall never be used as it will lead eddy current generation due to changing flux. This eddy current will introduce inaccuracy as eddy current damping is not used in electrodynamic instrument.



Damping: Air friction damping is employed in electrodynamic type instrument. To provide air friction damping, a pair of aluminium vane is attached to the spindle at the bottom. These vanes move in a sector shaped chamber. Now you might ask, why didn't we provide eddy current damping by wounding moving coil on metallic former?

Thing is that, the magnetic field produced by the fixed coils are very weak because of air cored coil. Therefore an introduction of eddy current damping will distort the main magnetic field and hence will introduce appreciable inaccuracy.

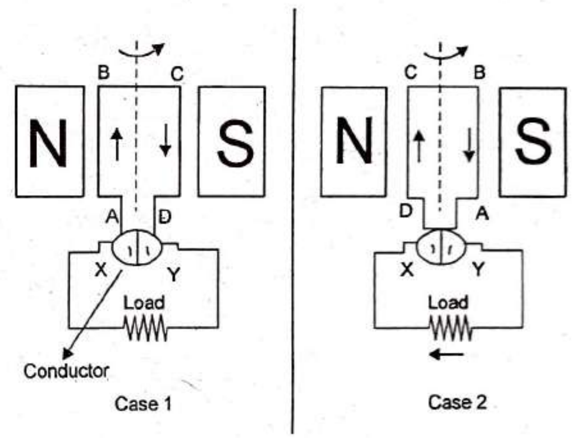
Shielding: The magnetic filed in electrodynamic type instrument is very week of the order of 0.005 to 0.006 Wb/m^2. Therefore it becomes very important to protect the instrument from the effect of external magnetic field. To provide magnetic shielding, normally electrodyneamic type instrument is enclosed in a high permeability alloy.

UNIT-IV

Q.8. (a) State the principle of operation of a DC machine and derive the expression for the em.f. generated. **(6.5)**

Ans. Working principle:

According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of DC generator. If the conductor is provided with the closed path, the induced current will circulate within the path. In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field. Thus, an electromagnetically induced emf is generated in the armature conductors. The direction of induced current is given by Fleming's right hand rule.



According to Fleming's right hand rule, the direction of induced current changes whenever the direction of motion of the conductor changes. An armature rotating clockwise and a conductor at the left is moving upward. When the armature completes a half rotation, the direction of motion of that particular conductor will be reversed to downward. Hence, the direction of current in every armature conductor will be alternating. If you look at the figure, the direction of the induced current is alternating in an armature conductor. But with a split ring commutator, connections of the armature conductors also gets reversed when the current reversal occurs. And therefore, we get unidirectional current at the terminals.

EMF Equation

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series.

Here,

Z = total numbers of conductor

A = number of parallel paths

Then,

Z/A = number of conductors connected in series

We know that induced emf in each path is same across the line

Therefore,

Induced emf of DC generator E = emf of one conductor × number of conductor connected in series.

Induced emf of DC generator is

$$e = \phi P \frac{N}{60} \times \frac{Z}{A} \text{ volts}$$

Simple wave wound generator

Numbers of parallel paths are only 2 = A

Therefore,

Induced emf for wave type of winding generator is

$$\phi \frac{PN}{60} \times \frac{Z}{2} = \frac{\phi ZPN}{120} \text{ volts}$$

Here, number of parallel paths is equal to number of conductors in one path *i.e.* P = A

Therefore,

Induced emf for lap-wound generator is

$$E_g = \frac{\phi ZN}{60} \times \frac{P}{A} \text{ volts}$$

Q.8. (b) Describe the methods to control the speed of induction motors. **(6)**

Ans. Methods of speed control of induction motor

The speed control of three phase induction motor from stator side are further classified as :

1. V / f control or frequency control.
2. Changing the number of stator poles.
3. Controlling supply voltage.
4. Adding rheostat in the stator circuit.

The speed controls of three phase induction motor from rotor side are further classified as:

1. Adding external resistance on rotor side.
2. Cascade control method.
3. Injecting slip frequency emf into rotor side.

(1) V / f control or frequency control - Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E \text{ or } V = 4.44\phi K.T.f \text{ or } \phi = \frac{V}{4.44KTf}$$

Where, K is the winding constant, T is the number of turns per phase and f is frequency. Now if we change frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor

and stator cores which will further cause increase in no load current of the motor. So, its important to maintain flux, ϕ constant and it is only possible if we change voltage. i.e if we decrease frequency, flux increases but at the same time if we decrease voltage flux will also decrease causing no change in flux and hence it remains constant. So, here we are keeping the ratio of V/f as constant. Hence its name is V/ f method. For controlling the speed of three phase induction motor by V/f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.

(2) Controlling supply voltage: The torque produced by running three phase induction motor is given by

$$T \propto \frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

In low slip region $(sX)^2$ is very very small as compared to R_2. So, it can be neglected. So torque becomes

$$T \propto \frac{sE_2^2}{R_2}$$

Since rotor resistance, R_2 is constant so the equation of torque further reduces to

$$T \propto sE_2^2$$

We know that rotor induced emf $E_2 \propto V$. So, $T \propto sV^2$.

From the equation above it is clear that if we decrease supply voltage torque will also decrease. But for supplying the same load, the torque must remains the same and it is only possible if we increase the slip and if the slip increases the motor will run at reduced speed. This method of speed control is rarely used because small change in speed requires large reduction in voltage, and hence the current drawn by motor increases, which cause over heating of induction motor.

Q.9. (a) Derive the em.f equation a single phase transformers. **(6)**

Ans.

$$\varnothing = \varnothing_m \sin \omega t$$

By Faraday's law of electromagnetic induction EMF induced is, for a single turn.

$$e = \frac{-d\varnothing}{dt}$$

For N, number of turn

$$e = \frac{-N\,d\varnothing}{dt}$$

$$e = N\left(\frac{-d\varnothing}{dt}\varnothing_m \sin \omega t\right)$$

$$= N\varnothing_m \cos \omega t$$

$$\omega = -N\varnothing_m\, 2\pi f \cos \omega t$$

$$e = \varnothing_m N.2\pi \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$e_{max} = N.\varnothing_m 2\pi f$$

$$E_{RMS} = \frac{e_{max}}{\sqrt{2}} = 4.44\, N\varnothing_m f$$

Primary induced emt,

$$E_1 = 4.44N_1 \varnothing_m f$$

$$E_2 = 4.44N_2 \varnothing_m f$$

Q.9. (b) List and explain the various Losses occurring in a transformer. **(6.5)**

Ans. The transfomer is a static machine and, therefore, there are no friction or windage losses. The various power losses occuring in a transformer are enumerated below:

1. **Iron or Core Losses:** Iron loss is caused by the alternating flux in the core and consists of hysteresis and eddy current losses.

(a) **Hysteresis Loss.** The core of a transformer is subjected to an alternating magnetizing force and for each cycle of emf a hysteresis loop is traced out. The hysteresis loss per second is given by the equation.

Hysteresis loss, $P_h = \eta' (B_{max})^x f v$ joules per second or watts

where f is the supply frequency in Hz, v is the volume of core in cubic metre. η' is the hysteresis coefficient, B_{max} is peak value of flux density in the core and x lies between 1.5 and 2.5 depending upon the material and is often taken as 1.6.

(b) **Eddy Current Loss:** If the magnetic circuit is made up of iron and if the flux in the circuit is variable, currents will be induced by induction in the iron circuit itself. All such currents are known as eddy currents.

Eddy current results in a loss of power, with consequent heating of the material.

The eddy current loss is given by equation

$$P_e = K_e(B_{max})^2 f^2 t^2 v \text{ watts or joules per second}$$

From the above equation for eddy current loss in a thin sheet it is obvious that eddy current loss varies (i) as the square of maximum flux density (ii) as the square of the frequency and (iii) as the square of thickness of laminations.

The hysteresis and eddy current losses depends upon the maximum flux density in the core and supply frequency. Since it has been determined that the mutual flux varies somewhat with the load (its variation being 1 to 3% from no load to full load), the core losses will very somewhat with the load its power factor, It may be emphasized here that core losses are assumed to remain constant from no load to full load, the variation in losses from no load to full load being very small and negligible.

These losses are determined from the open circuit test.

The input to the transformer with rated voltage applied to the primary and secondary open circuited is equal to the core loss.

These losses are minimized by using steel of high silicon constant for the core and by using very thin laminations (0.3 mm to 0.5 mm) insulated from each other either by insulating varnish or by layer of papers.

2. **Copper or Ohmic Losses.** These losses occurs due to ohmic resistance of the transformer windings. If I_1 and I_2 are the primary and secondary current respectively and R_1 and R_2 are the respective resistance of primary and secondary winding then copper losses occuring in primary and secondary winding will be $I_1^2R_1$ and $I_2^2R_2$ respectively. So total copper losses will be $(I_1^2 R_1 + I_2^2 R_2)$. These losses vary as the square of the load current or kVA. For example if the copper losses at full load are P_c then copper losses at one-half or one-third of full load will be $\left(\frac{1}{2}\right)^2 P_c$ or $\left(\frac{1}{3}\right)^2 P_c$, *i.e.*, $\frac{P_c}{4}$ or $\frac{P_c}{9}$ respectively.

Copper losses are determined on the basis of constant equivalent resistance R_{eq} determined from the short-circuit test and then corrected to 75°C (Since the standard operating temperature of electrical machines is taken 75° C).

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