Dear Engineers,

Mexa Training Centre started its humble beginning as a Maritime Training Institute with just one candidate. Today, we are proud to have trained 100 candidates in such a short time. Mexa aspires to be the pioneer in Maritime Training from India training the world. We at Mexa strongly believe in creating world class Engineers to become a dominant Maritime fraternity. We at Mexa Training Centre have been inspiring engineers to excel in their field. We are also involved in training with hands-on experience for those who have the desire to learn.

We are proud to release a verified set of answers for the benefit of all who are appearing for their Class IV exams. While we endeavor to compile answers for examination purpose, we would like to emphasize that understanding the subject matter and presenting it to surveyor in either the written format or oral delivery totally depends on the candidate and that alone will help you climb steadily and firmly on your career growth.

We want to ensure that the candidates are exposed to the correct answers. Please note that we will be releasing the online version soon so that the updates are available live on your mobile.

Having said the above, we would like to inform you that this edition will be charged minimum for printing costs and courier charges alone. It would be kind of you to not replicate the book.

- ***Author***
Mexa Training Centre

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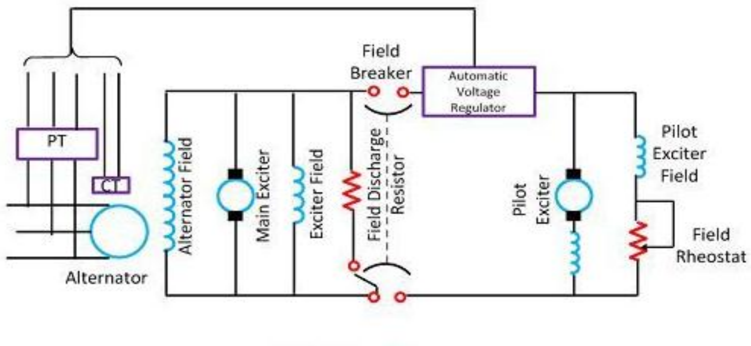
AC Generator

- **Notes:**

(a) What is the meaning of excitation in an alternator? (6)
(b) Explain a brushless alternator with an insight on how the excitation is achieved in these alternator. (10)

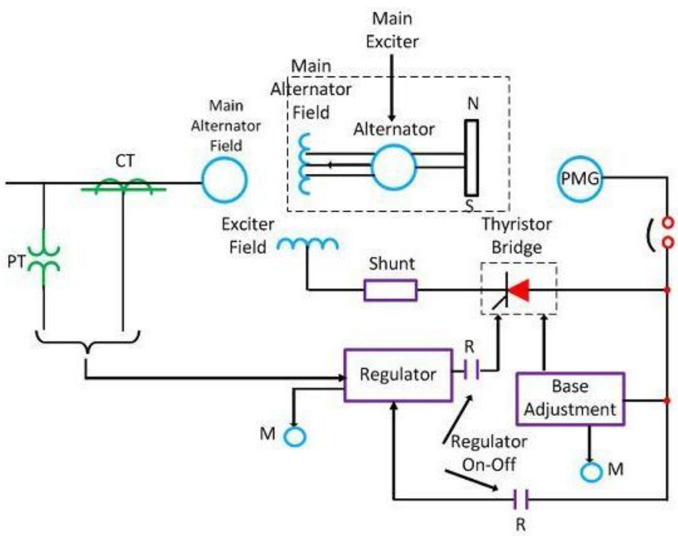
Dec 2024

(a) Excitation in an alternator refers to the process of supplying direct current (DC) to the field windings of the rotor to produce the magnetic field required for electromagnetic induction. This magnetic field interacts with the stator windings to induce an alternating current (AC) output. The strength of the excitation current directly affects the magnetic field strength and hence controls the voltage generated by the alternator.
In modern systems, an automatic voltage regulator (AVR) adjusts the excitation current automatically to maintain stable output voltage despite varying load conditions.



DC Excitation System

(b) A brushless alternator is a type of electrical generator that produces alternating current (AC) without the need for brushes and commutators.



Brushless Excitation System

Rotor: Instead of using brushes and a commutator, a brushless alternator has a rotor with permanent magnets or electromagnets. These magnets generate a rotating magnetic field when electricity is supplied to them.
Stator: The stator consists of coils of wire arranged around the rotor. As the magnetic field of the rotor rotates, it induces an alternating current in the stator windings through electromagnetic induction.
Rectifier: The alternating current produced in the stator windings is then converted into direct current (DC) by a rectifier assembly, typically consisting of diodes. This DC is necessary for the excitation of the rotor's magnets.

Excitation: The DC is fed to the rotor's electromagnets or permanent magnets, creating a steady magnetic field. This field interacts with the rotating magnetic field of the rotor, inducing a three-phase AC current in the stator windings.
Output: The threephase AC output from the stator windings is then available for use in powering electrical devices or for distribution in an electrical grid.

(a) Sketch a circuit diagram for an automatic voltage regulator illustrating how the A.V.R. utilizes a silicon-controlled rectifier to control the excitation system for an alternator. (10)
(b) Describe how the A.V.R. monitors output and controls the excitation system. (6)

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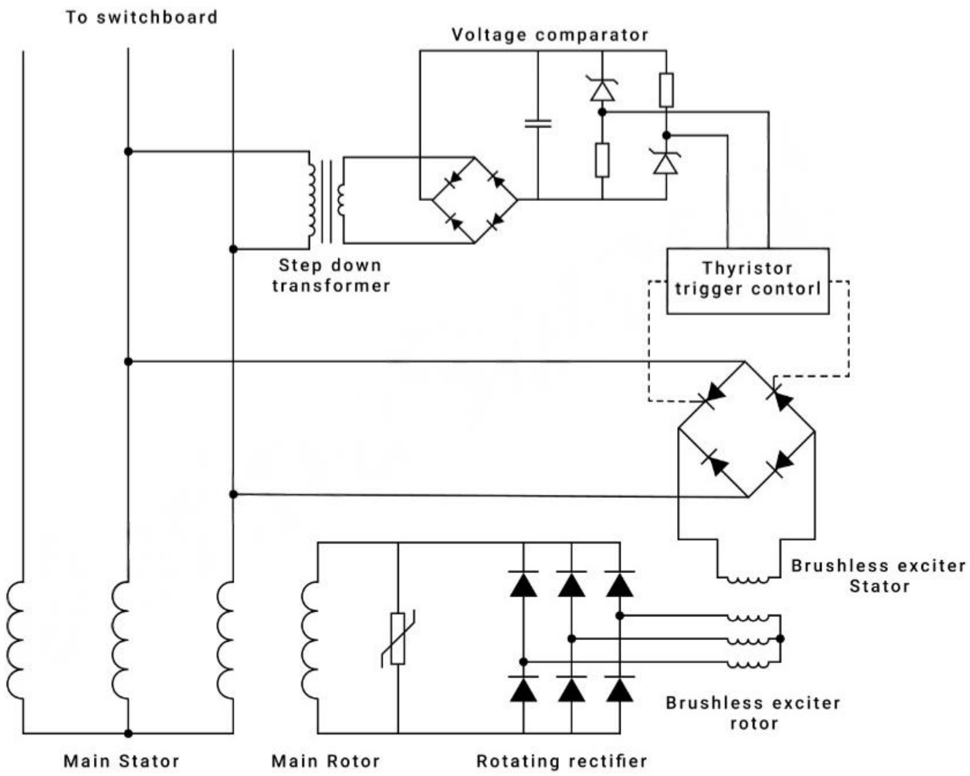
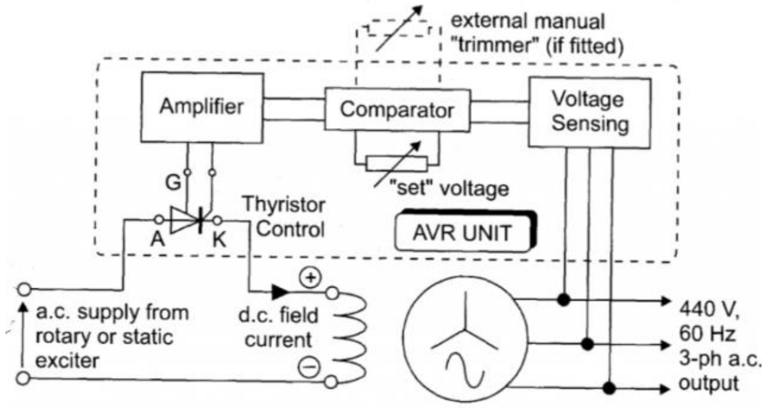
(a) The terminal voltage is sensed by a 3-ph star-delta stepdown transformer and rectifier to D.C by a 3-ph bridge rectifier bank and smoothened by an L-C filter to represent the actual terminal voltage in a reduced D.C form. This voltage is compared in a Zener reference bridge circuit with the desired voltage provided by the Zener breakdown voltage so that the output gives the error or deviation between the two (voltage difference between actual and desired value). This error voltage is utilised for the thyristor trigger control in the diode bridge. This thyristor diode bridge is provided with an A.C supply and the output depends on the conduction period of the thyristor which is triggered by the error voltage as mentioned earlier. The output from the thyristor diode bridge goes to the A.C exciter field of the alternator which in turn includes A.C voltage in A.C exciter 3-ph armature winding. This voltage is rectified by a bridge rectifier mounted on the rotor shaft and finally provides excitation for the main alternator field winding. This will generate a 3-ph AC voltage in the main armature winding.

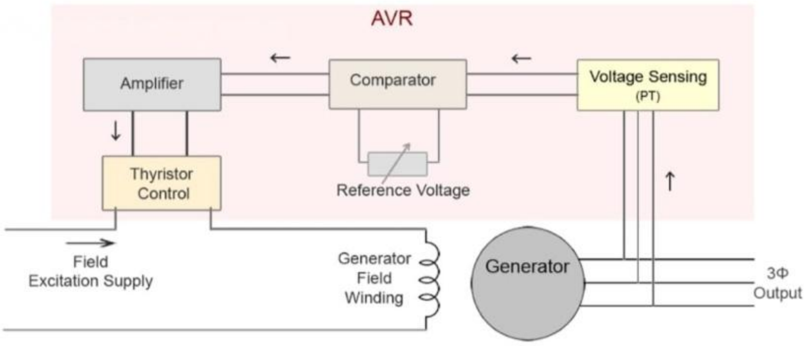


(b) The magnetic field crossing conductors produce relative motion between the two. The magnetic field is created by the field windings of the generator. The conductors are the armature windings of the generator. The relative motion of the magnetic field across the conductors is provided by the rotor shaft. The more magnetic field lines cross conductors the more current is induced in the conductors. The way you get more magnetic field is to put more current through the magnetic field windings so if you want more voltage induced you need to apply more current to the field windings, and If output voltage drops, the AVR applies more current to the field windings, if output voltage increases because of reduce load the AVR reduces current to the field windings

An Automatic Voltage Regulator (AVR) regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter.

The AVR controls the alternator output voltage by automatic adjustment of the exciter stator field strength. The AVR provides closed-loop control by sensing the alternator output voltage at the main stator windings and adjusting the exciter stator field strength.





(a) List the parts of an alternator fitted with temperature alarms. (6)
(b) Explain why heaters are fitted to an Alternator. (6)
(c) Explain the function of an automatic voltage regulator. (4)

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(a) Parts of an Alternator:

Stator winding: The stator winding is the stationary part of the alternator and is responsible for generating electricity when it is exposed to a rotating magnetic field. Temperature sensors may be installed in the stator winding to monitor its temperature.

Rotor: The rotor is the rotating part of the alternator and is responsible for providing a rotating magnetic field. Temperature sensors may be installed in the rotor to monitor its temperature.

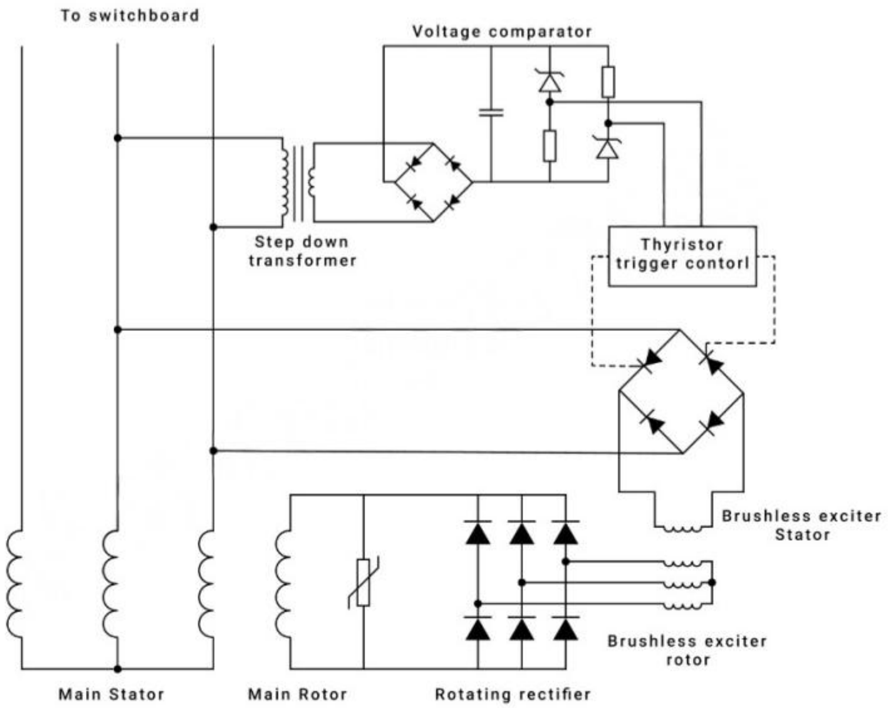
Bearings: Bearings support the rotation of the rotor and allow it to spin freely. Temperature sensors may be installed in the bearings to monitor their temperature.

Voltage regulator: The voltage regulator controls the output voltage of the alternator by regulating the field current ensuring that it stays within a specific range. Temperature sensors may be installed in the voltage regulator to monitor its temperature.

Cooling system: The alternator may be fitted with a cooling system, such as a fan or water-cooling system, to keep it at a safe operating temperature. Temperature sensors may be installed in the cooling system to monitor its temperature.

(b) Heaters are fitted to alternators to prevent the formation of moisture on the stator winding insulation due to temperature differences between the winding and ambient air. This moisture can cause insulation breakdown and lead to electrical failures. The heaters are typically placed in the alternator's ventilation system and are activated when the alternator is not running so that the winding temperature remains above the dew point. This helps to reduce the risk of moisture buildup and ensures the reliability of the alternator.

(c) A simplified circuit diagram of a typical AVR is shown below. The generator terminal voltage is transformed to a suitable level, rectified and smoothed within the voltage measurement element, it is then fed into the comparator circuit consisting of two zener diodes and two resistors.
The comparator circuit produces an error signal which is fed into the thyristor trigger control unit. This signal controls the output of a pulse generator circuit, to fire a thyristor circuit and adjust the excitation level in the generator exciter field. In this way, generator voltage is restored to its correct level and the error voltage returns to near zero.



(a) What is the purpose of AVR in an alternator? (6)
(b) With the aid of a simple circuit diagram explain the basic working of a brushless alternator. (10)

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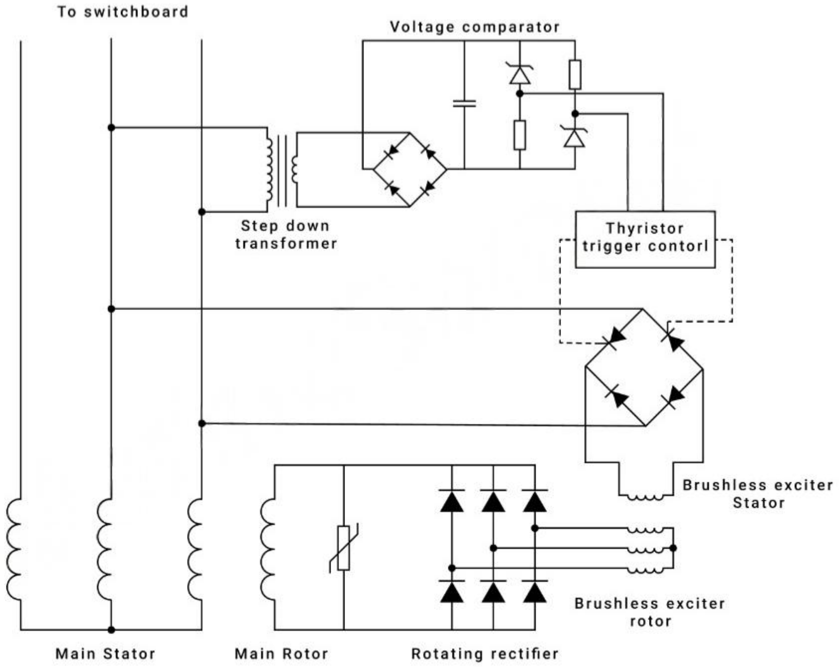
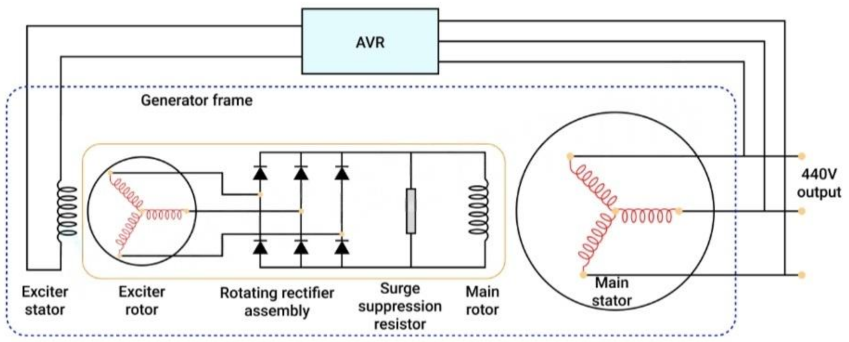
(a) An automatic voltage regulator (AVR) is a device that is used to regulate the output voltage of an electrical generator. It does this by automatically adjusting the excitation current of the generator's field winding, which in turn adjusts the magnetic field strength and the output voltage of the generator. The AVR is typically connected to a feedback control system, which uses sensors to measure the output voltage of the generator and compare it to a reference voltage. When the output voltage deviates from the reference voltage, the AVR adjusts the excitation current to bring the output voltage back to the desired level. The AVR helps to maintain a stable and consistent output voltage, which is important for ensuring the proper operation of the electrical equipment



(b) A brushless alternator is a type of electrical generator that produces alternating current (AC) without the need for brushes and commutators.



Rotor: Instead of using brushes and a commutator, a brushless alternator has a rotor with permanent magnets or electromagnets. These magnets generate a rotating magnetic field when electricity is supplied to them.
Stator: The stator consists of coils of wire arranged around the rotor. As the magnetic field of the rotor rotates, it induces an alternating current in the stator windings through electromagnetic induction.
Rectifier: The alternating current produced in the stator windings is then converted into direct current (DC) by a rectifier assembly, typically consisting of diodes. This DC is necessary for the excitation of the rotor's magnets.
Excitation: The DC is fed to the rotor's electromagnets or permanent.
A brushless alternator is a type of electrical generator that produces alternating current (AC) without the need for brushes and commutators.
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Excitation: The DC is fed to the rotor's electromagnets or permanent.

(a) Sketch a schematic arrangement of a three phase alternator with star connection. (6)
(b)A 500V, 3-phase, star-connected alternator supplies a star-connected induction motor which develops 45kW. The efficiency of the motor is 88 percent and the power factor is 0.9 (lagging). The efficiency of the alternator at this load is 80 percent. Determine (10)
(i) The line current
(ii) The power output of the alternator
(iii) The output power of the prime-mover

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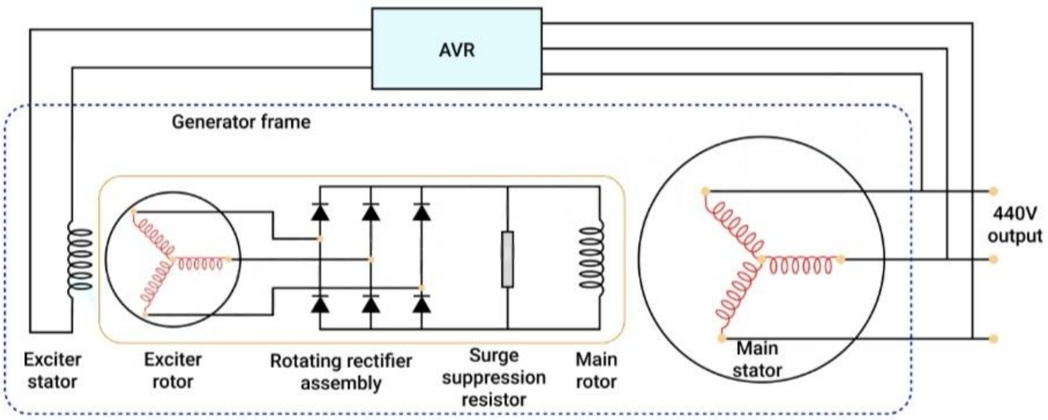
(a)



(b) Given:

Motor output = 45kW

$\eta m = 88$

$\cos \phi = 0.9$

$\eta_A = 80$

$\eta_m = \frac{(O / P)}{(I / P)}$

Input = $\frac{45000}{88} * 100$

= 51.136 kW

We know that P = $\sqrt{3}VI \cos \phi$

(i) Line current, I= $\frac{P}{\sqrt{3}*500*0.9}$ = $\frac{51136.36}{\sqrt{3}*500*0.9}$ = 65.6A

(ii) Alternator O/P = Motor I/P = 51136W

(iii) η_A= 80

I/P of Alternator= $\frac{51136}{80}$ *100

Prime mover output = 63920 W

(a) Compare Direct current with Alternating current. (6)
(b) A four-pole generator has a flux of 12mWb/pole. Calculate the value of e.m.f. generated in one of the armature conductors, if the armature is driven at 900 rev min (10)

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a) Comparision of DC with AC
Direction of Current:
- DC: Electrons flow in one direction, maintaining a constant polarity.
- AC: Electrons periodically change direction, resulting in a reversal of polarity.

Voltage Polarity:
- DC: Voltage remains constant with a fixed polarity.
- AC: Voltage alternates, switching between positive and negative polarities.

Power Transmission:
- DC: Suitable for short-distance power transmission.
- AC: Efficient for long-distance power transmission due to the ability to change voltage levels using transformers.

Power Losses:
- DC: Power losses are more significant in long-distance transmission.
- AC: Power losses are comparatively lower over long distances.

Transmission Efficiency:
- DC: High-voltage direct current (HVDC) systems improve efficiency for long-distance transmission.
- AC: Better suited for local distribution.

Transformer Usage:
- DC: Transformers cannot be used for direct current; conversion to AC is required.
- AC: Transformers efficiently change voltage levels in AC systems.

Devices and Appliances:
- DC: Batteries, electronic devices, and some motors operate on DC.
- AC: Common in household appliances, lighting, and most electric motors.

Frequency:
- DC: Frequency is not applicable as it involves a constant flow.
- AC: Frequency represents the number of cycles per second (Hertz).

Safety:
- DC: Generally considered safer for low-voltage applications.
- AC: High-voltage AC can be more dangerous due to the potential for stronger shocks.

Generation:
- DC: Generated by batteries, solar cells, and certain types of generators.
- AC: Produced by most power plants for grid distribution.

Waveform Shape:
- DC: Has a constant, unidirectional waveform.
- AC: Waveform can vary (e.g., sinusoidal, square, triangular).

(b) In 1 revolution a conductor cuts

$4 \times 12 \times 10^{-3} = 0.048Wb$

Time of 1 revolution of the armature= $\frac{1}{900}$ minutes

$= \frac{60}{900}$ or $\frac{1}{15}$ seconds

∴ Rate of cutting flux =$\frac{\text{Flux cut per revolution}}{\text{time taken to complete a revolution}}$

Thus E = $\frac{0.048}{1/15}$

= 0.048 x 15

= 0.72 volts/conductor

(a) List the different combinations of motor-generators that are often made, to suit load conditions. (6)
(b) A diesel engine has a measured indicated power of 7.5 kW and a mechanical efficiency of 85 percent. It drives a generator which supplies a lamp load at 110V.
How many 60W lamps can be supplied, if the efficiency of the generator is measured to be 88 percent? Find the total load current. (10)

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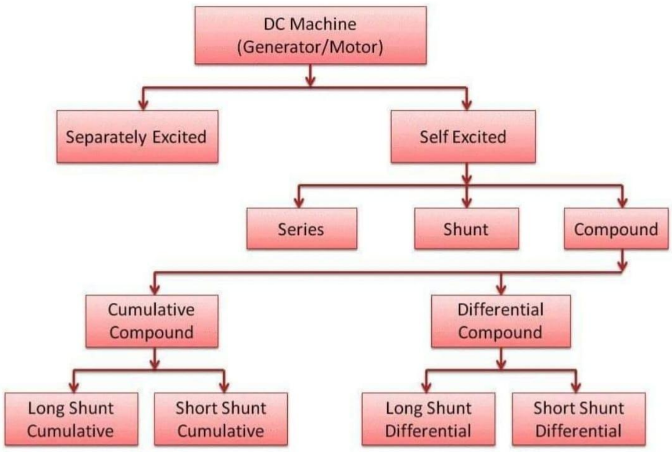
(a)



(b) Output of the engine = input × efficiency

$7.5 * \frac{85}{100} = 6.375kW$

At the coupling between the engine and generator, it can be assumed that there is no loss of energy, so the power input to the generator must be the power output of the engine as follows

Output of engine = input to gen = 6.375kW

∴ Gen output = input* efficiency

$6.375 * \frac{88}{100} = 5.61kW$

No. of lamps = $\frac{Gen\ output}{\text{load of lamp}}$

$= \frac{5610}{60} = 93.5$

We say 93 lamps

Load current= $\frac{GEN\ POWER\ OUTPUT}{VOLTAGE}$

$= \frac{5610}{110} = 51A$

(a) What is a direct connected alternator (8)
(b) What is the difference between direct connected and direct coupled units. (8)

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(a) A direct connected alternator refers to an alternator that is directly connected to the engine crankshaft. In this configuration, the alternator and the engine share the same shaft, and the alternator rotates at the same speed as the engine. The rotation of the engine crankshaft drives the alternator to generate electrical power.
In other words, A direct connected alternator refers to an alternator that is directly connected to the prime mover, typically an engine, without any intermediary components like belts or gears. This direct connection ensures efficient power transmission from the prime mover to the alternator, often used in applications where space is limited or where simplicity and efficiency are prioritized.

(b) The terms "direct connected" and "direct coupled" are often used interchangeably, but there can be a slight difference in their meanings:
Direct Connected: In the context of alternators, direct connected refers to the arrangement where the alternator is physically connected to the engine's crankshaft, sharing the same shaft and rotating at the same speed as the engine. It implies a mechanical connection between the engine and the alternator.

Direct Coupled: Direct coupled can have a broader meaning and can refer to a system where the alternator is connected to the engine using a flexible coupling or a drive mechanism (gears) other than a direct mechanical connection. In this case, the alternator and the engine may not share the same shaft or rotate at the same speed. The coupling or drive mechanism allows the transfer of power from the engine to the alternator without a direct mechanical connection.

- Direct connected alternators are typically less expensive than direct coupled alternators.
- Direct connected alternators are typically less efficient than direct coupled alternators.
- Direct connected alternators are typically more reliable than direct coupled alternators.
- Direct connected alternators are typically easier to maintain than direct coupled alternators.

AC Motor

- **Notes:**

(a) What are the differences between synchronous and induction motor? (6)
(b) What do you understand by the term 'slip'? (4)
(c) How do you check continuity of a circuit? Explain the process in brief. (6)

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(a) Difference between Synchronous motor and induction motor:

1. Speed:

- **Synchronous Motor:** Operates at a constant speed that matches the supply frequency (synchronous speed). It does not vary with load.
- **Induction Motor:** Operates at a speed slightly less than the synchronous speed (this difference is called slip).

2. Power Supply:

- **Synchronous Motor:** Requires an external DC source to excite the rotor.
- **Induction Motor:** Does not require an external power source; the rotor current is induced by electromagnetic induction.

3. Starting:

- **Synchronous Motor:** Needs additional mechanisms (like a separate motor or damper windings) to start because it cannot start on its own.
- **Induction Motor:** Can start directly when connected to the power supply.

4. Efficiency:

- **Synchronous Motor:** More efficient at constant loads.
- **Induction Motor:** Slightly less efficient due to slip and rotor losses.

5. Applications:

- **Synchronous Motor:** Used where constant speed is essential (e.g., clocks, compressors, and power factor correction).
- **Induction Motor:** Used in industries for pumps, fans, and conveyors due to its simple design and ruggedness.

(b) 'Slip' in an induction motor:

- **Slip** refers to the difference between the theoretical motion and actual motion of mechanical components. A common example is in **electric motors**:
- **In an induction motor**, **slip** is the difference between the **synchronous speed** (speed of the magnetic field) and the **rotor speed**.
- It is usually expressed as a percentage:

$$\text{Slip} = \frac{Ns - Nr}{Ns} \times 100$$

where:

Ns = Synchronous speed
Nr = Rotor speed

(c) To check the continuity of a circuit, you can use a multimeter to measure the resistance between two points in the circuit. If the circuit is continuous, the multimeter will beep or display a low resistance reading.

Steps

1. Ensure the circuit is off.
2. Set the multimeter to the continuity mode or to measure resistance (Ω)
3. Connect the red probe to the "V" socket and the black probe to the "COM" socket.

4. Connect the probes to the ends of the circuit.
5. Touch the probes together to test the connections.
6. If the circuit is continuous, the multimeter will beep or display a low resistance reading, usually zero ohms (Ω)

(a) Sketch the following types of electric motor connections: (8)
(i) A star connection
(ii) A delta connection
(b)Explain how and why star and delta connections are combined to produce a Star / Delta starter for an electric motor. (8)

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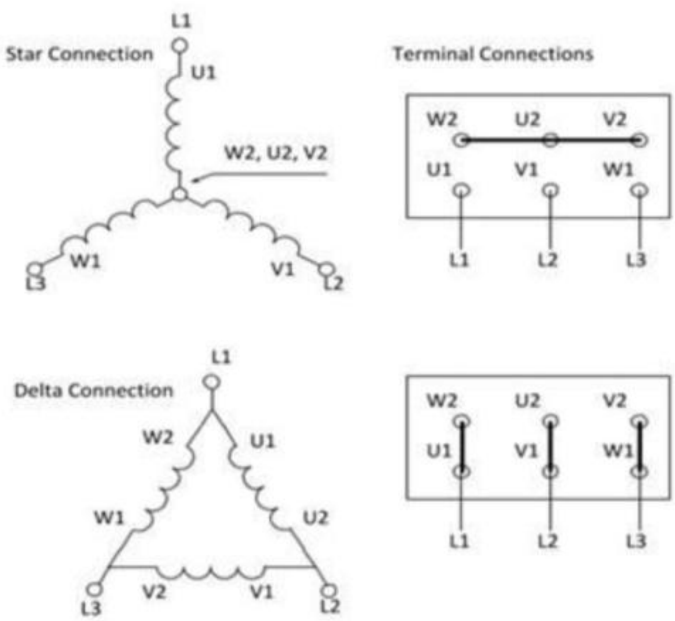
(a) Star and Delta connection:



(a) Explanation of how and why star delta connections are combined to produce star delta starter:

- This starter reduces both starting torque and starting current during the starting period.
- Both end connections of the 3 windings of the induction motor are usually brought out to facilitate the star delta starting scheme.
- Suitable change-over provision from star to delta connection is available in the starter assembly
- These change-over contacts enable the 6 ends to be star-connected for starting and then reconnected in delta after the rotor comes up to speed.
- In Star connection, phase voltage equals 1/√3 Line voltage; in delta connection, phase voltage equals line voltage.
- During starting, the contactor closes and stator winding is connected in star.
- The voltage applied to the individual motor windings is therefore reduced by a factor of 1/√3 (57.8%). Hence, the starting torque is reduced by one-third
- The starting current will be one-third of what it would be in DOL starting.
- This is because torque is proportional to the square of applied voltage and current is proportional to the applied voltage
- When the motor reaches normal running speed, the contactor KM1 opens and KM2 closes.
- Now stator winding is connected in delta.

(a)Differentiate between squirrel cage and wound rotor motors, of the three phase a.c. induction type, in respect of the following: (16)
(a) Rotor construction
(b) Torque characteristics
(c) Speed variation

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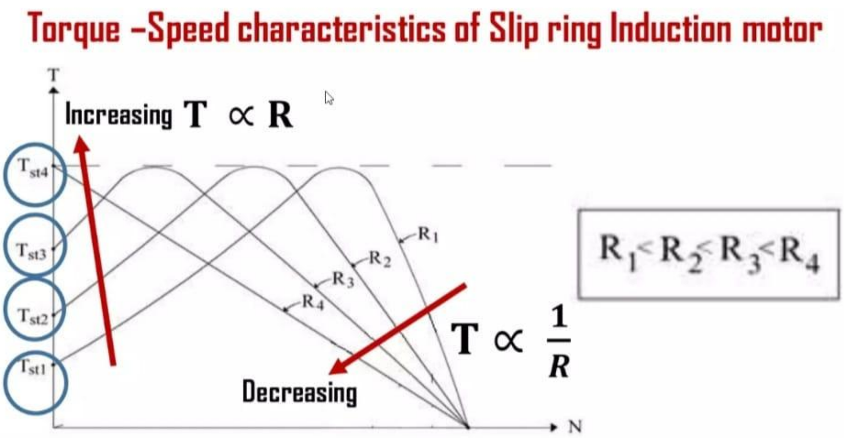
(a) Differences between squirrel cage and wound rotor motors(a) Rotor Construction
Squirrel Cage Motor:
- Rotor consists of aluminum or copper bars embedded in a laminated steel core.
- These bars are short-circuited at both ends using end rings, forming a cage-like structure.
- Construction is simple, robust, and cost-effective.

Wound Rotor Motor:
- Rotor contains a three-phase winding similar to the stator winding.
- The winding is connected to slip rings and brushes.
- Slip rings enable connection of external resistors to the rotor, allowing for control of rotor current.
- Construction is more complex and expensive compared to squirrel cage motors.

(b) Torque Characteristics
Squirrel Cage Motor:
- Provides high starting torque (150%–200% of full-load torque).
- Exhibits low slip at full load, resulting in constant speed operation.
- Ideal for applications requiring high starting torque.

Wound Rotor Motor:
- Has high starting torque compared to squirrel cage motors, due to the additional resistance in the rotor circuit.
- Allows for adjustable torque by varying external resistance.
- Suitable for high inertia loads and applications needing smooth starting and controlled acceleration.
- A wound rotor induction motor is primarily used in applications where high starting torque and variable speed control are required, such as in cranes, hoists, large pumps, crushers, large grinding mills in cement and mining industries, punch presses, and other heavy-duty machinery with high inertia loads due to its ability to control starting current through external rotor resistance adjustments.
- By adjusting the resistance in the rotor circuit, the motor speed can be controlled, making it useful in applications requiring precise speed regulation.



(c) Speed Variations
Squirrel Cage Motor:

- Speed is almost constant at a fixed frequency due to low slip.
- Speed regulation is poor, with minor variations under load.
- Limited speed control, typically achieved through supply voltage variation or by using variable frequency drives (VFDs).

Wound Rotor Motor:

- Allows wide speed variation by adjusting external resistance connected to the rotor winding.
- Offers good speed regulation with proper control methods.
- Capable of adjustable speed, making it suitable for applications requiring speed control.

With reference to the protection of electric motors explain EACH of the following:
(a) Fuse back up protection (6)
(b) How a motor fitted with fuse back up protection may exceed its rated temperature without being tripped by the primary protection (6)
(c) The value of current rating at which the over current relay should be set (4)

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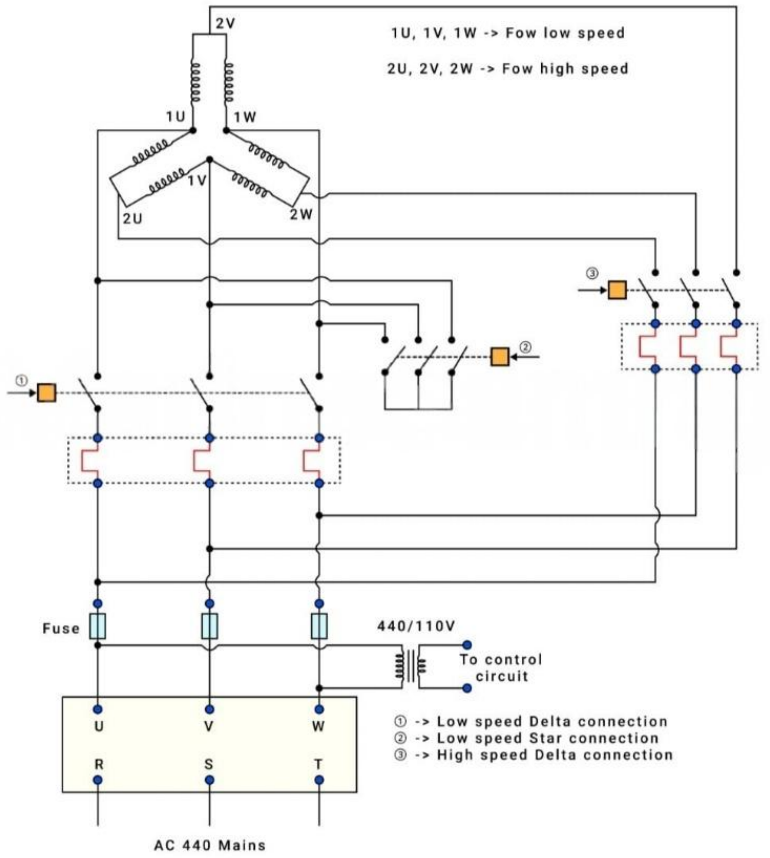

(a) Fuse backup protection is commonly used to protect electric motors from overcurrent conditions. In this setup, fuses act as primary protection devices, while overcurrent relays serve as secondary backup protection. While fuses are effective at quickly interrupting the circuit during severe overcurrent situations, they have limitations when it comes to mild overloads or prolonged overcurrent conditions that are below their melting current rating.

(b) In scenarios where the motor experiences an overload or overcurrent condition just below the fuse's melting current rating, the fuse may not blow, allowing the current to continue

flowing through the circuit. This situation arises because the fuse is designed to withstand currents below its melting point without tripping. Consequently, the motor continues to operate without any interruption from the primary protection.
However, if the overcurrent relay, which acts as the secondary protective device, is not properly calibrated or set at a higher current rating, it may fail to detect the mild overload. The overcurrent relay is supposed to sense the current level and trip the motor to prevent damage. But if its threshold is set too high, it may not trigger even in the presence of an overload. As a result, the motor may operate beyond its rated capacity, leading to overheating and potential damage.

(c) It is the value of the current above which the relay operates. For example, if the relay is set at 1 A, it operates when the current exceeds 1 A. A number of tappings are provided on the relay current coil that is used to alter the number of turns of the coil using plugs for the current setting.
The current setting is either given in ampere or as percentages of rated current. An over-current relay used for line-to-line fault is set at 50% to 200% of rated current in steps of 25%, and for earth fault, it is set at 20% to 80% of rated current in steps of 10%.
If the relay is set at 75% for line-to-line fault, it operates when the current exceeds 0.75 A. If the relay is set at 40% for earth fault, it operates when the current exceeds 0.4 A.

If the motor terminal markings are unknown how would you identify the start, run and common terminal connections? (16)

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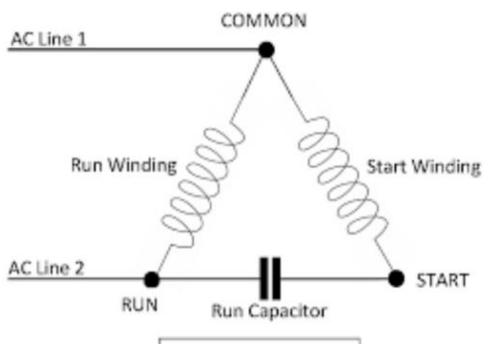
Start, Run and Common terminals belong to single phase induction motor where a parallel starter winding with a series capacitor (as shown in figure) is used to produce rotating magnetic field and help motor generate net torque in one direction, especially while starting.



PSC Motor Diagram

Procedure to find out the terminals:

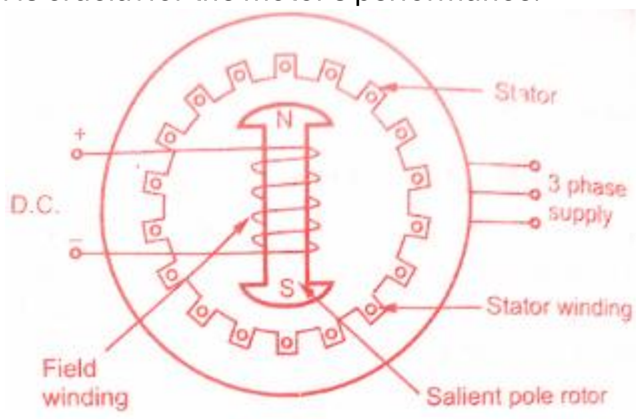
- Use a well calibrated multimeter to check insulation between earth and all terminals individually.
- Now with the multimeter knob on resistance setting, check and note the values of resistance between all three terminals.
- The terminals having lowest resistance between them are Common and Run , so mark the left out terminal as the START terminal.
- The terminals having highest resistance between them are run and start, since start is already identified then mark the other one here as RUN.
- Now the remaining terminal is the COMMON terminal.
- Verify Rotation Direction: After identifying the start, run, and common terminals, you can verify the rotation direction of the motor. Energize the motor temporarily and observe the

direction of rotation. If the rotation is incorrect, swap any two of the three wires to reverse the direction.

(a) Explain the working principle of a synchronous motor. (6)
(b) What are the starting methods of a synchronous motor? (4)
(c) List the merits and demerits of synchronous motor over induction motor (6)

Nov 2023

(a) Working Principle of a Synchronous Motor:
A synchronous motor operates based on the principle of maintaining synchronism with the rotating magnetic field. In a synchronous motor, the stator is equipped with a 3-phase armature winding connected to a balanced 3-phase power supply. The rotor comprises a set of salient poles excited by direct current (DC), resulting in alternating North and South poles. The rotor is designed to rotate at synchronous speed, which is directly related to the frequency of the power supply and the number of poles in the machine. The key feature is the synchronization between the rotor and the rotating magnetic field, ensuring that the rotor follows the field at synchronous speed, aligning its poles with the stator poles. This synchronous operation is crucial for the motor's performance.



(b) Synchronous motors are not self-starting due to their inherent nature. Various methods are employed for starting:

Use of a Induction(Pony)Motor:
- A small induction motor, known as a pony motor,is mounted on the same shaft and is used to bring the rotor close to synchronous speed.

Using a DC Machine/Source:
- The synchronous motor can be started as a DC motor by providing DC supply to the rotor.

Damper Windings:
- Damper windings are basically squirrel cage windings embedded in the rotor poles, which allows the motor to start like an induction motor and then pull into synchronism when the rotor windings are energized.

(c) Merits and Demerits of Synchronous Motor over Induction Motor:
Merits:
- Synchronous motors can operate with a leading or lagging power factor, and this power factor can be controlled by adjusting the excitation.
- Synchronous motors are generally more efficient than induction motors of the same rating.
- Synchronous motors operate at a constant speed, making them suitable for applications requiring precise speed control.

- Suitable for applications where constant speed and power factor correction are critical, such as in power plants.
- Demerits:
- Synchronous motors are more expensive than induction motors of the same rating.
- The construction of synchronous motors is more complicated compared to induction motors.
- Synchronous motors are not self-starting and require additional means for starting.
- Synchronous motors have relatively lower starting torque compared to induction motors.

(a) Name the three main types of a.c. motor and explain the use to which they are put in marine engineering. (6)
(b) A four pole motor is fed at 440 V and takes a armature of 50 A. The resistance of the armature circuit is 0.28 ohm. The armature winding is wave connected with 888 conductors and the useful flux per pole is 0.023 wb. Calculate the speed. (10)

Dec 2023 | Mar 2023 | Sep 2022

(a) 3-Φ Sq. cage induction motor (large)
- Main S.W. pump motor
- Main L.O. pump motor
- Main J.C.W. pump motor

3-Φ synchronous motor (large)
- Main electrical propulsion motor
- Bow thruster motor
- Synchronous motor acting as synchronous condenser in the shaft generator system

Small 1-Φ syn motor
- Radar motor
- Gyrocompass motor
- Clear glass motor

(b) Given:
Poles, P = 4
Volt, V = 440 V
Current, Ia = 50 A
Resistance, Ra = 0.28 Ω
Conductors, Z = 888
Flux per pole, ϕ = 0.023 Wb
Speed, N = ? rpm
Eb = V − Ia × Ra
= 440 − 50 × 0.28
= 426 V

$$Eb = \frac{(\phi \times P \times N \times Z)}{(60 \times A)}$$ (A = 2 for wave connected)

$$426 = \frac{(0.023 \times 4 \times N \times 888)}{(60 \times 2)}$$

$$426 = \frac{(81.648 \times N)}{120}$$

$$N = \frac{(426 \times 120}{81.648})$$

N = 625.7
N = **626 rpm**

Write short notes on:
(a) Short circuit protection to Induction motors (8)
(b) Overload protection to induction motors. (8)

Sep 2023

(a) Short circuit protection for an induction motor:

1. **Fuses:** Fuses are the simplest form of protection against short circuits. They are placed in series with the motor circuit and will blow (break the circuit) when excessive current flows due to a short circuit. Fuses need to be selected carefully to match the motor's starting and running currents.
2. **Circuit Breakers:** Circuit breakers are another common form of protection. They operate similarly to fuses but can be reset after they trip. They offer more convenience than fuses but may be slower to respond to short-circuit faults.
3. **Thermal Overload Relays:** These devices protect the motor against overloads and short circuits. They measure the motor's current and temperature and trip the circuit if they detect abnormal conditions. Thermal overload relays provide a more sophisticated protection mechanism, taking into account both current and temperature.
4. **Motor Protection Relays:** These are specialized devices designed to protect induction motors against various faults, including short circuits. They monitor parameters such as current, voltage, and phase balance and can trip the circuit quickly in case of a short circuit or other fault.

(b) Overload protection is crucial for induction motors to prevent damage caused by excessive heat buildup due to prolonged operation at high currents. Here are some common methods of providing overload protection for induction motors:

- **Thermal Overload Relays:** These devices monitor the current flowing through the motor windings and trip the circuit if the current exceeds a preset threshold for a certain period. They contain a bimetallic strip or other temperature-sensitive elements that respond to the heat generated by the current. Thermal overload relays are typically integrated with motor starters or contactors.
- **Electronic Overload Relays:** These relays use electronic circuits to monitor the current and provide more precise and adjustable overload protection compared to thermal overload relays. They offer features such as adjustable trip settings, phase imbalance protection, and communication capabilities for integration with control systems.
- **Motor Protection Relays:** Motor protection relays offer comprehensive protection for induction motors, including overload protection. In addition to monitoring current, they may also monitor parameters such as voltage, power factor, phase sequence, and phase imbalance to provide more accurate and reliable protection.
- **Inherent Motor Protection:** Some motors have built-in protection features, such as built-in thermal sensors embedded in the motor windings. These sensors can detect temperature rise and trigger an alarm or trip the motor to prevent damage.
- **Current Sensing Devices:** Current sensors or transducers can be installed in the motor circuit to monitor the current continuously. These sensors can provide feedback to a control system, which can then take appropriate action to protect the motor in case of overload conditions.
- **Fuse Protection:** While primarily used for short circuit protection, appropriately sized fuses can also provide some level of overload protection for induction motors. However, they are not as precise or adjustable as dedicated overload protection devices.

With reference to the protection of electric motors explain EACH of the following in relation to Fuse back up protection:
(a) How a motor fitted with fuse back up protection may exceed its rated temperature without being tripped by the primary protection (8)
(b) The value of current rating at which the over current relay should be set. (8)

Jul 2023

(a) Fuse backup protection is a common method used to protect electric motors from overcurrent conditions. In this setup, fuses act as primary protection devices, while overcurrent relays serve as secondary backup protection. While fuses are effective at quickly interrupting the circuit during severe overcurrent situations, they have limitations when it comes to mild overloads or prolonged overcurrent conditions that are below their melting current rating.
In scenarios where the motor experiences an overload or overcurrent condition just below the fuse's melting current rating, the fuse may not blow, allowing the current to continue flowing through the circuit. This situation arises because the fuse is designed to withstand currents below its melting point without tripping. Consequently, the motor continues to operate without any interruption from the primary protection.
However, if the overcurrent relay, which acts as the secondary protective device, is not properly calibrated or set at a higher current rating, it may fail to detect the mild overload. The overcurrent relay is supposed to sense the current level and trip the motor to prevent damage. But if its threshold is set too high, it may not trigger even in the presence of an overload. As a result, the motor may operate beyond its rated capacity, leading to overheating and potential damage.

(b) The current setting of over current relay is generally ranges from 50% to 200%, in steps of 25%. For earth fault relay it is from 10% to 70% in steps of 10%.
Overcurrent relays are normally supplied with an instantaneous element and a time-delay element within the same unit. When electromechanical relays were more popular, the overcurrent protection was made up of separate single-phase units. The more modern microprocessor protection has a three-phase overcurrent unit and an earth-fault unit within the same case. Setting overcurrent relays involves selecting the parameters that define the required time/current characteristic of both the time-delay and instantaneous units.

(a) Explain the term single phasing as applied to poly phase induction motors.(4)
(b) State the likely causes of single phasing and the consequences if motors are not adequately protected (6)
(c) Describe with the aid of sketches THREE methods for motor protection should single phasing occur. (6)

Jul 2023 | Oct 2022

(a) Single phasing in a polyphase induction motor can be caused by a fault in the electrical supply system, such as a blown fuse or a break in one of the phases. Consequences of single phasing include unbalanced currents, overheating of the motor windings, reduced torque output, and potential mechanical damage due to increased stresses on the motor components. Without adequate protection, such as phase failure relays or motor overload protection devices, the motor is at risk of damage, reduced lifespan, and operational downtime.

(b) The likely causes of single phasing are:
- A blown fuse.

- A loose connection.
- A problem with the power line.

The consequences of single phasing are:

- The motor will continue to run, but it will be much less powerful.
- The motor may overheat.
- The motor may catch fire or even explode.

(c) Motor Protection Methods for Single Phasing:

- **Thermal Overload Relay:** A thermal overload relay is connected to each phase of the motor. When single phasing occurs, the relay senses the increased current in the remaining two phases and trips the motor to prevent damage.
- **Phase Failure Relay:** A phase failure relay monitors the presence of all three phases. If one phase is lost, the relay immediately disconnects the motor from the power supply to protect it.
- **Electronic Motor Protection Relay:** An electronic motor protection relay offers advanced features like phase loss detection, overcurrent protection, and phase imbalance protection. It can be. programmed to trip the motor based on specific parameters, providing comprehensive protection.

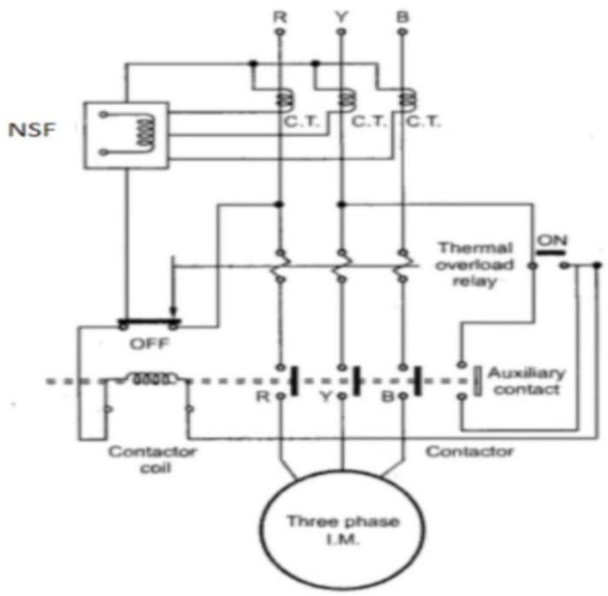
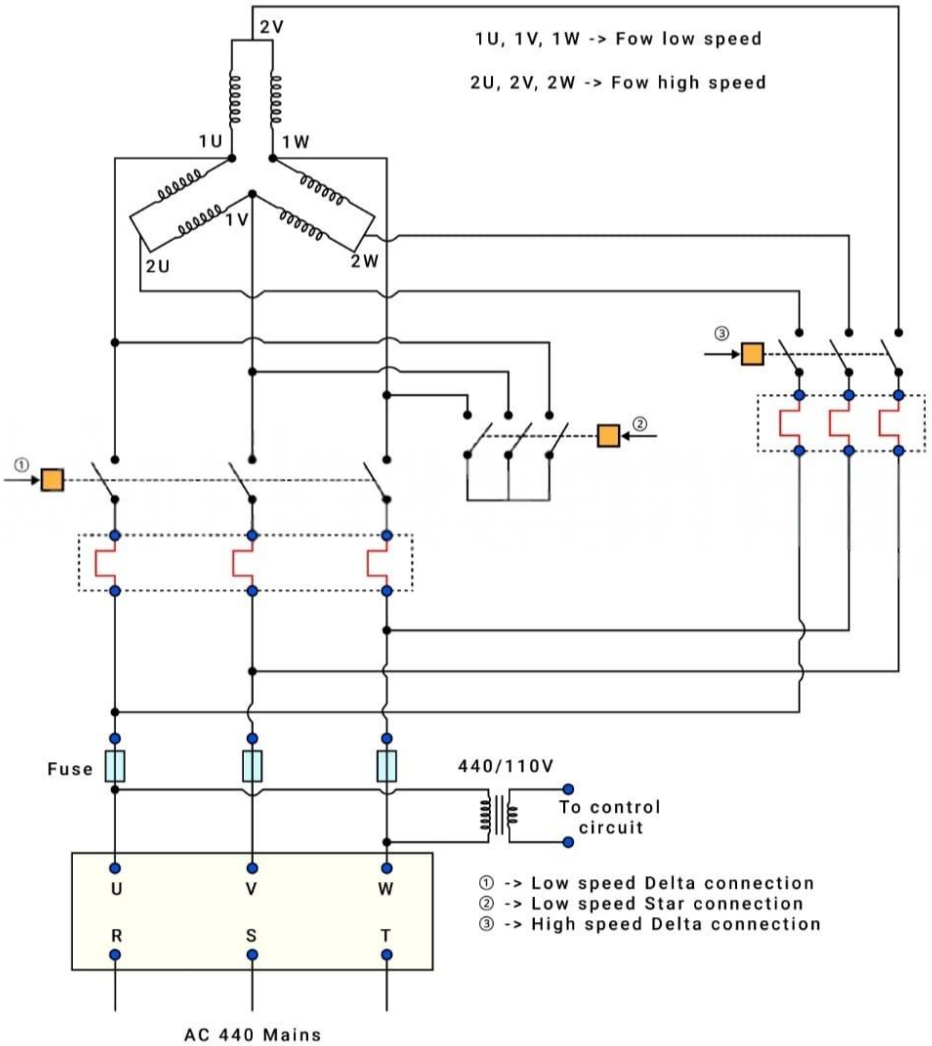


Fig (a) Connection of Single Phasing Preventer

With reference to a 3-speed A.C Cage motor driven cargo winch:
(a) Sketch a circuit diagram for a pole change motor (8)
(b) Describe how speed change and braking are achieved (8)

Dec 2022	Feb 2024

(a) **Circuit diagram for a pole change motor:**



(b) In a 3-speed A.C cage motor driven cargo winch, the speed change and braking are achieved through the following methods:

Speed Change:

Pole Change Method: The number of stator poles in the motor is varied to provide different stepped speeds. This is accomplished by having two or more independent stator windings in the same slots. By changing the connection of the stator coils, the number of poles can be altered. This method allows for fixed speeds with constant torque. The motor operates at different speeds corresponding to the number of poles, such as 2, 4, 6, 8, etc. The synchronous speed of the motor is given by

$$N_s = \frac{120f}{P}$$

where,

- N_s is the synchronous speed,
- f is the frequency of power supply, and
- P is the number of poles.

Methods to Achieve Speed Change:

Multiple Stator Windings:

Two sets of windings are installed on the stator, each designed for different pole numbers. On ly one winding is energized at a time, allowing a change in speed.

Consequent Pole Method:

A single stator winding is divided into coil groups. By altering the connections (series or parallel), the number of poles is changed, resulting in different speeds.

Pole Amplitude Modulation (PAM):
Used when a speed ratio other than 2:1 is required. The winding is split into parts that can be connected in series or parallel. The current direction in specific parts of the winding determines the pole configuration, allowing finer speed adjustments.

Braking Mechanism:
Braking is used to reduce the torque and stop the motor.

Plugging:
Plugging is a braking method where the power supply to the motor is switched over in a way that two phases are interchanged. This creates a reverse torque that quickly reduces the motor speed. Once the speed becomes negligible, the power is switched off to prevent the motor from running in the opposite direction. An electromagnetic brake is then applied to stop the motor.

Rheostatic Braking:
In this method, the motor is switched off, and all three phases are shorted through rheostats. The rheostats act as resistors, dissipating the kinetic energy of the motor in the form of heat through copper losses. The resistance provided by the rheostats slows down the motor and brings it to a stop.

Regenerative Braking:
For regenerative braking, the motor is switched off from the A.C. power supply, and the stator winding is provided with a D.C. supply from batteries. The fixed magnetic flux of the D.C. tries to create a magnetic locking with the rotating rotor poles, generating a retarding torque that reduces the motor speed. When the speed drops to zero, the D.C. supply is switched off, and an electromagnetic brake is applied to stop the motor.

(a) Describe the effect of running an induction motor on reduced voltage. (6)
(b) A motor takes a current of 60 amperes at 230 volts the power input being 12kW. Calculate the power component and the reactive of the input current.

Dec 2022

(a) Running an induction motor on reduced voltage has several effects, including:

- When the voltage supplied to the motor is reduced, the current drawn by the motor increases to maintain the power requirement (P = VI). Higher current can lead to several issues.
- The increased current results in higher losses in the motor windings, leading to elevated temperatures. Overheating is a major concern as it can damage the insulation, winding, and other components of the motor.
- Lower voltage leads to reduced starting torque, affecting the motor's ability to accelerate and start rotating properly. This can result in difficulties in starting heavy loads or moving the motor from a standstill.
- The pullout torque, which is the maximum torque the motor can deliver without stalling, is significantly reduced under reduced voltage conditions.
- Operating the motor at reduced voltage results in lower efficiency. Motors are designed to operate optimally at their rated voltage, and deviating from this value can lead to inefficiencies in power consumption.

- The combination of increased current, overheating, and reduced current, overheating, and reduced performance can contribute to a shortened overall lifespan of the motor. Continuous operation at reduced voltage accelerates wear and tear on the motor components.
- Induction motors are sensitive to voltage sags or fluctuations. A significant drop in voltage, even for a short duration, can cause a motor to stall or operate erratically.

b) V = 230V

P = 12kW

1. Calculate the Power Factor:

The Power Factor (PF) is calculated using the formula

PF= $\frac{P_{input}}{V*I}$

Where,

Where,
Pinput is the power input
V is the voltage
I is the current
PF= $\frac{12000}{230\times60}$ = $\frac{12000}{12800}$ = 0.87

2. Calculate the power component of the current:

The power component of the current

I_p= I×PF

I_p=60×0.87=52.2A

3. Calculate the Reactive Component of the current:

The reactive component of the current Iq is calculated using the Pythagorean theorem in the c

ontext of power triangle

Iq = $\sqrt{I^2 - I_p^2}$ = $60^2 - 52.2^2$ = $\sqrt{60^2 - 52.2^2}$ = $\sqrt{3600 - 2724.84}$ = $\sqrt{875.16}$ =29.58A

The power component of the input current is 52.2A and the reactive component is 29.58A

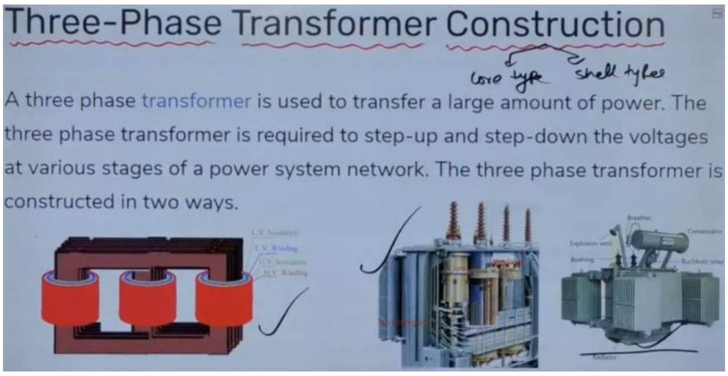
(a)Explain the construction of three phase transformers and their four main types of connections. (10)
(b) Explain the procedure of terminal identification of single phase and three phase induction motor. (6)

Nov 2022

(a) The Three-Phase Transformer is a transformer made up of three sets of primary and secondary windings. They operate as an electrical system that has three phases. The three-phase transformers can be constructed in two ways, one is three identical single-phase transformers are connected to form a three-phase transformer bank, or else a single unit of a three-phase transformer with the windings of three phases wound on a single core.

- **Delta-Delta (Δ-Δ) Connection:** Both primary and secondary windings are connected in a delta (A) configuration.

- **Delta-Star (Δ-Y) Connection:** The primary winding is connected in a delta (A) configuration, while the secondary winding is connected in a star (Y) configuration.
- **Star-Delta (Y-A) Connection:** The primary winding is connected in a star (Y) configuration, while the secondary winding is connected in a delta (A) configuration.
- **Star-Star (Y-Y) Connection:** Both primary and secondary windings are connected in a star (Y) configuration.
- **Open Delta (V-V) Connection:** Only two transformers are used to create a three-phase connection, typically in a delta (A) configuration.



(b) Three-phase induction motor: Using a multimeter set to the resistance (ohms) mods, Measure the resistance of terminals and note the reading. 1. Set the multimeter to the ohms setting. 2. Touch the red probe to one of the terminals and the black probe to the other terminal. 3. Record the resistance reading. 4. Repeat steps 2 & 3 for the other two terminals. 5. The terminal with the highest resistance is the start terminal. 6. The terminal with the lowest resistance is the run terminal. 7. The terminal with the resistance in between the start and run terminals is the common terminal.

A 3 phase induction motor which is wound for 4 pole, when running full load develops a useful torque of 100Nm, also rotor emf is observed to make 120 cycles/ min. It is knows that the torque lost on account of friction and core loss is 7Nm. Calculate the shaft power output, rotor cu loss, Motor Input and Efficiency (4 x 4) (10)

Jul 2022

Given:

Shaft torque, T_{sh} = 100 Nm

Rotor frequency, f_r = 120/60 = 2 Hz

Assume supply frequency is 50 Hz, ∴fs = 50 Hz

Slip = $\frac{fr}{fs} = \frac{2}{50}$ = 0.04

Synchronous speed = $N_s = \frac{120f}{p}$

$= \frac{120 \times 50}{4}$ = 1500 rpm

Rotor speed = $N_r = (1 - S) * N_S$

= (1 -0.04) × 1500

= 1440 rpm

Rotor's radian speed, $\omega_r = \frac{2\pi Nr}{60}$

$= \frac{2*3.141*1440}{60}$ = 150.7 rad/sec

(i) Shaft power output, $P_{out} = T_{sh} * \omega_r$

= 100 * 150.7 = 15070 W

P out =15.07 kW

Gross torque, $T_g = T_{sh} + T_{loss}$ = 100 + 7 = 107 Nm

But $T_g = \frac{Pm}{Wr}$

Rotor gross output power $P_m = T_g * \omega_r$

= 107 *150.7

= 16.12kW

Rotor input power, $P_2 = \frac{Pm}{(1-S)}$

$= \frac{16.12}{(1-0.04)}$ = 16.79 kW

(ii) Rotor C_u loss = $S \times P_2$ = 0.04 × 16.79

Rotor C_u loss = 0.67 kW

(iii) Motor power input, $P_{in} = P_2$ + stator C_u loss

P_{in} = 16.79 + 0.7 (Assume stator C_u loss= 0.7 kW)

Pin = 17.49 kW

(iv)Efficiency, $\eta = \frac{Pout}{Pin}$

$= \frac{15.07}{17.49} * 100$

η = 86.16

(a)Describe how you would overhaul an electric motor that has been flooded with sea water (5)
(b) Explain how to check the insulation resistance of the motor, stating the minimum acceptable value (6)
(c) Principle of rotation of rotor and how to reverse the direction of a three-phase induction motor(5)

Jul 2022

(a)

- Put off the breaker
- Remove fuses
- Put tag 'Men at work'
- Remove terminal box cables and wind them in insulating tapes
- Dismantle the motor
- Clean all parts with Fresh Water.
- Make sure all salts have been removed.
- If oil is present then use an oil degreaaser to clean
- Dry with the help of a powerful lamp around 100w - 500w or low power heater.
- Keep proper ventilation to remove all moisture.
- Apply air during insulation varnish to the winding and leave it for some time to dry
- Check the bearings
- Check insulation resistance
- Assemble back the motor
- Run it idle for some time and then take it on load slowly
- Check noise/ vibration/temperature/ smell and any other abnormality.

(b) Insulation resistance is carried out with the aid of an appropriately rated IR Tester (Megger). Before carrying out the job, appropriate safety paperwork such as Risk Assessment and Permit to Work is completed; this will ensure that the motor is isolated and it is safe for the

test to be carried out. To prove the basic operation of the tester, short the two probes together and press the 'test' button. The display should read OΩ. For an IR test on a three-phase machine, measure and log the phase-to-phase insulation resistance values. Three readings should be measured as U-V, V-W, and W-U. Measure and log the phase-to-earth insulation resistance values. Three readings should be measured as U-E, V-E and W-E.
The minimum acceptable IR value should be above 1 mega-ohm at 60°C

(c) The principle of rotation in a motor involves the interaction between magnetic fields generated by the stator (stationary part) and the rotor (rotating part). When electric current flows through the stator windings, it creates a magnetic field that interacts with the magnetic field of the rotor, causing it to rotate. To reverse the direction of rotation in a motor, you can do one of the following:

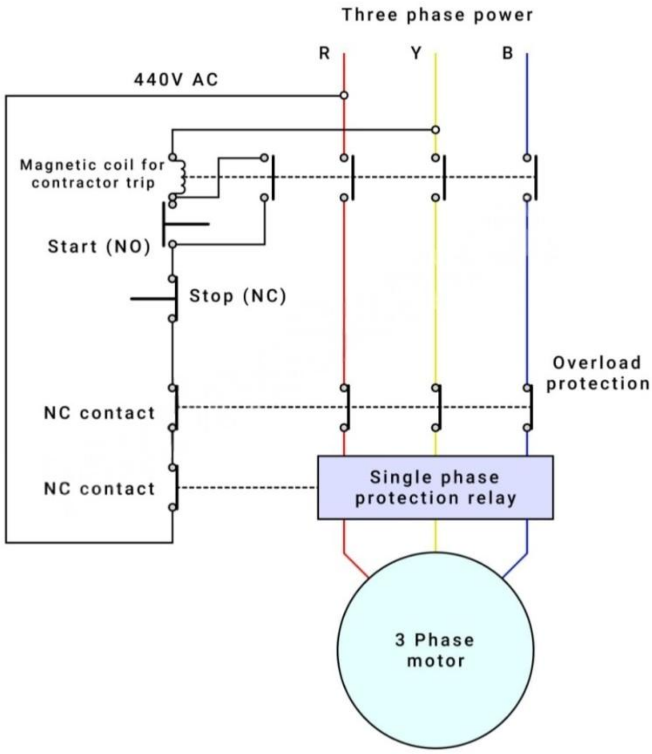
- Switching the polarity of the power supply: By reversing the connections to the stator windings, you can change the direction of the magnetic field, thus reversing the rotation direction of the motor.
- Using a reversible motor: Some motors are designed to be reversible, allowing you to change the direction of rotation by simply changing the direction of the current flow through the windings.
- Using external control devices: In some cases, external control devices such as motor controllers or inverters can be used to reverse the direction of rotation by changing the phase sequence or controlling the speed of the motor.
- Each method may be more suitable depending on the specific motor and application requirements.

AC Starters

- **Notes:**

(a) Explain about the working of D.O.L starting of A.C motor with the help of a diagram (8)
(b) Explain about the auto transformer starting of an A.C motor with the help of a diagram. (8)

Jul 2022



- The main supply is connected to the contactor, which, when energized, connects the AC motor to the supply. - The START push button activates the contactor, allowing the motor to start running. - Overload protection (O/L Relay) and Single Phase Protection Relay are connected in series with the contactor in the control circuit. If any protection device detects a fault (e.g., overload or single phasing), the contactor drops, opening the normally closed (NC) contacts and stopping the motor. – The STOP push button also causes the contactor to drop, stopping the motor. -The START and STOP push buttons can be located remotely for remote operation of the motor. The contactor has a solenoid with normally open (NO) and normally closed (NC) contacts, facilitating then control system's requirements. - The main electrical equipment is connected to the supply through the contacts of the contactor, ensuring controlled motor operation and protection against faults.

(b) Auto transformer has only one winding per phase, which is divided into two parts i.e. Primary and secondary winding. The winding of the autotransformer has 3 tap points, two of them are fixed while the third one is a variable tap point.

The variable tap point can be moved to increase or decrease the number of secondary turns. Thus increasing or decreasing the output voltage.

It can be used in either configuration to step up or step down the input current and voltage. The output voltage can be decreased (step-down) if the supply is connected to the fixed terminals. In the reverse configuration, the output voltage will exceed the input (step-up)

The secondary winding is electrically connected to the primary, so there is no electrical isolation but it decreases the magnetic leakage flux.

The EMF in the winding is also induced due to self-induction. So the output voltage is the resultant of conduction and induction.

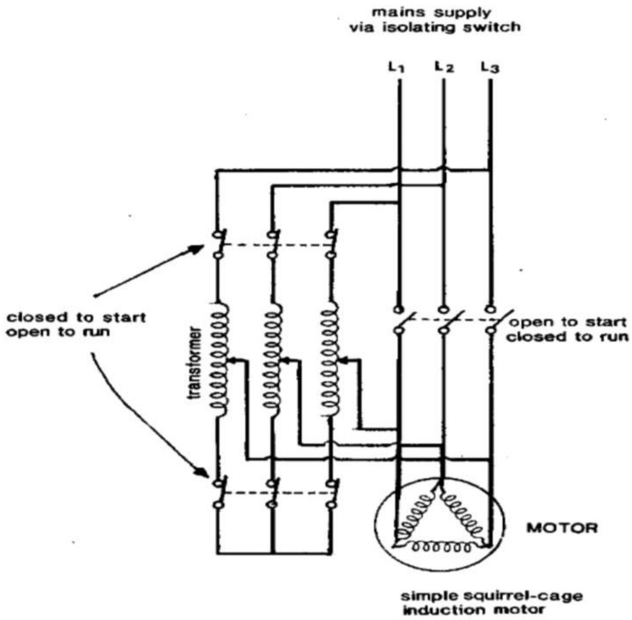


Figure 5.9 *Autotransformer starter*

Batteries & E'mcy power supplies

- **Notes:**

(a) Describe an alkaline battery cell, listing the materials used in its manufacture. (6)
(b) With reference to alkaline batteries used on ships, state each of the following (10)
(i) Significance of the relative density reading of the electrolyte;
(ii) When the electrolyte would normally be renewed;
(iii) Reasons why the voltage reading of this type of battery is not necessarily indicative of its condition;
(iv) The normal temperature range and safe temperature limit of battery;
(v) Effects of high and low temperature.

Dec 2024

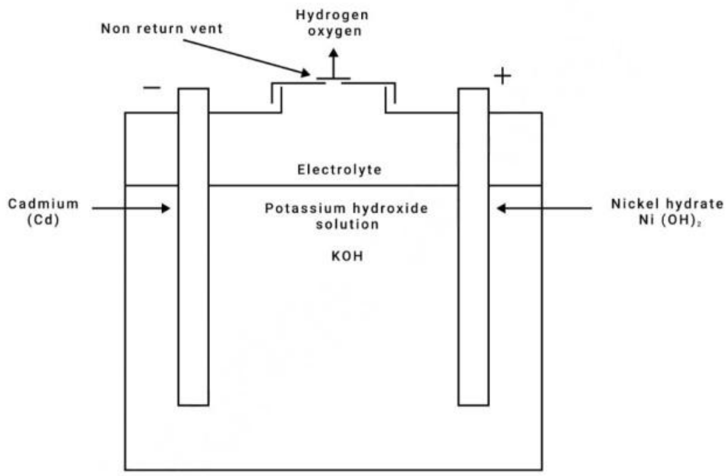
(a) The common form of an alkaline cell is the Nickel-cadmium type.
In this type of battery,

- The positive electrode is made up of nickel hydroxide (NiOOH)
- The negative electrode is made of cadmium (CD)
- Electrolyte of potassium hydroxide (KOH)
- Separators made of rubber Housing made of strong plastic.

A series of alternating positive and negative plates are fully immersed in the electrolyte; separators are inserted between the interleaving plates to prevent contact/ internal short-circuiting. A non-return pressure relief valve is fitted in the housing to release the gases, which evolve especially during the period of overcharge. Relief valves are non-return type to prevent 'poisoning' of the electrolyte from the atmosphere.

Chemical Reaction:
At the Cathode: Cd+2OH− =>Cd (OH)2+2e−
At the Anode: 2NiO(OH)+2H2O+2e− => 2Ni (OH)2+ 2OH−
The overall cell reaction: Cd+2NiO(OH)+2H2O=>2Ni(OH)2+Cd(OH)2

Working process:
Discharge: On discharge, nickel hydroxide loses oxygen and is reduced to a lower form, while the cadmium in the negative plates is oxidised to cadmium oxide.
Charging: On charging, the reverse of discharge occurs, the material at the positive terminal is oxidised to nickel hydroxide, and the material at the negative terminal is reduced to cadmium.



(b)
(i) Significance of the Relative Density Reading of the Electrolyte:
The relative density of the electrolyte in an alkaline battery (typically potassium hydroxide solution) indicates the concentration of the electrolyte. A higher density reading indicates a stronger electrolyte, meaning the battery has good capacity and charge retention. A low

density reading could indicate electrolyte degradation or excessive evaporation, signalling potential issues like reduced battery performance or a need for maintenance.

(ii) When the Electrolyte Would Normally Be Renewed:
The electrolyte is typically renewed when its relative density drops below the manufacturer's specified threshold, indicating that the electrolyte has become diluted or contaminated. This can happen due to evaporation, leakage, or chemical reactions during use. Typically, this renewal occurs every 2-3 years or as per the manufacturer's guidelines and operational conditions.

(iii) Reasons Why the Voltage Reading of This Type of Battery is Not Necessarily Indicative of Its Condition:
The voltage reading of an alkaline battery can remain normal even when the battery's capacity is degraded or its internal chemistry has changed. This happens because the voltage can still be maintained at the nominal level (e.g., 1.5V per cell) despite a loss in efficiency or capacity. The battery may not be able to deliver the required current or maintain the voltage under load, which is why the voltage reading alone does not provide a full picture of the battery's health.

(iv) The Normal Temperature Range and Safe Temperature Limit of the Battery:
- Normal Temperature Range: Alkaline batteries typically operate in a temperature range of 0°C to 40°C (32°F to 104°F).
- Safe Temperature Limit: The maximum safe operating temperature is generally around 50°C (122°F). Exceeding this limit can cause leakage, reduced performance, or even catastrophic failure of the battery.

(v) Effects of High and Low Temperature:
High Temperature:
- Increased rate of chemical reactions within the battery.
- Can lead to the degradation of electrolyte, reducing battery life and capacity.
- Risks of leakage, corrosion, or rupture of the battery casing.

Low Temperature:
- Reduced electrolyte conductivity, leading to decreased battery efficiency.
- Lower chemical reaction rates, causing lower output voltage and capacity.
- Batteries may become sluggish or unresponsive in extremely cold conditions, especially if left uncharged for prolonged periods.

(a)What are the hazards associated with batteries? (4)
(b) What safety precautions are to be taken while operating and maintaining the batteries including in battery room.(6)
(c) What are the safety arrangements seen in the Battery room of a ship? (6)

Mar 2024-1 | Mar 2024-1

(a) Hazards Associated with Batteries:
1. Lead-acid batteries and some other types of batteries use acidic electrolytes, such as sulfuric acid. This acid is highly corrosive and can cause severe burns and damage to skin and clothing upon contact.
2. During charging, lead-acid batteries produce hydrogen gas, which is highly flammable and can lead to explosion hazards if not properly ventilated.
3. Batteries can store a significant amount of electrical energy, and accidental short circuits or improper handling can result in electric shocks or electrical fires.

4. Large batteries can be extremely heavy and pose a risk of physical injury if not handled properly.
5. Improper disposal of batteries can lead to environmental pollution due to the presence of toxic materials like lead, cadmium, and mercury.
6. Overcharging or overheating of batteries can lead to electrolyte leakage, battery swelling, and the release of harmful gases.

(b) The following are the precautions which must be adhered to for all batteries:

1. Compartments in which batteries are kept should be well-ventilated to prevent any buildup of dangerous and flammable toxic gases.
2. A conspicuous label stating "No Smoking/No Naked Lights" should be displayed on the outside of the door leading into the compartment as well as inside the compartment so that the personnel makes no mistakes
3. The compartment for the storage of batteries should be strictly used for the purpose of storing batteries and nothing else. For example, other pieces of lights and scraps such as NUC or RAM lights must not be lying around
4. The light bulbs in the compartment must be protected by gas-tight enclosures and all the wiring leading into the lights must be well insulated and not a messy bunch
5. All battery connections must be clean neat and tight
6. Batteries must be securely stowed in their position
7. Metal tools must be squared up and not left lying on top of the batteries as they may lead to short circuits.
8. Whenever the batteries are moved, especially big ones, they should be carried horizontally. In case of a really heavy battery, sufficient personnel must be assigned for the carriage of the same. 9. The liquid solution within the batteries might cause corrosive injuries and even damage the clothing, hence utmost care while handling them is important
9. The circuits formed by the batteries must be dead/inactive when leads are being connected or disconnected. A live battery can cause a live wire which can lead to serious injuries
10. The battery compartment must be kept locked to prevent inadvertent use and the key safely placed in a box outside
11. Portable electrical instruments must be avoided or not used at all in such compartments When handling alkaline batteries
12. The metal cases of these batteries are 'live' and should not be touched with the body or tools
13. The electrolyte is corrosive and in the event of a mishap it should be neutralised with boric acid powder or by large amounts of fresh water. Eyes should be washed with fresh water and then washed with a boric acid solution.
14. Alkaline and lead acid batteries must not be stowed in the same compartment. Every tool used for the workings of one battery must be thoroughly cleaned before using it on another type of battery.

(c) Safety arrangements in the battery room of a ship typically include:

1. Ventilation systems to prevent the buildup of hazardous gases like hydrogen.
2. All the electric equipment in the battery room is Intrinsically safe (Exi).
3. Acid-resistant flooring and walls to contain spills and prevent corrosion.
4. Safety showers and eye wash stations in case of contact with battery acid.
5. Personal protective equipment (PPE) such as gloves, goggles, and acid-resistant clothing for personnel working in the battery room.
6. Fire suppression systems like fire extinguishers and sprinkler systems.

7. Proper signage indicating hazardous areas and emergency procedures.

With reference to an emergency source of electrical power in cargo ships:
(a) Describe a typical power source (6)
(b) Give a typical list of essential services, which must be supplied simultaneously.(5)
(c) Explain how the emergency installation can be periodically tested. (5

Dec 2023 | **Oct 2024** | **May 2024** | **Apr 2024-2** | **Mar 2023** | **Aug 2022**

(a) A typical power source for emergency generators in cargo ships is typically an internal combustion engine, often diesel- powered. The engine is connected to an alternator, which generates electrical power. The size and capacity of the emergency generator depend on the ship's size and requirements. Emergency generators are designed to provide electrical power in case of a main power failure, ensuring essential systems like emergency lighting, communication, and safety equipment remain operational.

(b) List of essential services, which must be supplied simultaneously are:
- One Steering gear motor
- Emergency fire pump
- Emergency air compressor
- BA compressor
- Sprinkler/ Hi-fog pump
- Fire detectors
- Navigation equipment
- Communication equipment
- Water tight doors
- Life boat davits
- CO2 room exhaust fan
- One E/R vent fan
- E/R pumps and system required for first start from 'Dead ship'
- Emergency lights
- Battery chargers
- E/R alarms system
- UPS system

(c) The emergency installation is periodically tested to ensure its reliability and functionality in case of a main power failure. Typical testing procedures include:
1. Weekly Testing (No Load): The emergency generator is started and run without load to check its starting capabilities (using both primary and secondary starting methods if available), voltage, and frequency. The running parameters like exhaust temperature and sump oil level are also checked.
2. Monthly Testing (Simulated Automatic Start): The automatic starting system is tested by simulating a main power failure. This is often done by opening the interconnector breaker between the main and emergency switchboards. The emergency generator should automatically start and connect to the emergency switchboard.
3. Quarterly Testing (On Load): The emergency generator is run on load for a more extended period (e.g., at least 30 minutes) to ensure it can supply the essential services under load conditions and achieve normal operating temperatures and pressures. As much of the emergency load as safely practicable is connected during this test.
4. Annual Testing (Blackout Test): A more comprehensive test involving a simulated or controlled blackout may be conducted. This involves shutting down the main power

source (if safe and practical) to ensure the emergency generator starts automatically, takes over the load, and the essential services function correctly. This test verifies the entire emergency power system's response to a complete power loss.

5. Battery Testing: If an accumulator battery is part of the emergency power source, it is periodically tested for its charge level, discharge capability, and the condition of its terminals and connections. Controlled discharge tests (though not typically done at sea) may be conducted to assess its capacity.
6. Testing of Automatic Transfer Switches: The automatic transfer switches that connect the emergency power to the essential services upon main power failure are also tested to ensure they function correctly.
7. Verification of Fuel Supply: Regular checks are made to ensure the emergency generator has an adequate supply of fuel of the correct quality.

(a) Explain the working principle of an alkaline battery. (8)
(b) Compare the alkaline battery with Lead-Acid battery. (8)

Nov 2023 | **Sep 2024-2** | **Apr 2025** | **Apr 2024-2** | **Apr 2024-2**

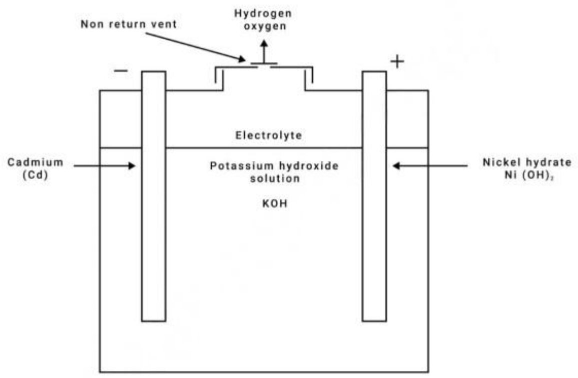
(a) The common form of an alkaline cell is the Nickel-cadmium type.
In this type of battery,

- The positive electrode is made up of nickel hydroxide (NiOOH)
- The negative electrode is made of cadmium (CD)
- Electrolyte of potassium hydroxide (KOH)
- Separators made of rubber Housing made of strong plastic.

A series of alternating positive and negative plates are fully immersed in the electrolyte; separators are inserted between the interleaving plates to prevent contact/ internal short-circuiting. A non-return pressure relief valve is fitted in the housing to release the gases, which evolve especially during the period of overcharge. Relief valves are non-return type to prevent 'poisoning' of the electrolyte from the atmosphere.

Chemical Reaction:
At the Cathode: Cd+2OH− =>Cd (OH)2+2e−
At the Anode: 2NiO(OH)+2H2O+2e− => 2Ni (OH)2+ 2OH−
The overall cell reaction: Cd+2NiO(OH)+2H2O=>2Ni(OH)2+Cd(OH)2

Working process:
Discharge: On discharge, nickel hydroxide loses oxygen and is reduced to a lower form, while the cadmium in the negative plates is oxidised to cadmium oxide.
Charging: On charging, the reverse of discharge occurs, the material at the positive terminal is oxidised to nickel hydroxide, and the material at the negative terminal is reduced to cadmium.



(b)

Lead-Acid	Alkaline
Develops a nominal 2 volts per cell, deman ding 12- cell batteries for the normal 24-volt supply.	Develops 1.2 volts per cell, so 20 cells are required for a normal 24-volt supply.
Less expensive in initial cost and more effici ent.	Costly but has a longer life of 15 years co mpared to 5 years of lead acid.
Preferred for regular recycling duty of essent ial power supplies operating on a charge/dis charge basis.	Preferred for emergency power supply bei ng more suited to long periods of idle oper ation on standby. It is regarded as more re liable.
The electrolyte is dilute H2SO4, evolves gas continuously during charging.	The electrolyte is an aqueous KOH solutio n that evolving gas when nearing the top o f the charging.
Hydrogen & Oxygen gases are evolved due t o the chemical breakdown of water. Cells ar e vented to allow gases to escape.	Hydrogen and Oxygen gases are evolved d uring charging and vented through non-return values.
Gases are highly explosive and acidic in natue.	Gases are highly explosive and alkaline in nature.
The evolution of gas causes water loss, whic h should be topped up with distilled water.	The evolution of gas causes water loss du ring charging, which should be topped up.
Life starts reducing considerably above 25° C.	It can be operated continuously at 45°C w ithout loss of life.
Care must be taken not to cause sparks or p roduce naked flame when inspecting batteri es.	Sparking and naked film are prohibited in the battery room.

(a) Define Work, Power and Efficiency (6)
(b) A battery is charged with a constant current of 16 amperes for 11 hours after which time it is considered to be fully charged, its voltage per cell being recorded as 2.2V. Find its ampere hour efficiency if it is (10)
(i) Discharged at a rate of 16 amperes for 10 hours, and
(ii) 28 amperes for 4 hours. In either case discharge was discontinued when the voltage per cell fell to 1.8 V.

Feb 2023 **Sep 2023**

(a) Work: is defined as the transfer of energy that occurs when a force is applied to an object and causes it to move in the direction of the force. Work (W) is calculated by multiplying the magnitude of the force (F) applied to an object by the displacement (d) of the object in the direction of the force. Mathematically, work is expressed as W = F * d. The SI unit of work is the joule (J).

Power: Power is the rate at which work is done or the rate at which energy is transferred or converted. It measures how quickly work is performed or how quickly energy is transformed. Power (P) is calculated by dividing the amount of work done (W) by the time (t) taken to do that work. Mathematically, power is expressed as P = W / t. The SI unit of power is the watt (W).

Efficiency: Efficiency is a measure of how effectively a system or device converts input energy into useful output energy. It quantifies the ratio of useful output work or energy to the total input work or energy. Efficiency (n) is calculated by dividing the useful output work or energy (Wout) by the total input work or energy (Win) and multiplying by 100 to express it as a percentage. Mathematically, efficiency is expressed as η = (Wout / Win) * 100.

(b) Given:
I = 16 amps
t = 11 hrs
voltage per cell = 2.2 v
amphr efficiency = ?
condition
(i) discharge rate of 16 amp for 10 hrs

(ii) 28 amp for 4 hrs
(i) total input amp = 16×11 = 176
total output amp = 16×10 = 160

Amphr eff^n = $\frac{\textbf{Amphr of discharge}}{\textbf{Amphr of charge}}$

$= \frac{160}{176}$ = 0.91 or 91percentage

(ii) Total output = 28 × 4 = 112
Input = 16 × 11 = 176
Eff^n = $\frac{112}{176}$ = 0.63 or 63 percentage

(a) What are the regulations regarding Emergency Generator onboard a cargo ship? (6)
(b) Describe the functioning of the emergency generator with the help of a flow chart. (10)
Batteries & E'mcy power supplies.

Sep 2023

(a) SOLAS Regulations for Emergency Generator of the ship

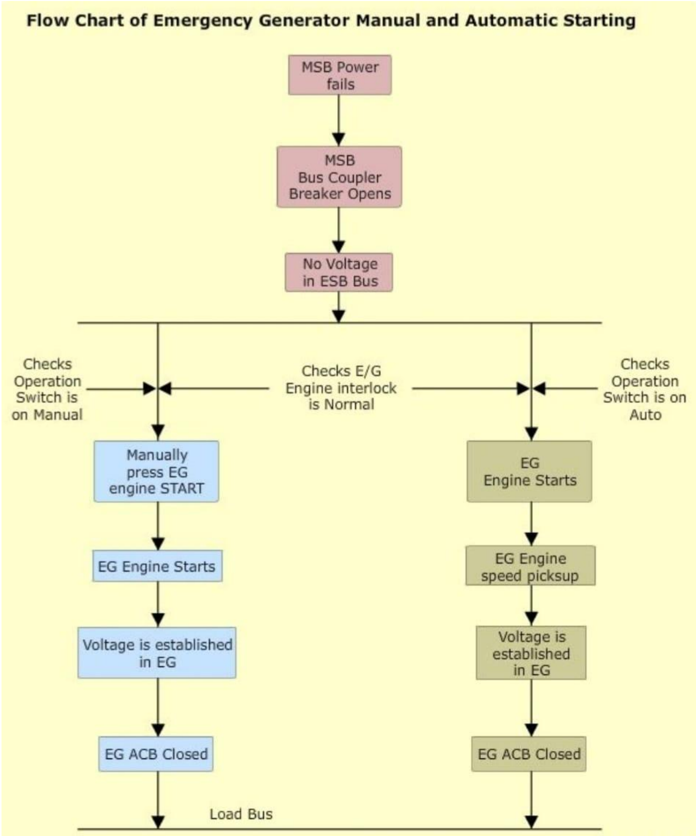
1. All passenger and cargo vessels shall be provided with emergency sources of electrical power, for essential services under emergency conditions.
2. Emergency generator and emergency switchboard of the ship should be located above the uppermost continuous deck, away from machinery space, behind the collusion bulkhead.
3. The main switchboard of the ship should not interface with supply, control, and distribution of emergency power.
4. Emergency source of power should be capable of operating with a list of up to 22° and a trim of up to 10°
5. The generator should have independent fuel supply having flash point not less than 43°C.
6. Emergency generator should be capable of giving power for the period of 18 hours for the cargo ship and 36 hours for the passenger ship.
7. Emergency generator should start at O°C and if temperature fall below this then there should be heating arrangement.
8. Emergency generator should come on load automatically within 45s after the failure of main power supply.
9. If the emergency generator fails to come on load the indication should be given to ECR.

Emergency generator should have two different starting arrangement

- Primary may be the battery, should be fully charged at all times and capable of providing 3 consecutive Start.

- Secondary may be pneumatic or hydraulic, capable of providing 3 consecutive starts within 30 minutes, and 1st start within 12 minutes.

(b) Flow chart of emergency generator operation



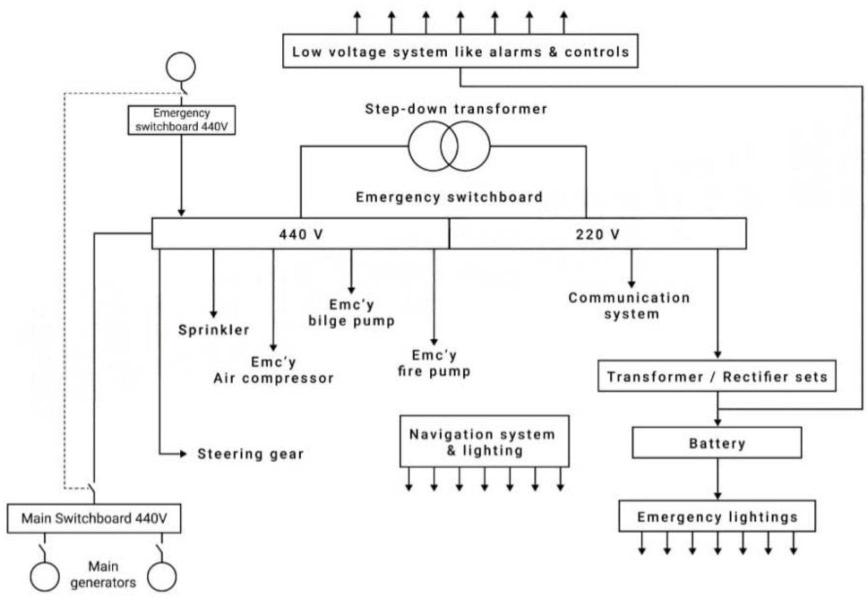
In the event of a failure of the main electrical power supply on a ship, an emergency source of power must be available. State the circuits which must be fed from such a source and discuss the reasons governing the selection of such circuits.

Aug 2023

In the event of a failure of the main electrical power supply on a ship, certain circuits must be fed from the emergency source of power to ensure the safety and operational capability of critical systems. These circuits are essential for maintaining the functionality of key equipment and systems that are essential for the safety of the vessel and its crew. The selection of these circuits is based on several factors aimed at prioritising important functions and ensuring the vessel's ability to respond to emergencies effectively.

1. Steering Gear Motor: The steering gear motor is essential for controlling the direction of the vessel, ensuring manoeuvrability and avoiding collisions, especially in emergency situations.
2. Emergency Fire Pump: The emergency fire pump is vital for supplying water to firefighting systems in case of fire onboard, helping to contain and extinguish fires to prevent them from spreading.
3. Emergency Air Compressor: The emergency air compressor provides compressed air for starting from a dead ship or if all the air from the main air bottle is lost.
4. Breathing air compressor: for filling SCBA bottles that can be used during fire fighting and entry into enclosed spaces.
5. Sprinkler/Hi-fog Pump: These pumps are responsible for spraying water for fire suppression to control and extinguish fires in different areas of the vessel.

6. Fire Detectors: Fire detection systems continuously monitor various areas of the ship for signs of fire or smoke, providing early warning to enable prompt response and evacuation if necessary.
7. Navigation Equipment: Navigation equipment, including radar, GPS, and gyrocompass systems, is essential for maintaining situational awareness, determining the vessel's position, and navigating safely, especially in adverse weather conditions or restricted visibility.
8. Communication Equipment: Communication systems, such as radios, satellite communication terminals, and distress alert systems, enable the crew to communicate with shore authorities, other vessels, and emergency responders in case of distress or emergencies.
9. Watertight Doors: Watertight doors are important in maintaining the vessel's watertight integrity and preventing the ingress of water in case of flooding or damage to the hull.
10. Lifeboat Davits: Lifeboat davits are used for launching lifeboats and rescue boat, providing a means of evacuation for the crew and passengers in emergencies such as abandon ship.
11. CO2 Room Exhaust Fan: The CO2 room exhaust fan is essential for ventilating the spaces where carbon dioxide (CO2) fire suppression systems are installed, ensuring that the room is safe to enter.
12. Engine Room Vent Fan: One of the Engine room blower power is supplied from the Emergency generator, which helps in air supply to E/R and provides safe entry to the Engine room.
13. E/R Pumps and Systems for First Start from 'Dead Ship': These pumps and systems are necessary for restarting the required pumps and systems in the engine room, enabling the vessel to restore power and propulsion from a state of complete power loss ('Dead Ship').
14. Emergency Lights: Emergency lights are provided in the Engine room, accommodation, upper deck, escape routes, stairwells, and muster stations, ensuring visibility during power outages or emergencies.
15. Battery Chargers: Battery chargers maintain the charge of essential batteries, including those for emergency lighting, communication equipment, and control systems, ensuring their readiness for use in emergencies.
16. E/R Alarm System: The engine room alarm system monitors various parameters and conditions in the engine room, providing early warning of abnormalities, malfunctions, or hazards that could jeopardise the safety and operation of the vessel.



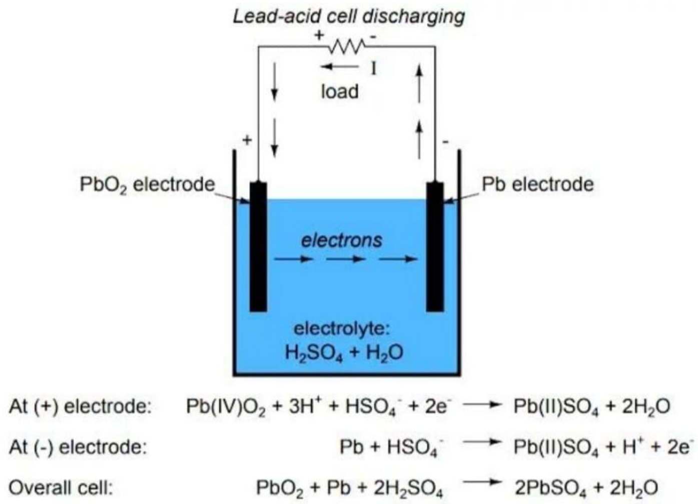
The open-circuit voltage of a cell as measured by a voltmeter of 100 ohm resistance, was 1.5 V, and the p.d. When supplying current to a 10 ohm resistance was 1.25 V; measured by the same voltmeter. Determine the e.m.f. and internal resistance of the cell (16)

Jul 2023

Let E =e.m.f of cell and
R1 = internal resistance
With the voltmeter across the cell terminals only,
Current taken by voltmeter = $\frac{1.5}{100}$ = 0.015A
= 1.5 + 0.015R_1-----①
With voltmeter and resistor across the cell terminals,
Current taken by resistor = $\frac{1.25}{10}$ = 0.125 A
Current taken by voltmeter =$\frac{1.25}{100}$ = 0.0125A
Current supplied by cell
= 0.125 + 0.0125 = 0.1375A
Thus E = 1.25 + 0.1375R1 and E=1.25+ 0.1375R1----②
Solving and ① and ②
Thus E = 1.25 + 0.1375R_1 and
E = 1.5 + 0.015R_1
Subtracting ① and ②= 0.25 – 0.1225R_1
R1 = $\frac{0.25}{0.1225}$ = 2.04Ω and E = 1.5 + (0.015 * 2.04) = 1.5+0.031
Thus cell e.m.f = 1.531V

(a)Sketch and describe the working of a Lead Acid battery (12)
(b) What routine maintenance is carried out on these batteries. (4)

Jun 2023



- Lead and lead peroxide plates are arranged alternatively and immersed in a dilute sulphuric acid electrolyte solution.
- Lead combines with the sulphate ion of the electrolyte to create lead sulphate and electrons.
- Lead dioxide, hydrogen ions, sulphate ions and electrons from the lead plate combine to form lead sulphate and water.
- As the battery discharges both the plates build up with lead sulphate and water build up in the electrolyte tank.

- 2V is released from the cell, six such constitutes a 12V battery.
- Reaction is completely reversible if you apply DC voltage to the battery higher than the EMF of the battery, lead and lead oxide form again and the battery is recharged.

b) Routine maintenance of Lead Acid batteries:

- The battery terminals must be kept clean and petroleum jelly to be applied to prevent corrosion.
- The battery vent should be checked and cleared so that the gases developed during the charging can escape.
- Battery connections should be tightened adequately.
- Top off the electrolyte in the battery to the correct level due to loss of water during electrolysis. The electrolyte should cover the electrodes and be below the vent cap.
- Check specific gravity to check the concentration of electrolyte using a voltmeter or hydrometer test.

Distinguish between primary and secondary cells. (4)
(b) Explain Internal resistance in a battery. (4)
(c) What are the factors affecting internal resistance of a battery. (8)

Oct 2023 **Sep 2023**

(a) Primary cells are single-use batteries that are not rechargeable. They are commonly used in devices that require a small, portable power source, such as flashlights, remote controls, and smoke detectors. Primary cells are typically made of chemicals that produce a chemical reaction when they are used, which generates electricity.
Secondary cells, on the other hand, are rechargeable batteries. They are typically used in devices that require a longer- lasting power source, such as laptops, cell phones, and electric vehicles. Secondary cells are made of chemicals that can be recharged by applying a current to them, reversing the chemical reaction that occurs when they are used. Some common types of secondary cells include lead-acid batteries, nickel-cadmium batteries, and lithium-ion batteries.

Primary cell	Secondary cell
Primary cells are irreversible i.e., once they get discharged, they cannot be charged again.	Secondary cells are reversible and can be easily charged by electrical supply.
Their internal resistance is very high.	They possess low internal resistance.
They are cheaper.	They are comparably expensive.
They can be easily used.	In comparison to primary cells, they are difficult to handle.
They have a short lifetime.	They are durable.
They are smaller in size.	They are larger.
They are used in small devices like a torch and, other portable appliances.	In large devices like inverters and automobiles, secondary cells are used.
They are made up of dry cells.	They are made of wet cells and molten salts.
They cause an irreversible chemical reaction.	They cause a reversible chemical reaction.

(b) The internal resistance (IR) of a battery is defined as the opposition to the flow of current within the battery. There are two basic components that impact the internal resistance of a battery; they are electronic resistance and ionic resistance.

(c) The internal resistance of a cell depends on the following factors.
1. The internal resistance of a cell is directly proportional to the distance between the electrodes. This implies that, as the distance between the electrodes increases, the internal resistance also increases and vice versa.
2. The internal resistance of a cell is inversely proportional to the effective area of the electrodes. This implies that, as the effective area of the electrodes increases, the internal resistance decreases and vice versa.
3. The internal resistance of a cell decreases with the concentration of the solution. Because, with the increase in the concentration of the solution, the number of ions per unit volume increases and, in turn, their bombardment also increases.
4. The increase in temperature of the solution increases the kinetic energy of the ions present, thus, the internal resistance of a cell decreases. The electromotive force of a cell is always greater than the potential difference across the same cell.

(a) What are the hazards associated with batteries? (6)
(b) What safety precautions are to be taken while operating and maintaining the batteries including in battery room. (10)

May 2023-2

(a) Hazards associated with batteries:
- Batteries contain electrolytes that can be corrosive and harmful to skin and eyes. Leakage of electrolytes poses a risk of chemical burns and environmental contamination.
- Overcharging or short-circuiting of batteries can lead to overheating and fires.
- Lithium-ion batteries, in particular, can be prone to thermal runaway and combustion.
- High voltage in batteries poses a risk of electric shock.
- Short circuits or accidental contact with conductive materials can lead to electrical hazards.
- Lead-acid batteries emit hydrogen gas, which is flammable and can lead to explosion hazards in confined spaces.
- Batteries are often heavy, and improper lifting or handling can result in injuries.
- Improper disposal of batteries can lead to environmental pollution due to the release of toxic substances.

(b) Safety Precautions for Operating and Maintaining Batteries:
Ventilation:
- Adequately ventilate battery rooms to prevent gas accumulation, especially hydrogen.
- Ventilation outlets should be at the top of the room, and corrosion- resistant materials must be used.
- Electrical equipment in the room should be certified for hydrogen- containing atmospheres.

Electrical Equipment:
- Ensure that light fittings and electrical equipment are suitable for operation in hydrogen-rich atmospheres.

Charging Dangers:
- Hydrogen explosion and short circuits are dangers during charging.

- Only authorized personnel should enter battery rooms, avoiding sources of ignition.

Tool Usage:
- Use caution with metal tools to prevent contact with battery terminals.
- Metal water jugs should be avoided during topping up to minimize sparking risks.

Battery Room Safety:
- Only authorized personnel should enter battery rooms, and smoking is prohibited.
- Keep battery rooms clear of potential ignition sources and refrain from using them as storage spaces.

Storage and Interaction:
- Separate storage for lead-acid and alkaline batteries due to possible electrolyte interaction.

Inspection and Servicing:
- Provide safe means for inspecting and servicing batteries, including adequate lighting and access.
- Seafarers engaged in topping up batteries should wear personal protective clothing.

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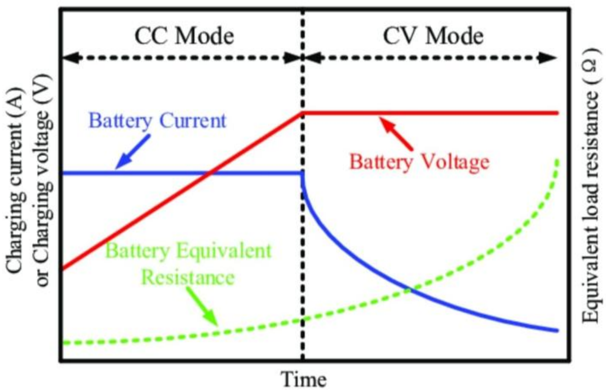
a) Compare constant current method and constant voltage method of charging batteries (6)
(b) A 24V emergency battery is to be charged from the 110V ship' mains when the e.m.f per cell has fallen to a minimum value of 1.8V. The battery consists of 12 cells in series, has a capacity of 100Ahr at a 10 hr rate and the internal resistance is 0.032/cell. If charging continues until the voltage per cell rises to 2.2V, find the values of the variable resistor needed to control the charging. The charging current can be assumed to be equal to the maximum allowable discharge current (10)

Feb 2023 | Feb 2024

(a)



- The constant voltage charging is more rapid than the constant current charging. The time of charge in a constant voltage system as compared to the constant current system is almost reduced to half.
- In a constant voltage charging method of battery, the charging current from discharged to fully charged condition decrease.
- The current control mode is used for constant battery charging.
- The constant current charging is more efficient than the consonant voltage charging as in case of constant voltage charging the charging current may be excessive which causes heating of the battery during charging.

- The practical charging method uses two types of sources. The constant current charging at the start where the battery is relatively empty.* Once the battery reaches a certain voltage near the maximum voltage then constant voltage charging is accomplished.

(b)
24 V battery charged by 110 V main
V_{min} = 1.8 V
Number of battery = 12
Capacity = 100 Ah
Rate = 10 hr
R = 0.03 Ω/cell
V_{max}= 2.2V

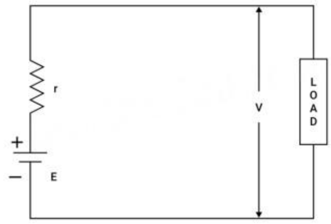
Total internal resistance:
R_{int} = 0.03*12 = 0.36 Ω
Max allowable current:
$I_{max}= \frac{100}{10}$ =10A
Max V= 2.2×12=26.4V
Min V=1.8×12=21.6V
Voltage across battery:
$V_{charging}=V_{max}+I_{max}\times R_{max}$
26.4+10×0.3626.4+10×0.36
$V_{charging}$=30V
Voltage drop:
$V_{resistance}$ =110−30=80V
So,R= $\frac{V}{I} = \frac{80}{10}$
R=8Ω

(a)What are condition under which cells are connected in Series, Parallel, Series & Parallel (6)
(b) The total resistance of a battery of series connected cell is 0.15 Ω. The resistance of a connected load is 0.6 Ω and the terminal voltage at this load is 12 V. Calculate the power loss in the battery (10)

Jan 2023

(a) Connected in series to increase voltage, connected in parallel to increase current, connected in series and parallel to increase voltage and current.
In series circuit electrons travel only in one path. Here the current will be the same which passes through each resistor. The voltage across resistors in a series connection will be different. Series circuits do not overheat easily. The design of series circuit is simple compared to parallel circuits.
In parallel circuit electrons travel through many branches in it. In this case, the voltage remains the same across each resistor in the circuit. Here the current in the circuit is divided among each branch and finally recombines when the branches meet at a common point. A parallel circuit can be formed in many ways, which means cells can be arranged in different forms. Parallel circuits can be used as a current divider.

(b) Given:
Terminal voltage (V) = 12V
Internal resistance (r) = 0.15Omega
Load resistance (R) = 0.6 Ω



Current, I = V/R = 12/0.6 =20Amps

Power loss in the battery = 1^2r

= $20^2 * 0.15$ = 60W

Sketch and describe an arrangement for automatic connection of emergency batteries upon loss of main power. Include in your answer:

(i) Means of obtaining d.c charging supply from a.c mains (3)

(ii) A method of maintaining charge on lead acid batteries (3)

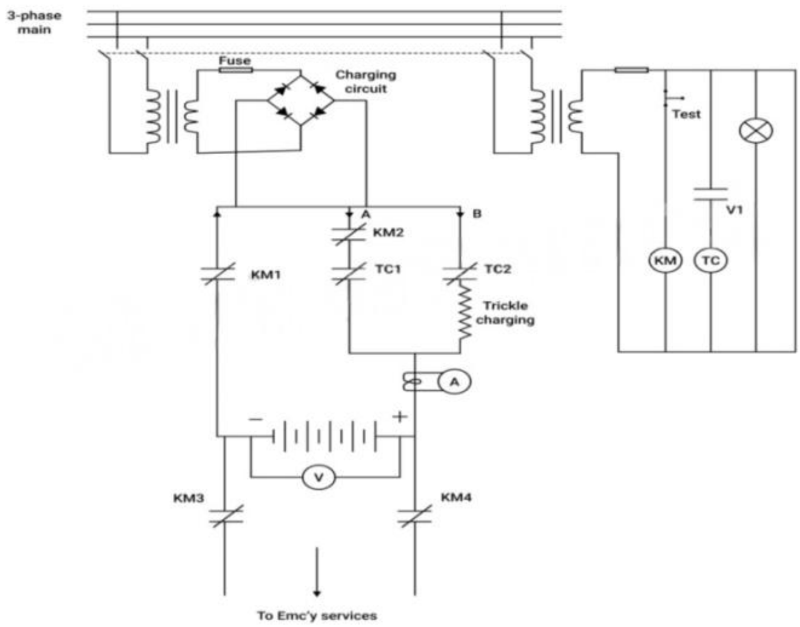
(iii) The arrangement to check the batteries operate at a loss of main power.(2)

(iv) The length of time for which emergency battery of passenger and cargo ship must provide power (2)

(b) write short notes on primary and secondary cells. (6)

Oct 2022

(a)



The DC charging supply is obtained from the main busbar. A transformer will step down the voltage to required charging voltage and a rectifier will provide DC voltage at required charging emf. When charging from a discharged state, emf is supplied through a branch 'A' at full charging voltage

A voltage monitor 'V' monitor the voltage of the cell and gets energised when cell its full charge emf of 2.2V/cell.

'V' closes contact V1 and energises contact 'TC', then TC gets open and TC2 gets closed and current passes through a resistor for trickle charging.When main power failure occurs, the contactor KM gets de-energised, so contacts KM1 & KM2 get open and KM3 & KM4 are closed. Opening of KM1 & KM2 isolates the battery from charging circuit and KM3 and KM4 closes to allow the battery to supply to emergency services.A test switch provides means for testing the battery.

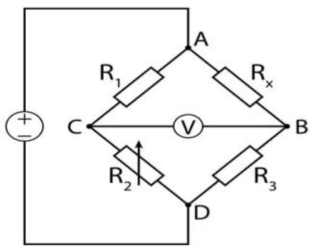
(b) Primary cells are single-use batteries that are not rechargeable. They are commonly used in devices that require a small, portable power source, such as flashlights, remote controls, and smoke detectors. Primary cells are typically made of chemicals that produce a chemical reaction when they are used, which generates electricity.

Secondary cells, on the other hand, are rechargeable batteries. They are typically used in devices that require a longer- lasting power source, such as laptops, cell phones, and electric vehicles. Secondary cells are made of chemicals that can be recharged by applying a current to them, reversing the chemical reaction that occurs when they are used. Some common types of secondary cells include lead-acid batteries, nickel-cadmium batteries, and lithium-ion batteries.

(a) Discuss on Wheatstone bridge and one of its applications, namely "on all electric gear".(12)

(b) Compare lead acid batteries with alkaline batteries (4)

Jul 2022



A Wheatstone bridge is an electrical circuit that measures an unknown resistance value by maintainin g a balance between two legs of a bridge circuit. The primary advantage of using the Wheatstone bridg e is its accuracy in finding the unknown (electrical resistance) value when compared to instruments lik e a simple voltage divider. Wheatstone Bridge R_1, R_2 and R_3 are the resistances of known value and the resistance R_2 is the one which has to be adjusted until no current flows through the galvanometer V. This condition where the current through the Galvanometer is zero and thus voltage between two midp oints B & C also comes to be zero is called the balanced bride condition of Wheatstone bridge. Therefore the ratio of two resistances in one leg (R_1/R_2) is equal to the ratio of another two resistances i n the other leg (Rx/R_3). If somehow the bridge is unbalanced, the direction of the current indicates whe ther R_2 is too high or too low.

At bridge balanced condition,

$R_1/R_2 = R_x/R_3$

and hence $Rx = R_3 * (R_1/R_2)$ could be measured easily.

Applications of Wheat Stone Bridge:

- Strain measurement
- Light detector using Wheatstone Bridge
- Light measurement using a photoresistive device (a light-dependent resistor is placed as a substitute for one of the resistors)
- Measuring strain with the help of a Bridge (strain gauge is used in place of the variable resistor)
- It is also used for sensing mechanical and electrical quantities.
- The circuit is used to measure the changes in pressure.
- It is used in thermometers for temperature measurements with high accuracy.

Calculations

- **Notes:**

(a) Explain how excitation of the rotor is produced and supplied. (6)
(b) A 25 kVA, single phase transformer has 250 turns on the primary and 40 turns on the secondary winding. The primary is connected to 1500 V, 50 Hz mains calculate: (10)
(i) Secondary emf
(ii) Primary and secondary current on full load
(iii) Maximum flux in the core.

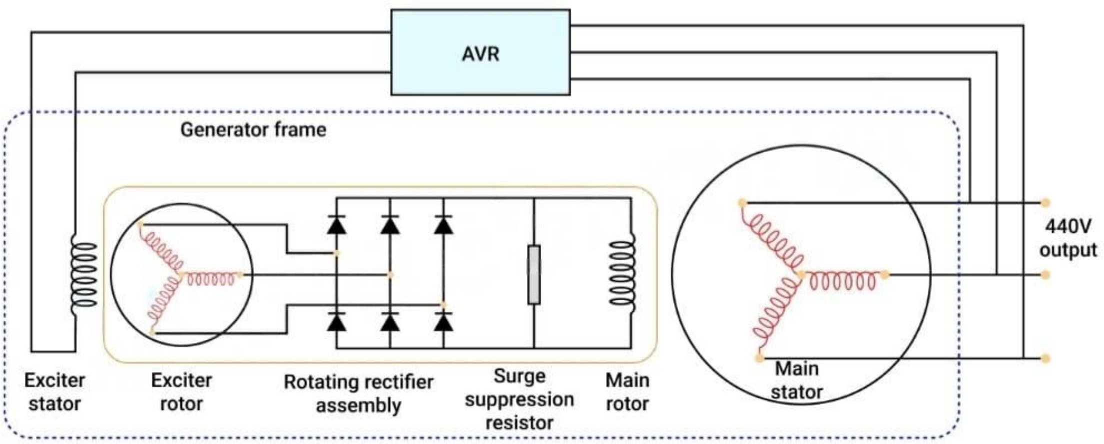
Feb 2025

(a) In an AC generator, excitation of the rotor is a process that involves creating a magnetic field in the rotor, leading to the generation of alternating current in the stator windings. Excitation is necessary to induce the flow of electric current within the generator.

There are typically two main types of excitation systems in AC generators: brushless excitation systems and brush excitation systems.

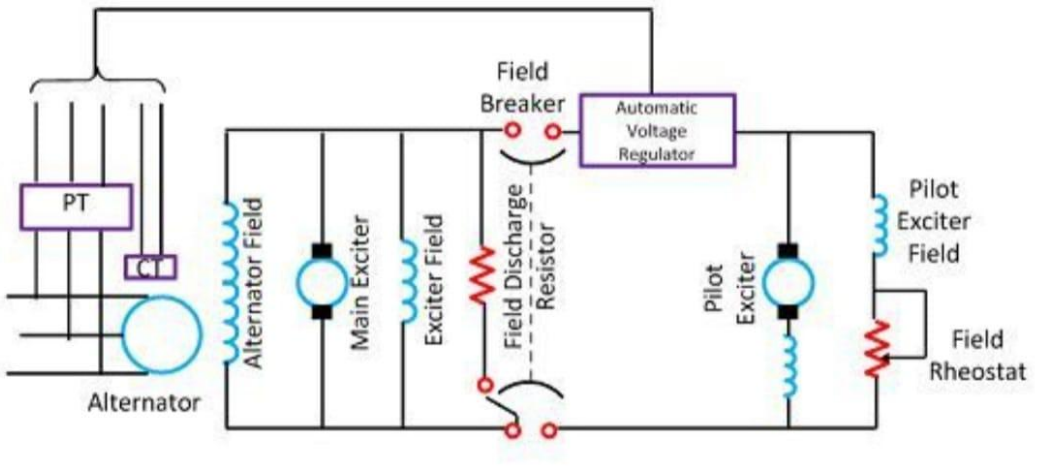
Brushless Excitation System: In brushless excitation systems, the rotor is equipped with a rotating field winding. The excitation process involves the following steps:

- **AC Voltage Generation:** The stator windings of the generator produce an initial AC voltage. This voltage is often derived from an auxiliary AC power source or from the generator itself during initial startup.
- **Rectification:** The AC voltage is then rectified into DC voltage by a rectifier system. This system usually includes diodes or thyristors (SCRs) that convert the AC voltage into a unidirectional flow of current.
- **Rotor Excitation:** The DC voltage is supplied to the rotor winding, creating a magnetic field. This field induces an electromotive force (EMF) in the stator windings, leading to the generation of AC power.
- **Voltage Regulation:** The excitation system may include a control mechanism to regulate the DC voltage supplied to the rotor. This control ensures that the generator output voltage remains stable and within the desired range.



- **Brush Excitation System:** In brush excitation systems, the rotor is equipped with a direct current (DC) field winding. The excitation process involves the following steps:
- **External DC Source:** A separate DC source, often a DC generator or a rectified DC power supply, provides the initial excitation to the rotor.
- **Rotor Winding Excitation:** The external DC source supplies a constant DC voltage to the rotor's field winding, creating a strong and steady magnetic field.
- **AC Voltage Generation:** As the rotor rotates within the stator windings, the magnetic field induces an AC voltage in the stator windings, generating electrical power.

- **Voltage Regulation:** Similar to the brushless excitation system, a control mechanism is employed to regulate the DC voltage supplied to the rotor, ensuring stable generator output.



DC Excitation System

(b) Given:
P=25kVA $=25\times10^3$VA
N1=250
N2=40
V1=1500
F=50Hz
To find:
(i) Secondary emf(V2)
$\frac{N1}{N2}=\frac{V1}{V2}$
V2=V1×N2/N1
$=1500\times\frac{40}{250}$
V2=240V

(ii) Primaryandsecondarycurrent(I1andI2)(ii)Primaryandsecondarycurrent(I1andI2)
P=VI
$P=V_1I_1$
I_1=P/ V1
$I_1=\frac{25\times103}{1500}$
I_1=16.667A
$P= V_2I_2$
$I_2=\frac{25*103}{240}$

iii) Max Flux in core:
Use induced voltage formula and solve for φm
V_2= φm*4.44*N_2*f
$\varphi m=\frac{V2}{4.44*N2*f}$
$\varphi m=\frac{240}{4.44*40*50}$
φm = 0.027wb

(a) What is the difference between a DC Generator and a DC motor? (6)
(b) A 4-pole, 32 conductor, lap-wound DC shunt generator with terminal voltage of 200 V delivering 12 A to the load has Ra = 2 and the circuit resistance of 200 Ω. It is driven at 1000 RPM. Calculate the (10)
(i) Flux per pole of the machine.
(ii) If the machine has to be run as motor with the same terminal voltage and drawing 5 A from mains, maintaining the same magnetic field, find the speed of the machine.

Dec 2024 | Mar 2025 | Jun 2023

(a) Differences between DC Generator and DC motor.
Function:
- DC Generator: Converts mechanical energy into electrical energy. It generates a direct current (DC) output voltage when a conductor moves within a magnetic field.
- DC Motor: Converts electrical energy into mechanical energy. It utilizes a direct current to produce rotational motion.
  Operational Principle:
- DC Generator: Operates based on Faraday's law of electromagnetic induction. When a coil or conductor cuts through magnetic lines of flux, an electromotive force (EMF) is induced in the conductor, resulting in electrical voltage.
- DC Motor: Operates based on the principle of the Lorentz force. When a current-carrying conductor is placed in a magnetic field, a force is exerted on the conductor, causing it to move.

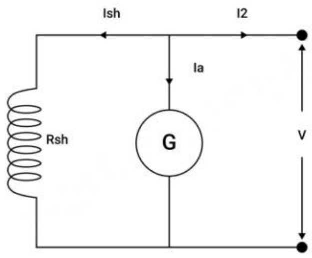
Construction:
- DC Generator: Typically consists of a coil (armature), a magnetic field (provided by field windings or permanent magnets), and a commutator and brushes.
- DC Motor: Comprises a coil (armature), a magnetic field (provided by field windings or permanent magnets), and a commutator and brushes.
  Output and Input:
- DC Generator: Takes mechanical input (rotation) and produces electrical output (voltage/current).
- DC Motor: Takes electrical input (voltage/current) and produces mechanical output (rotation).

Commutation:
- DC Generator: Utilizes a commutator to convert alternating current (AC) generated in the armature coils into direct current (DC).
- DC Motor: Utilizes a commutator to maintain a unidirectional current flow in the armature, ensuring continuous rotation.
  Use Cases:
- DC Generator: Used in applications where a portable or backup source of DC power is needed, such as in small power plants, battery charging, or certain types of electric vehicles.
- DC Motor: Widely used in various applications, including electric vehicles, industrial machinery, robotics, and household appliances.

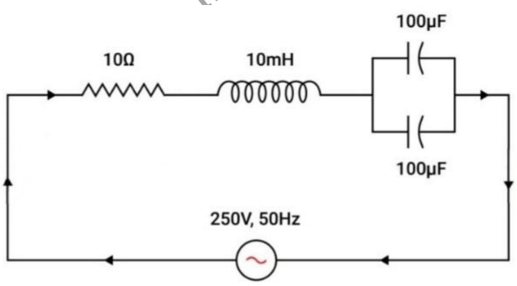
(b) Given:
P=4P=4
A=P(lap)
Z=32
V=200V

I_L=12A
Ra=2Ω
Rsh=200Ω
N=1000rpm

When running as a generator, shunt current



$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{200}$=1A
Armature current, Ia=IL+ Ish=12+1=13A
EMFinduced, Eb=V+ IaRa=200+(13×2)=226V
$Eb=\frac{\phi ZNP}{60A}$
$\phi = \frac{226\times 60}{32\times 1000}$ =0.423wb
When running as a motor, Armature current

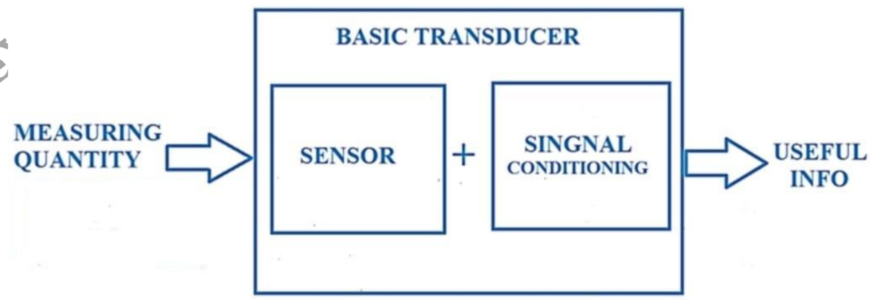


Ia= Il-Ish = 5-1= 4A
EMF induced, Eb= V-IaRa = 200(4*2)
Eb= 192V

(a) Explain what do you understand by the term 'transducer'? (6)
(b) A coil of resistance 10 Ω and inductance 100mH is connected in series with two parallel capacitors each of value 100 μF across a 250 V, 50Hz supply. Determine: (10)
(i) The circuit current
(ii) The total power factor
(iii) The power taken from the supply.

Dec 2024

(a) A transducer is a device which converts one form of energy into another form of signal most commonly a non electrical quantity to a readable electrical quantity. They are used for measurements of physical properties and in automation systems.



Transducers can be classified according to their electrical operation principles,

- Passive transducers can change the resistance, inductance and capacitance value in an electric network. Accordingly to the change of physical quantity being measured and their output is a measure of some variation. The various examples included are strain gauge, LVDT etc. They require an external power excitation.
- Active transducers where it can convert non-electrical energy (say, temperature, pressure, etc.) into an electrical output. They do not require an external power and their output is an analog voltage or current. Example: thermocouples.
  The following parameters are taken into consideration when selecting a transducer for a specific application
- Operating range - The input physical signals can be converted to electrical signals by the sensor. The signals apart from the range of a sensor cause unacceptably large inaccuracy
- Sensitivity - The relationship between the output electric signal and input physical signal.
- Accuracy - It is the largest expected error between actual and ideal output signals taken at any point within the range.
- Noise – The sensors will produce output noise with the output signal generated. The noise being produced will limit the system based performance in the sensor.

(c) Given:

Resistance(R)= 10Ω

Inductance(L)= 100mH =100×10−3H

Capacitance(C)=two capacitors connected in parallel with 100μF each

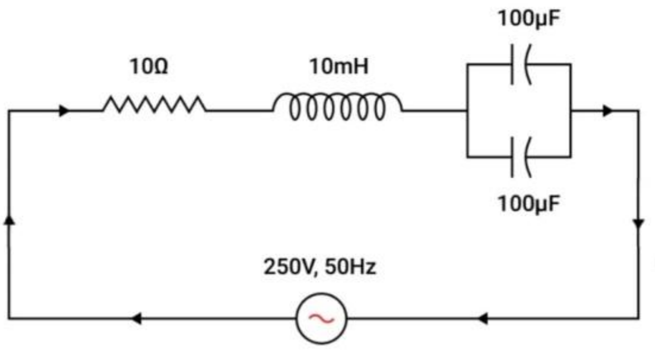
So, total capacitance in parallel, CT=C1+C2

So, wehave=100+100μF

$C=200\times10^{-6}F$

V=250V

Frequency=50Hz



To calculate total impedence, $Z=\sqrt{R^2+(X_L-X_C)^2}$

$X_L=\omega L=2\pi fL=2\times3.14\times50\times0.1=31.4\Omega$

$X_C=\frac{1}{\omega c}=\frac{1}{2\pi fL}=\frac{1}{12\times3.14\times50\times200\times10-6}=15.92\ \Omega$

$Z=\sqrt{(10^2)+(31.14-15.92)^2}=\sqrt{100+15.48^2}$

Z= Total impedence = 18.43Ω

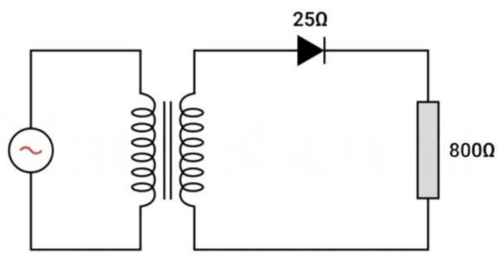
(i)Current in circuit= V= IZ

$I=\frac{V}{Z}=\frac{250}{18.43}=13.56A$

(ii) Power Factor= $\cos\theta=\frac{R}{Z}$

$\text{Cos}\theta=\frac{10}{18.43}=0.5425$

(iii)

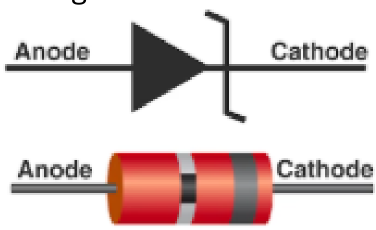


Power taken; P=VI cosφ = I^2R
P= (13.56)2*10
P= 1838.7W
P=1.8387KW

(a) What is a zener diode? (6)
(b) Find the generated e.m.f./conductor of a 6-pole d.c generator having a magnetic flux/pole of 64mWb and a speed of 1000 rev/min. If there are 468 conductors, connected in six parallel circuits, calculate the total generated e.m.f. of the machine. Find also the total power developed by the armature when the current in each conductor is 50A. (10)

Dec 2024

(a) Zener Diode:
A Zener diode is a p-n junction semiconductor designed to operate in its reverse breakdown region. When a reverse voltage (anode to negative, cathode to positive) is applied and reaches the Zener voltage, the diode undergoes breakdown, allowing a large current to flow while maintaining a relatively constant voltage across it.



(Zener diode)

Applications: Voltage regulation, voltage comparison in automatic voltage regulators (AVRs).

(b) Given
P=6=A
$\phi=64\times10^{-3}$wb
N=1000rpm
Z=468
To find

- EMF
- Power developed when current in each conductor is 50A

We know that
E= $\frac{P\phi NZ}{60}$
E= $\frac{6\times64\times10-3\times1000\times468}{60*6}$
E=499.2V
Now, Current per conductor = 50A
Current in 6 parallel path is
50×6=300A
So power developed=EMF×I
=499.2×300 =149.8kW

(a) Explain about non-linear resistors with some examples and illustration on how they differ from linear resistor. (6)
(b) A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required. (10)

May 2024 **Oct 2024**

(a) The non-linear resistor is a resistive component that doesn't change linearly in response to voltage, current, temperature, or other parameters. Non-linear resistors are used for a variety of purposes, including:

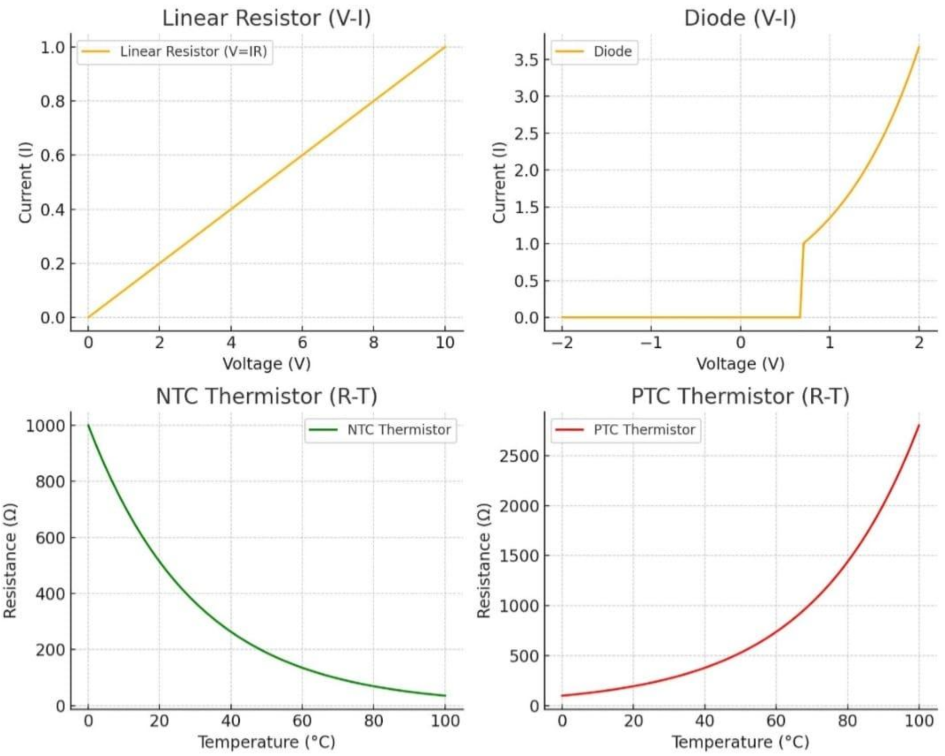
- **Transient and surge protection:** Non-linear resistors can help protect circuits from transient and surge issues.
- **ESD protection:** Non-linear resistors can help protect circuits from ESD issues.
- **Temperature detection and compensation:** Non-linear resistors can help detect and compensate for temperature changes.

There are several types of non-linear resistors, including:

- Light-dependent resistors (LDRs): These resistors have a resistance that decreases as light increases.
- Voltage-dependent resistors (VDRs): These resistors have a resistance that decreases significantly when the voltage exceeds a certain value.
- Thermistors: These resistors are sensitive to temperature changes.
- NTC Thermistors (Negative Temperature Coefficient): Resistance decreases as temperature increases.
- PTC Thermistors (Positive Temperature Coefficient): Resistance increases with temperature.
- Varistors: These resistors are sensitive to current changes
- Memristors: These resistors depend on the previous stage.

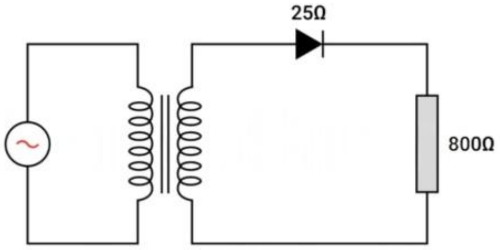
Illustration of V-I Curves:

- Linear Resistor: The graph is a straight line, showing a constant slope representing constant resistance.
- Non-Linear Resistors: The V-I graph is curved, indicating that the resistance changes with voltage and current.



The difference between linear and non-linear resistance is based on the relationship between the current and voltage in a circuit element. A component with non-linear resistance will have a non-linear I-V curve.

(b)



Given:
Vdc = 50 V
RL=800Ω
Rd=25Ω
Idc= $\frac{Vdc}{RL}$ = $\frac{50}{800}$ =0.0625
Imax =Idc×π
=0.0625×π = 0.0625×π
Imax = 0.196A
Vmax = Imax×(RL+Rd)
=0.196×(800+25)
Vmax = 161.7V
Vrms = $\frac{Vm}{\sqrt{2}}$ = $\frac{161.7}{\sqrt{2}}$
Vrms =114.3

(a) Discuss the open circuit and short circuit test performed for transformer (6)
(b) The primary and secondary windings of a 30 KVA, 76000/230 V, 1 ph transformer have resistance of 10 Ω and 0.016 Ω respectively. The reactance of the transformer referred to the primary is 34 Ω. Calculate the primary voltage required to circulate full load current when the secondary is short circuited. What is the power factor on the short circuit? (10)

Dec 2024

(a) Open Circuit Test:
The primary purpose of the open circuit test, also known as the no-load test, is to determine the core losses and exciting current when the transformer is under no-load conditions. To carry out open circuit test, proceed as follows:

- Connect the transformer to a variable AC voltage source.
- Keep the secondary winding open-circuited.
- Gradually increase the voltage until the rated voltage is reached.
- Record the input voltage, current, and power.

Short Circuit Test:
The short circuit test, also known as the impedance test or the full-load test, is conducted to determine the copper losses and leakage reactance of the transformer under full-load conditions. Short circuit test is described as follows:

- Connect the transformer to a variable AC voltage source.
- Short-circuit the secondary winding.
- Gradually increase the voltage until the rated current is reached.
- Record the input voltage, current, and power.

(b)

Transformation ratio,K= $\frac{230}{6000} = \frac{23}{600}$

Equivalent resistance referred to primary, R_{01} = R1 +$\frac{R2}{K2}$

10+0.016(600/23)^2=20.89Ω

Equivalent reactance referred to primary,,X_{01}=34Ω

Equivalent impedance referred to primary, Z_{01}= $\sqrt{(R_{01})^2+(X_{01})^2}$

=√(20.89)2+(34)2= 39.904Ω

Full-load primary current,,$I_1 = \frac{\text{RatedKVA}\times 1000}{V1}$

= $\frac{30\times 1000}{6000}$ =5A

Primary voltage required to circulate full load current when the secondary is short-circuited

$V_s = I_1 Z_{01}$

5×39.904=199.52V

Power factor on short circuit:

PF(Cosϕ)=($\frac{Ra}{Za}$)=($\frac{20.89}{39.90}$)

Cosφ = 0.52

(a) What are the different types of DC motors? (6)

(b) A 10 H.P. 230 V shunt motor takes an armature current of 6A from 230 V mains at no load runs at 1200 r.p.m. The armature resistance is 0.25Ω. Determine speed and electromagnetic torque when the armature takes 36 amps. with the same flux. (10)

May 2024 **Oct 2024**

(a) D.C motors are classified as series, shunt and compound motors based on these armature and field winding connections.

- Series motor: In series motor field windings are connected in series with the armature windings
- Shunt motor: In the shunt motor field, windings are connected in parallel with the armature winding.
- Compound motor: These have both series and shunt field windings. Compound motors are classified as long-shunt and short-shunt compound motors
- In long shunt compound motors, the shunt field winding is connected parallel to the series combination of series field and armature winding
- In a short shunt compound motor, the series field is connected series to the parallel combination of the armature and shunt field winding.
  The compound motors are further classified into cumulative and differential compound motors.
- In cumulative compound motor, series field flux and shunt field flux are in the same direction.
- In differential compound motor, series field flux opposes the direction of shunt field flux.

(b) Given:

Power=10hp

V=230V

Ia1=6A

Ia2=36A

Ra=0.25Ω

No load:

Eb1=V−(Ia1×Ra)

Eb1=230−(6×0.25)

=228.5V=228.5V

At 36A:

Eb2=V−(Ia2×Ra)

Eb2=230−(36×0.25)

=221V

$\frac{Eb1}{Eb2} = \frac{N1}{N2}$

N2= $\frac{1200\times221}{228.5}$

N2=1160.6RPM

Torque:

Power=$\frac{2\pi NT}{60}$

Pout=Eb×Ia

=221×36=7956W

7956=$\frac{2\pi\times1160.6\times T}{60}$

T=65.47Nm

A 4 pole, lap wound shunt generator delivers 200 A at terminal voltage of 250 V. It has a field and armature resistance of 50 Ω and 0.05 Ω respectively.

Determine: (16)

(a) Armature current

(b) Generated e.m.f

(c) Current per armature parallel paths

(d) Power developed

May 2024-2 | **Apr 2025-1** | **Aug 2024**

Given:

Number of poles = 4

Load current, I_L=200A

Terminal voltage, V=250V

Armature resistance, Ra=0.05Ω

Shunt resistance, Rsh=50Ω

To find:

(i) Armature current, Ia=?

Current per parallel path=?

EMF generated, Eg=?E_g = ?, Eg=?

Power delivered to load= ?

Solution:

(i) Armature current We know that the shunt field current is calculated using:

Ish= $\frac{V}{Rsh} = \frac{250}{50}$ =5A

The armature current is calculated using,

Ia=IL+Ish

=200+5=205=200+5 = 205

Armature current,Ia = 205A

(ii) Current per parallel path

Current per parallel path = $\frac{\text{Armaturecurent,Ia}}{\text{Number of poles,P}} = \frac{Ia}{4} = \frac{205}{4}$= 51.25A

(iii) EMF generated Eg = V+Ia Ra

= 250+205*0.05 = 260.25

EMF generated, Eg = 260.25V

(iv) Power delivered power = Eg Ia

= 260.25*205 = 53.35 kw

(v) Power delivered = 53.35 KW

An amplifier has an open-circuit voltage gain of 1000, an input resistance of 2000 Ω and an output resistance of 1.0 Ω. Determine the input signal voltage required to produce an output signal current of 0.5A in a 4.0Ω resistor connected across the output terminals. If the amplifier is then used with negative series voltage feedback so that one tenth of the output signal is fed back to the input, determine the input signal voltage to supply the same output signal current.

May 2024 | **Oct 2024**

A_0= 1000

R_{in}= 2000Ω

R_{out} = 1Ω

V_{in}= ?

I_2= 0.5 A

R_L= 4Ω

Current gain , Ai = $\frac{A0*Rin}{Rout+Rl} = \frac{1000*2000}{1+4}$ = 4*10^5

$I_1 = \frac{I2}{I1} = \frac{0.5}{4*105}$ = 1.25* 10^{-6} A

→V_{in} = I_1 R_{in} = 1.25*10^{-6} *2000 = 2.5*10^{-3}V

With Feedback:

$\beta = \frac{1}{10}$; V=?

A= $\frac{Ao*Rl}{Rout+Rl} = \frac{1000*4}{1+4}$ = 800

R_{if} = R_{in} (1+β A)

=2000(1+ ($\frac{1}{10}$ *800))

=1.62* 10^2 Ω

V= I_1 R_{if} = 1.25*10^{-6} * 1.62*10^5

=0.2025 V

(a) Describe the basic principles of self-excited generators (6)

(b) The armature resistance of a 200V-shunt motor is 0.4 Ohms. The no load (this is the term used when the motor is running light, i.e. not loaded) armature current is 2A. When loaded and taking an armature current of 50A, the motor speed is 1200 rev/min. Find the approximate no load speed (10)

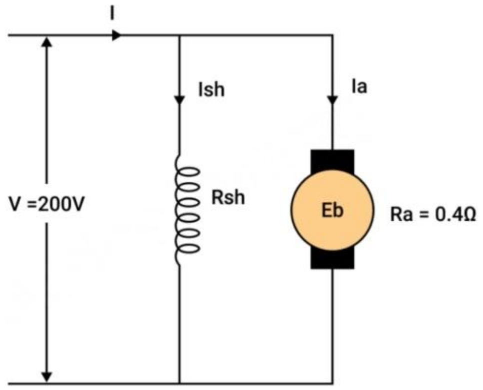
Apr 2024 | **Jan 2025**

(a) The basic principles of a self-excited generator:

When the generator is first started, there is a small amount of residual magnetism in the rotor winding. This residual magnetism is due to the fact that the rotor winding is made of ferromagnetic material, which retains a small amount of magnetism even when there is no current flowing through it. The prime mover (usually a diesel engine or a turbine) rotates the rotor of the generator. As the rotor rotates, the residual magnetism in the rotor winding induces an electromotive force (EMF) in the stator winding. The EMF induced in the stator winding is proportional to the speed of rotation of the rotor and the strength of the residual magnetism.

The EMF induced in the stator winding is fed to the automatic voltage regulator (AVR). The AVR rectifies the AC from the stator winding and uses it to excite the rotor winding. The DC current from the AVR flows through the rotor winding, creating a magnetic field. This magnetic field interacts with the residual magnetism in the rotor winding, creating a stronger magnetic field. The stronger magnetic field induces a higher EMF in the stator winding.

(b) Given,
$V=200V$
$R_a=0.4\Omega$
$I_{a1}=2A$
$I_{a2}=50A$
$N_2=1200$
$N_1=?$ $N_1=?$

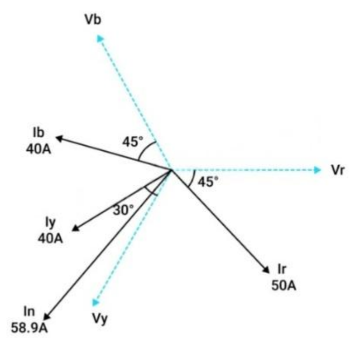


Back EMF at NO LOAD:
$E_{b1}= V-(I_{a1}R_a)$
$=200-(2\times0.4)$
$=199.2V$
Back EMF at LOAD:
$E_{b2}=V-(I_{a2}R_a)$
$=200-(50\times0.4)$
$=180V$
We know,
$E_b \propto N$
$\frac{Eb1}{Eb2}=\frac{N1}{N2}$
$\frac{199.2}{180}=\frac{N1}{1200}$
$N_1=\frac{199.2}{180}\times1200$
$N_1=1328$ rpm

The loads of a 4-wire, 3-phase systems are:
Red line to neutral current = 50 A, power factor of 0.707 (lagging)
Yellow line to neutral current = 40 A, power factor of 0.866 (lagging)
Blue line to neutral current = 40 A, power factor 0.707 (leading)
Determine the value of the current in the neutral wire. (16)

Apr 2024 **Jan 2025**

With reference to below diagram
Ir=50 A lagging the voltage by 45° since cos45=0.707
Iy=40 A lagging the voltage by 30° since cos30=0.866
Ib=40 A lagging the voltage by 45° since cos45=0.707



Resolving the horizontal and vertical components
$I_h=(50\times\cos45)-(40\times\cos 30)-(40\times\cos15)$
$=(50\times0.707)-(40\times0.866)-(40\times0.966)$
$=35.35-34.64-38.64=-37.93A$
$I_v=-(50\times\sin 45)-(40\times\sin30)+(40\times\sin15)$ $Iv=-(50\times\sin 45)-(40\times\sin30)+(40\times\sin15)$
$=-(50\times0.707)-(40\times0.5)+(40\times0.259)=-(50\times0.707)-(40\times0.5)+(40\times0.259)$
$=-35.35-20+10.36=-44.99=-35.35-20+10.36=-44.99$
Current in the neutral (In) is the resultant of
$I_n=\sqrt{37.93^2+44.99^2}=58.9$ A=58.9A

Cos θ=$-\frac{-37.93}{58.9}$ =−0.643

θ=49.5°

Note: the -ve sign gives the quadrant in which In lies. This is shown on the diagram

---

(a) Describe the effect of running an induction motor on reduced voltage.
(b) A motor takes a current of 60 amperes at 230 volts, the power input being 12 kW. Calculate the power component and the reactive component of the input current. (10)

Oct 2023

(a) 1. Reduced Starting Torque:
The starting torque of an induction motor is proportional to the square of the voltage. When the voltage is reduced, the starting torque decreases significantly. This can result in the motor struggling to start or taking a longer time to reach full speed, especially under heavy load conditions. This can also cause mechanical stress and overheating.

2. Higher Current Draw:
To produce the same mechanical output at reduced voltage, the motor will draw more current. This increased current can lead to overheating of the windings and other electrical components, potentially damaging the insulation and leading to a shorter lifespan or even motor failure.

3. Reduced Efficiency:
When running at reduced voltage, the motor operates at a lower efficiency. The motor will consume more power for the same output, resulting in energy wastage. This inefficiency is caused by increased copper losses (I^2R losses) due to higher current.

4. Excessive Heating:
The higher current draw at reduced voltage increases the I^2R losses in the motor windings. This leads to excessive heating, which can damage the motor's insulation, reduce its lifespan, and in extreme cases, cause winding failure.

5. Reduced Speed:
The motor may run at a slightly lower speed than its rated speed due to the lower voltage. In induction motors, the speed is determined by the frequency of the supply, but running at reduced voltage may cause a small reduction in speed, particularly under load.

6. Vibration and Noise:
Reduced voltage can lead to unstable or uneven motor performance, resulting in increased vibration and noise. This happens because the motor is not able to maintain steady torque under reduced voltage conditions, leading to mechanical stress and potentially damaging motor components over time.

7. Risk of Stalling:
If the motor is running under heavy load, reduced voltage may not provide enough torque to sustain rotation, causing the motor to stall. A stalled motor under load draws a large current, which can cause overheating and eventual burnout of the windings.

(b) Given:
I=60amps
V=230V
P=12kW
1. Calculate the Power Factor: The Power Factor (PF) is calculated using the formula
PF= $\frac{\text{Pinput}}{\text{V} \times \text{I}}$

Where,

- **P** is the power input
- **V** is the voltage
- **I** is the current

PF= $\frac{12000}{230\times60} = \frac{12000}{13800}$ =0.87

2. Calculate the power component of the current: The power component of the current
Ip= I×PF
Ip=60×0.87=52.2A

3. Calculate the Reactive Component of the current: The reactive component of the current Iq is calculated using the Pythagorean theorem in the context of power triangle

$Iq=\sqrt{I^2-Ip^2} = \sqrt{60^2-52.2^2}$

$= \sqrt{3600-2724.84}$

$=\sqrt{875.16}$

= 29.58A

The power component for the input current is 52.2A and the reactive component is 29.58A.

(a) Explain the principle of conservation of charge and its relationship to Kirchhoff's current law. (6)
(b) The open-circuit voltage of a cell as measured by a voltmeter of 100 ohm resistance, was 1.5 V, and the p.d. when supplying current to a 10 ohm resistance was 1.25 V, measured by the same voltmeter. Determine the e.m.f. and internal resistance of the cell. (10)

Apr 2024 **Jan 2025**

(a) Conservation of Charge:
The fundamental principle is that in an isolated system, the total electric charge remains constant; charge cannot be created or destroyed, only transferred.

Kirchhoff's Current Law (KCL):
KCL, or the junction rule, states that at any junction (or node) in a circuit, the sum of currents entering the junction must equal the sum of currents leaving the junction.
The Connection:
Since current is the flow of electric charge (I = Q/t, where Q is charge and t is time), if the total charge entering a junction equals the total charge leaving it, then the total current entering must equal the total current leaving.

(b) Given:
Open circuit
$R_1=100\Omega$
$V_1=1.5V$
Close circuit
$R_2=10\Omega$
$V_2=1.25V$
To find
EMF (E) and R_i
Formula
$E=V+IR_1$
V=IR
In closed circuit, current taken by resistor

$I = \frac{v}{R}$

$I_2 = \frac{V2}{R2} = \frac{1.25}{10} = 0.125$ A

Current taken by voltmeter which has 100Ω resistor

$I_1 = \frac{V2}{R1} = \frac{1.25}{100} = 0.0125$A

$I = I_1 + I_2$

I=0.0125+0.125

I=0.1375A

Since the voltmeter is connected in parallel, we use Kirchoffs current law

$E = V + IR_i$

Apply V and I in equation

$E = 1.25 + (0.1375)R_i$------①

$E = 1.25 + (0.1375)R_i$------①

In open circuit current taken by voltmeter

$I = \frac{V1}{R1} = \frac{1.51}{100}$

I=0.015A

So,

$E = V + I_{ri}$

$E = 1.5 + (0.015)R_i$------②

Equation ❶= ❷

$1.25 + 0.1375R_i = 1.5 + 0.015R_i$

$0.1375\ R_i - 0.015R_i = 1.5 - 1.25$

$(0.1375 - 0.015)R_i = 0.25$

$0.122R_i = 0.25$

$0.1225\ R_i - 0.25$

$R_i = \frac{0.25}{0.1225} = 2.041Ω$

Apply Ri in equation 2

$E = 1.5 + 0.015(R_i)$

E= 1.5+(0.015 * 2.041)

E= 1.5 + 0.031

E= 1.531V

EMF = 1.531V

Internal resistance = 2.041Ω

(a) Define work, Power and Efficiency (6)

(b) A shunt motor has an armature resistance of 0.2 ohms and with an armature current of 120 amperes runs at 750 r.p.m. off a 400-volt supply. Calculate the speed and armature current of the motor if the flux per pole is reduced to 75 per cent of its initial value, the total torque remaining unaltered. (10)

Feb 2024 | **Jan 2025 - 1** | **Jul 2024**

(a) Work: is defined as the transfer of energy that occurs when a force is applied to an object and causes it to move in the direction of the force. Work (W) is calculated by multiplying the magnitude of the force (F) applied to an object by the displacement (d) of the object in the direction of the force. Mathematically, work is expressed as W = F * d. The SI unit of work is the joule (J).

Power: Power is the rate at which work is done or the rate at which energy is transferred or converted. It measures how quickly work is performed or how quickly energy is transformed. Power (P) is calculated by dividing the amount of work done (W) by the time (t) taken to do that work. Mathematically, power is expressed as P = work(joules) / t. The SI unit of power is the watt (W).

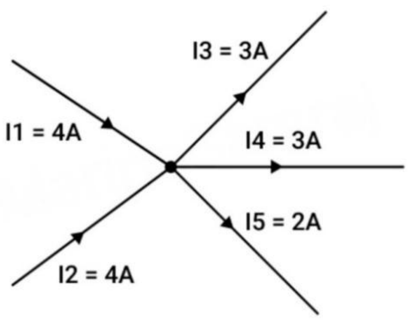
Efficiency: Efficiency is a measure of how effectively a system or device converts input energy into useful output energy. It quantifies the ratio of useful output work or energy to the total input work or energy. Efficiency (η) is calculated by dividing the useful output work or energy (Wout) by the total input work or energy (Win) and multiplying by 100 to express it as a percentage. Mathematically, efficiency is expressed as η = (Wout / Win) * 100.

(b)
Given:
$R_A=0.2\Omega$
N=750rpm
$\phi_2=0.75\phi_1$
$I_A=120A$
V=400V
We know, $T \propto \phi I_A$
But as the total torque is unaltered,
$\phi_1 IA_1=\phi_2 I_{A2}$
$\therefore \phi_1 \times 120=0.75\phi_1 I_{A2}$
$I_{A2}=160A$
$E_{B1}=V-I_{A1}R_A$
$=400-120\times0.2$
$=376V$
$E_{B2}=V-I_{A2}R_A$
$=400-160\times0.2$
$=368V$
$\because EB \propto \phi N$
$\frac{EB1}{EB2}=\frac{\varphi 1 * N1}{\varphi 2 * N2}$
$\frac{376}{368}=\frac{\varphi 1 * 750}{0.75\ \varphi 1 * N2}$
N_2 = 978.72 rpm

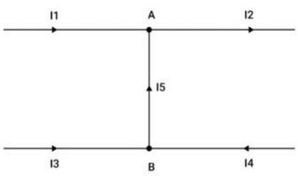
(a) Explain Kirchoff s current law (6)
(b) In the given circuit, find the current value I2 (10)

Feb 2024 | Jan 2025 | Jul 2024 | Feb 2023

(a) Kirchhoff's current law: This law is otherwise known as Kirchhoff's point rule, Kirchhoff's junction rule (or nodal rule) or Kirchhoff's first rule. The principle used in Kirchhoff's current law is on the basis of law of conservation of electric charge.
According to this law, the sum of currents moving towards the circuit is equal to the sum of currents leaving the circuit.



In this circuit I1 + I2 = I3 + I4 + I5
Alternatively, I1 + I2 - I3 - I4 - I5 = 0
According to Kirchhoff's law, the algebraic sum of current in the junction of network is zero. That means, the sum of currents entering a junction in a circuit is equal to the sum of currents leaving the junction.
Below is diagram for part (b) of question



In the node A,
$I_1+I_5-I_2=0$
therefore,
$I_2=I_1+I_5$-----①
In the node b,
$I_3+I_4-I_5=0$
therefore,
$I_5=I_3+I_4$-----②
Substituting equation (2) in equation (1) yields
$I_2=I_1+I_3+I_4$

(a) Differentiate between resistance, inductance and impedance in an a.c. circuit. (6)
(b) A circuit is made up from four resistors of value 2R, 4R, 5R and 10R connected in parallel. If the current is 8.6A, find the voltage drop across the arrangement and the current in each resistor. (10)

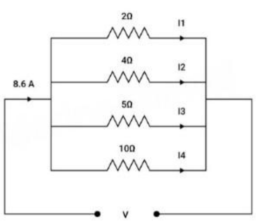
Jan 2024 | Feb 2025 | Nov 2024 | Jun 2024 | Jan 2023

(a) Resistance:
- Resistance (R) represents the opposition to the flow of electric current in a circuit.
- It is caused by the interaction of electrons with the atoms in a material, resulting in the conversion of electrical energy into heat.
- Resistance is measured in ohms (Ω) and remains constant regardless of the frequency of the AC signal.

Inductance:
- Inductance (L) is a property of an electrical circuit that opposes changes in current.
- It is caused by the presence of an inductor, which is a passive component typically made of coiled wire.
- Inductance stores energy in a magnetic field when current flows through it.
- Inductance is measured in henries (H) and increases with the number of turns in the coil and the strength of the magnetic field.

Impedance:
- Impedance (Z) is the total opposition to the flow of alternating current in a circuit, which includes both resistance and reactance.
- Reactance is the opposition to the change in voltage or current caused by inductive or capacitive elements in the circuit.
- Impedance accounts for both resistance and reactance and is represented as a complex number with a real (resistive) component and an imaginary (reactive) component.
- Impedance is measured in ohms (Ω) and depends on the frequency of the AC signal.

(b)



$\frac{1}{R}=\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}=\frac{1}{2}+\frac{1}{4}+\frac{1}{5}+\frac{1}{10}$
R= $\frac{20}{21}$ =0.9523Ω
Voltage drop across the arrangement = 8.6×0.9523 = 8.19V

∴Current in 2Ω resistance, $I_1 = \frac{V}{R1}$ = 28.19 = 4.085A

Current in 4Ω resistance ,$I_2 = \frac{V}{R2}$ =48.19 = 2.0425A

Current in 5Ω resistance, $I_3 = \frac{V}{R3}$ =58.19=1.638A

Current in 10Ω resistance, $I_4 = \frac{V}{R4} = \frac{8.19}{10}$ = 0.819A

(a) Explain how excitation of the rotor is produced and supplied. (6)
(b) A shunt motor has an armature resistance of 0.2 ohms and with an armature current of 120 amperes runs at 750 r.p.m. off a 400-volt supply. Calculate the speed and armature current of the motor if the flux per pole is reduced to 75 per cent of its initial value, the total torque remaining unaltered (10)

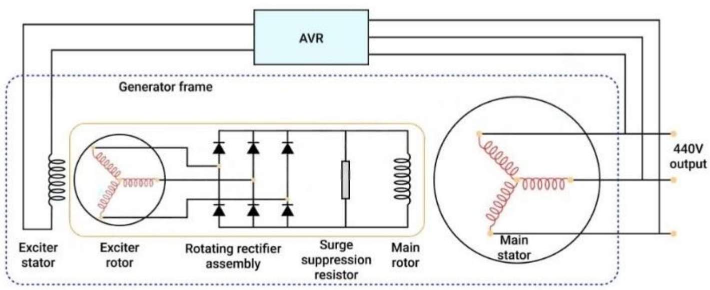
Jan 2024	Nov 2024	Jun 2024	Apr 2023

(a) In an AC generator, excitation of the rotor is a process that involves creating a magnetic field in the rotor, leading to the generation of alternating current in the stator windings. Excitation is necessary to induce the flow of electric current within the generator.

There are typically two main types of excitation systems in AC generators: brushless excitation systems and brush excitation systems.

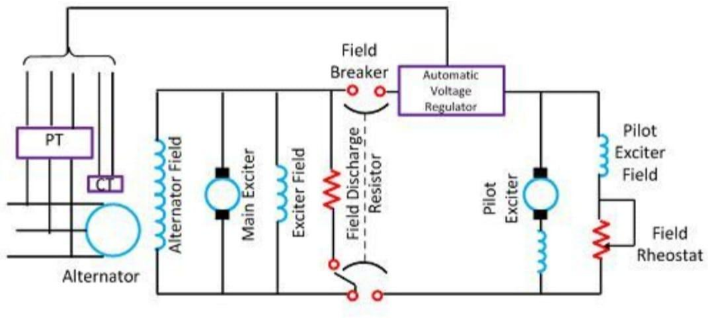
Brushless Excitation System: In brushless excitation systems, the rotor is equipped with a rotating field winding. The excitation process involves the following steps:

- **AC Voltage Generation:** The stator windings of the generator produce an initial AC voltage. This voltage is often derived from an auxiliary AC power source or from the generator itself during initial startup.
- **Rectification:** The AC voltage is then rectified into DC voltage by a rectifier system. This system usually includes diodes or thyristors (SCRs) that convert the AC voltage into a unidirectional flow of current.
- **Rotor Excitation:** The DC voltage is supplied to the rotor winding, creating a magnetic field. This field induces an electromotive force (EMF) in the stator windings, leading to the generation of AC power.
- **Voltage Regulation:** The excitation system may include a control mechanism to regulate the DC voltage supplied to the rotor. This control ensures that the generator output voltage remains stable and within the desired range.



- **Brush Excitation System:** In brush excitation systems, the rotor is equipped with a direct current (DC) field winding. The excitation process involves the following steps:
- **External DC Source:** A separate DC source, often a DC generator or a rectified DC power supply, provides the initial excitation to the rotor.
- **Rotor Winding Excitation:** The external DC source supplies a constant DC voltage to the rotor's field winding, creating a strong and steady magnetic field.

- **AC Voltage Generation:** As the rotor rotates within the stator windings, the magnetic field induces an AC voltage in the stator windings, generating electrical power.
- **Voltage Regulation:** Similar to the brushless excitation system, a control mechanism is employed to regulate the DC voltage supplied to the rotor, ensuring stable generator output.



DC Excitation System

(b)
Given:
R_A=0.2Ω, N=750rpm, ϕ_2=0.75ϕ_1, I_A=120A, V=400V
We know, $T \propto \phi I_A$
But as the total torque is unaltered,
$\phi_1 I_{A1} = \phi_2 I_{A2}$
$\therefore \phi_1 \times 120 = 0.75\phi_1 I_{A2}$
I_{A2}=160A
$E_{B1} = V - I_{A1}R_A$
=400−120×0.2
=376V
$E_{B2} = V - I_{A2}R_A$
=400−160×0.2
=368V
$\because EB \propto \phi N$
$\frac{EB1}{EB2} = \frac{\varphi 1 * N1}{\varphi 2 * N2}$
$\frac{376}{368} = \frac{\varphi 1 * 750}{0.75\ \varphi 1 * N2}$
N_2 = 978.72 rpm

(a) Briefly explain Static Induction and dynamic Induction. (6)
(b) A coil of 250 turns is wound uniformly over a wooden ring of mean circumference 500mm and uniform cross-sectional area of 400mm2. If the current passed through the coil is 4A find (10)
(i) the magnetizing force
(ii) the total flux.

Jan 2024	Feb 2025	Nov 2024	Jun 2024	Jan 2023

(a) Statically Induced EMF:
When the conductor is stationary and the magnetic field is changing, the induced EMF in such a way is known as statically induced EMF (as in a transformer). It is so called because the EMF is induced in a conductor which is stationary. The statically induced EMF can also be classified into two categories.
- Self Induced EMF

- Mutually Induced EMF

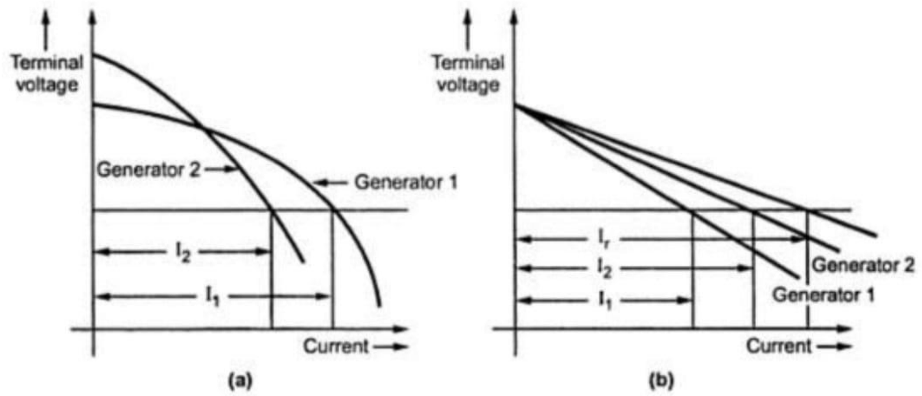
Dynamically induced EMF:
When the conductor is moved in a stationary magnetic field, the magnetic flux linking with it changes in magnitude. As the conductor is subjected to a changing magnetic field, an EMF will be induced in it. The EMF induced in this way is known as dynamically induced EMF (as in a DC or AC generator). It is so-called because EMF is induced in a conductor that is moving (dynamic).

(b) Given:
No. of turns, N=250
Mean circumference, l= 500mm = 0.5m
cross−sectional area, A=400mm^2= 400×10^{-6}m^2
Current, I = 4A
Magneto motive force, F=N×I =4×250 =1000A−turns
(i)
Magnetising force,H= $\frac{F}{l}$ mmf per meter length
$H = \frac{1000}{500*10-3}$
H = 2000A−t/m
(ii)
$\mu o = 4\times\pi\times10^{-7}\mu o$
$B=\mu o\times H$
$=4\times\pi\times10^{-7}\times2000$
$=2.5132\times10^{-3}$tesla
∴ Flux $\phi = B\times A$
$=2.5132\times10^{-3}\times400\times10^{-6}$
$=1.00528\times10^{-6}$webers
$\phi=1.00528\mu Wb$

(a) Shunt generators having drooping characteristics are best suited for parallel operation. Discuss. (6)
(b) Two 220 V d.c. generators each having linear external characteristics, operated in parallel. One machine has a terminal voltage of 270 V on no-load and 220 V at a load current of 35 A, while the other has a voltage of 280 V at no-load and 220 V at 50 A. Calculate the output current of each machine and the bus bar voltage when [10] the total load is 60 A. What is the kW output of each machine under this condition. (10)

Jan 2024 | Feb 2025 | Nov 2024 | Jan 2024 | Sep 2024 - 1 | Jun 2024 | Apr 2023

(a) For stable parallel operation, the most suitable type of d.c. generator is shunt generator as it has slightly drooping characteristics. If there is any tendency for a generator to supply more or less than its proper share of load it changes system voltage which certainly opposes this tendency. This restores the original division of load. Thus the shunt generators automatically remains in parallel, once they are paralleled.
Consider voltage-current characteristics of a shunt generator as shown in the Fig. 1(a) and Fig1(b).
Two shunt generators are considered. For common terminal voltage, the two generators are supplying a current of I1 and I2 respectively. It can be seen that generator 2 has more dropping characteristics and supplied less current.



The load will be divided properly within the two generators at all the points provided their voltage characteristics are similar with each generator having same voltage drop from no load to full load

(b)
Gen 1
Voltage drop for 35A= 270−220 = 50V
∴ Voltage drop/ampere= $\frac{50}{35}$= $\frac{10}{7}$ V/A
Gen 2
Voltage drop for 50A = 280−220 =60V
∴ Voltage drop/ampere = $\frac{60}{50}$ =1.2V/A
Let V=bus bar voltage
I_1 = Current output of Gen1
I_2 = current output of Gen2
∴V_1 =270−$\frac{10I1}{7}$
∴V_2= 280−1.2I2∴V2=280−1.2I2
∵ busbarvoltageissame,V1=V2
270−$\frac{10I1}{7}$ = 280−1.2I_2
4.2I_2−5I_1 = 35 ---❶
Also I_1 +I_2 =60 ----❷
Solving equation, we get,
I_1 = 23.6A
I_2 = 36.44A
Now V= 280-1.2I_2
=280 – 1.2* 36.4 = 236.3V
Output of 1st machine = VI
=236.3* 23.6 = 5576.68W
=5.577 kw
Output of the 2nd machine = VI
=236.3* 36.4 = 8601.32 W
=8.601kW

(a) What is meant by the term 'back e.m.f.' as applied to an electric motor?
(b) A 40kW, 220V shunt motor has a full-load efficiency of 90 per cent, an armature resistance of 0.075 ohms and a shunt-field resistance of 55ohms. When 'at starting', the starter handle is moved onto the first stud, it is desired to limit the current, through the armature to 1.5 times the value which it has when the motor is on full load. What must be the total value of the starting resistance? If, on overload, the speed falls to 90 per cent

of its normal full-load value, what would be the armature current? Neglect the effect of armature reaction. (10)

Dec 2023 | Oct 2022

(a) Back EMF, or counter-electromotive force, is the voltage that is generated in a motor by the rotation of the motor's shaft. It is caused by the magnetic field that is created by the current flowing through the motor's windings. The back EMF opposes the current that is flowing through the windings, which limits the amount of current that can flow and the amount of torque that can be produced.
The back EMF is proportional to the speed of the motor's rotation. As the motor's speed increases, the back EMF also increases. This causes the current that is flowing through the windings to decrease, which in turn causes the torque that is produced to decrease.

(b)
Output power = 40×10^3
FL efficiency = 90
∴ input power= output$\times\frac{100}{90}$

$=40\times10^3\times\frac{90}{100}$ =44,444W
Input current(I_L)= voltage power= $\frac{44444}{220}$ =202.02A
Shunt field current, I_{sh}= $\frac{V}{Rsh}$ =$\frac{220}{55}$ =4A
I_L=Ia+Ish
∴ Armature current,I_a=I_L−I_{sh}=202.02−4=198.02A
Armature starting current = 1.5×I_a = 1.5×198.02= 297.03A
Now, resistance of armature circuit = $\frac{220}{297.03}$ = 0.74Ω
Resistance to be added = 0.74−0.075 = 0.665Ω
Starting resistance = 0.665Ω(Ans)
On normal load, Eb= V-Ia Ra = 220- (198.02 *0.075)
Eb = 205.14V
On 90 percent = 205.14 * $\frac{90}{100}$ = 184.62
∴ Armature voltage drop = 220-184.62 = 35.3
Hence armature current = $\frac{35.38}{0.075}$ = 471.7A (Ans)

(a) Name the three main types of a.c. motor and explain the use to which they are put in marine engineering. (6)
(b) A four pole motor is fed at 440 V and takes a armature of 50 A. The resistance of the armature circuit is 0.28 ohm. The armature winding is wave connected with 888 conductors and the useful flux per pole is 0.023 wb. Calculate the speed. (10)

Dec 2023 | Mar 2023 | Sep 2022

(a)
3-Φ Sq. cage induction motor (large)
- Main S.W pump motor,
- Main L.O pump motor,
- Main J.C.W pump motor.

3-Φ synchronous motor (large)
- Main electrical propulsion motor
- bow thruster motor,

- Syn. motor acting as syn. condenser in the shaft generator system.

Small 1-Φ syn motor

- Radar motor
- gyrocompass motor
- clear glass motor.

(b) Given:

Poles, P= 4
Volt, V= 440 V
Current, Ia = 50 A
Resistance, Ra=0.28 Ω
Conductors, Z=888
Flux per pole, ϕ=0.023wb
Speed, N = ?rpm

$E_b = V - I_a R_a$
$= 440 - 50 \times 0.28$
$= 426V$

$Eb = \frac{\phi PNZ}{60A}$ (A=2 for wave connected)

$426 = 0.023 \times 4 \times N \times \frac{888}{60 \times 2}$

N=625.7 = 626rpm

A 4-pole lap wound DC shunt generator has an open e.m..f of 250V when the flux per pole is 0.08 Wb and the speed is 10 rev/sec. The speed of the generator is reduced to 10 per cent and the flux per pole is increased by 5% when the generator supplies a load of 100A. Determine the terminal voltage, if the armature resistance is 0.06 ohm and the new total field circuit reisitance is 200 ohm. (16)

Dec 2023

Given:

P=4
A=P(lap)
I_L=100A, Ra=0.06Ω, R_{sh}=200Ω I_L=100A,R_a=0.06Ω,R_{sh}=200Ω
To find

(i)

Terminal voltage, VT
Φ = 0.08 wb
n=10 rps,n= N/60
A= P
Eg= 250V

∴ $Eg = \frac{\phi ZPn}{A} = \phi Zn$

250 = 0.08×10×Z

Number of conductors, $Z = \frac{250}{0.08 \times 10}$ =312=312

Now, speed is reduced to 10, n‘=0.1×10 = 1 rps
Flux per pole is increased by 5%, Φ = 1.05×0.08 = 0.084 wb
New induced EMF, Eg= ϕZn
= 0.084×312×1 =26.2V
Also, $I_a = I_L + I_{sh}$

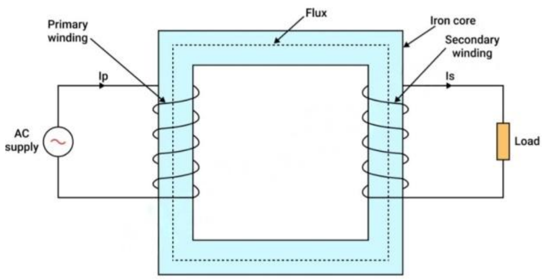
$I_a = I_L + \frac{VT}{R_{sh}}$ =100+VT200−−−①

But, V_t = Eg- IaRa---②
Substituting ① in ②
$V_T = 26.2-(100+\frac{Vt}{200})*0.06$
$= 26.2-6-0.0003V_T$
$V_T + 0.0003Vr = 20.2$
$V_T = \frac{20.2}{1.0003}$
$V_T = 20.2V$

(a) Describe a simple single phase transformer. (6)
(b) A 15 KVA, 440/110-volt, 50Hz cycle/sec, single-phase transformer has primary and secondary resistances of 0.12 ohm and 0.0077 ohm respectively. The iron loss of the transformer is 0.16 kW. Calculate the efficiency of the transformer (10)
(i) On full load unity power factor
(ii) On 80 per cent full load at a power factor of 0.9 lagging

Dec 2023 **Mar 2023** **Dec 2023**

(a) A transformer is static equipment which transforms electric power of one circuit into electric power of the same frequency of another circuit.
The basic principle of a transformer is mutual (electromagnetic) induction between two circuits linked by a common magnetic flux possessing high mutual inductance. Transformer ratio is the ratio of voltage in secondary windings to the voltage in primary windings.
Turns ratio is the ratio of number of turns in secondary windings to the number of turns in primary windings. If the turns ratio or transformer ratio is greater than 1, the transformer is said to be a step up transformer. If it is less than 1, it is said to be a step down transformer.
When the transformer is under no-load conditions, the primary input current magnetizes the core and supplies iron losses in the core. Equivalent circuit model is used to describe the no-load operation of transformer.
Iron loss and copper loss are the two main types of energy losses of transformers. Iron loss is divided into hysteresis loss and eddy current loss.



(b)Given:

Iron loss = 160w

kVA rating = 15k VA

V_1= 440V, R_1= 0.12Ω

V_2= 110v, R_2= 0.0077Ω

(i) $\eta f1 = \frac{x*kVA*cos\phi}{x*kVA*cos\phi+x2Pcu+Pi}$

X=1; $\cos\phi$ =1

$I_1 = \frac{P}{V1} = \frac{15k}{440}$ = 34.09A

$P_{cu1} = I_1^2 R_1$

$= 34.09^2 * 0.12 = 139.45W$

$I_2 = \frac{P}{V2} = \frac{15k}{110} = 136.36A$

$P_{cu2} = I_2^2 R_2$

= $136.362 * 0.0077 = 143.17W$

$\eta f1 = \frac{1*15*1}{1*15*1+0.13945+0.143317+0.16} = 97.13$

ii) η =80

x= 0.8, cos ϕ =0.9

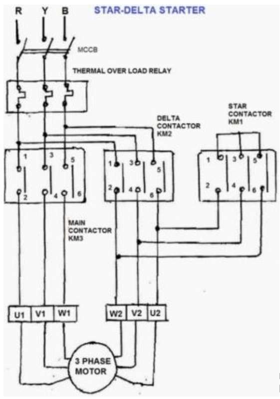
$\eta_{80} = \frac{0.8*15*0.9}{0.8*15*0.9+((0.8)2.(0.13945+0.1431))+0.16}$

= 96.94

(a) Sketch and describe a Star-Delta starter for starting an induction motor (10)
(b) Three similar coils, each having a resistance of 10 ohms and an inductance of 0.02 H are connected in
(i) Star
(ii) Delta to a 3-phase, 50-Hz supply with 500V.
Calculate the total power absorbed and the line current in each case. (6)

Dec 2023

(a)Star-delta starter for starting induction motor:



- Star delta starter is used to start the squirrel cage induction motor. This starter reduces both starting torque and starting current during starting period.
- Both end connections of the three windings of induction motor are usually brought out to facilitate the star-delta starting scheme.
- Suitable change over provision from star to delta connection is available in the starter assembly.
- These change over contacts enable the six ends to be started connected for starting and then, to be reconnected in delta after the rotor comes up to speed. It also has a timer for setting the time in star position.
- In star connection, phase voltage is equals to 1/√3 line voltage and in delta connection, phase voltage equals to line voltage.
- This will cause overheating of the motor and consequent failure. Further, the voltage across the windings is reduced resulting in reduced flux in the iron. This will reduce the torque of the motor

(b)
Solution:
R = 10 Ω
L = 0.02; X_L = 2π*FL = 2R * 50 * 0.02 = 6.283 Ω
V_L = 500V
f = 50 Hz
To Find
Total Power in Star Delta
Line current in Star, Delta
Solution:
Case 1 Star:
Phase Impedance = $\sqrt{R^2+(XL)^2}$ = $\sqrt{(10^2 + 6.28^2)}$ = 11.80 Ω
Phase Voltage= $\frac{Vl}{\sqrt{3}} = \frac{500}{\sqrt{3}} = 288.67$ V
$I_{ph} = \frac{VL}{\sqrt{3}Z} = \frac{500}{\sqrt{3} * 11.80}$
I_{ph}= 24.46 Amp

I_{ph} = I Line in Star Connection
Cos φ = R/2 = 10/11.80 = 0.84
Power:
P = 3x Vph *Iph* Cos φ
= 3x 288.6 x 24.45 X 0.84
P = 17929.982 watt
P= 17.92 Kw
Case 2 Delta
Vp = VL = 500V
Zph = 11.80.2
Iph= $\frac{Vph}{z} = \frac{500}{11.80}$ = 42.37 Amp
$I_L = \sqrt{3} * I_{ph}$
= $\sqrt{3} * 42.33$
IL = 73.38 Amp
Power = 3*x Vsh * Iph* cosφ
= 3x 500 x 42.37 x 0.84
= 53.38 Kw

A wooden ring having a mean diameter of 200mm and a cross-sectional area of 400mm2 is wound uniformly with a coil of 300 turns. If the current passed through the coil is 5A calculate the value of flux produced in the coil. (16)

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Given:
d= 200mm= 0.2m
A= $400mm^2 = 400 \times 10^{-6} m^2$
N= 300turns
I= 5A
mmf of coil= I×N
5×300 =1500A−turn
Circumference=π×d
=π×0.2m=0.628m

magnetising force(H)= $\frac{\text{A−turn}}{\text{circumf erence}}$

H= $\frac{1500}{0.628}$ =2388.5A−turn/m

Fluxdensity(B)=μ_oH

B=4×3.14×10^{-7}×2388.5

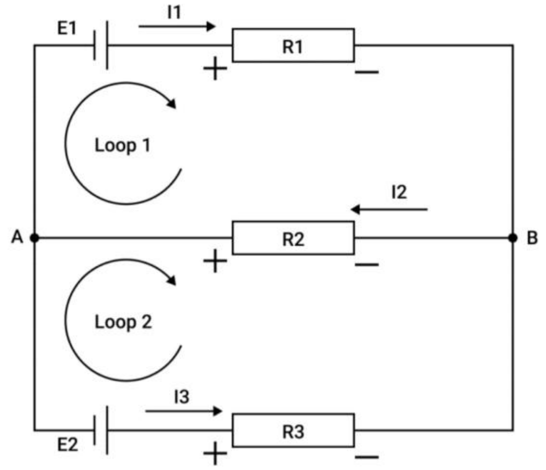
B=0.003T

Total flux(ϕ)= B×A

=0.003×400×10^{-6}

ϕ=1.2×10^{-6}wb

In the following circuit, E1 = 13V, E2 = 19.5V, R1 = 5Ω, R2 = 7Ω, R3 = 9Ω. Find the current flowing through each resistor.



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Kirchhoff's Voltage Law (KVL) Equations:

The equations derived from KVL are:

- Loop 1: $13 - 5I_1 - 9(I_1 - I_2) = 0 \Rightarrow 13 - 14I_1 + 9I_2 = 0$
- Loop 2: $19.5 - 7I_2 - 9(I_2 - I_1) = 0 \Rightarrow 19.5 + 9I_1 - 16I_2 = 0$

Solving the system of equations:

Multiply the first equation by 16 and the second by 9 to eliminate I_2:

$208 = 224I_1 - 144I_2$
$175.5 = 81I_1 - 144I_2$

Subtract the second equation from the first:

$32.5 = 143I_1$

Solve for I_1:

$I_1 = \frac{32.5}{143} \approx 2.682$ A

Substitute I_1 into the first equation:

$13 - 14(2.682) + 9I_2 = 0$
$13 - 37.548 + 9I_2 = 0$
$9I_2 = 24.548$
$I_2 \approx 2.727$ A

Calculate the current through R_3:

$I_R3 = I_1 - I_2 \approx 2.682 - 2.727 = -0.045$ A

A coil of resistance 10Ω and inductance 0.1H is connected in series with a capacitor of capacitance 150µF, across a 200V, 50Hz supply.
Calculate:
(a) The inductive reactance (3)
(b) The capacitive reactance (3)
(c) The circuit impedance (2)
(d) The circuit current (2)
(e) The circuit power factor (2)
(f) The voltage drop across the coil (2)
(g) The voltage drop across the capacitor. (2)

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Given:
R=10Ω
L=0.1H
C=150µF
V=200V
f=50Hz
(a)$X_L=2\pi fL=2\times3.14\times50\times0.1$
$X_L=31.4\Omega$
(b)$X_C= \frac{1}{2\pi f\ C} = \frac{1}{2\times3.14\times50\times150\times10-6}$
$X_C= 21.2\Omega$
(c)Resultant reactance = 31.4−21.2
=10.2Ω
$Z=\sqrt{R^2+X^2}= \sqrt{10^2+10.2^2}$
Z= 14.28Ω
(d) $I=\frac{V}{Z}=\frac{200}{14.28}$
I= 14A
(e)
$\text{Cos}\ \phi= \frac{R}{Z} = \frac{10}{14.28}$
Cos ϕ = 0.7
(f) Impedance of coil=$\sqrt{R^2+X_L^2}$
$= \sqrt{10^2+31.4^2}$
(g) Voltage drop across capacitor= 14*21.2
= 297V

A 24V emergency battery is to be charged from the 110V ship's mains when the e.m.f. per cell has fallen to a minimum value of 1.8V. The battery consists of 12 cells in series, has a capacity of 100 Ahr at a 10 hr rate and the internal resistance is 0.03Ω/cell. If charging continues until the voltage per cell rises to 2.2V, find the value of the variable resistor needed to control the charging. The charging current can be assumed to be equal to the maximum allowable discharge current. (16)

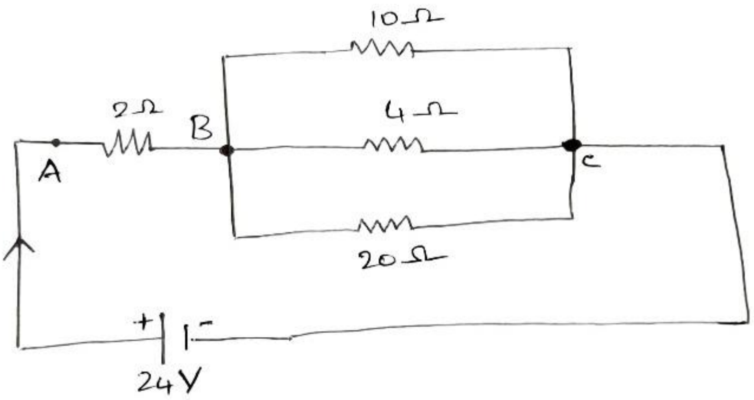
Nov 2023 | **Apr 2025** | **Sep 2024 - 2** | **Apr 2024 - 2**

Given:
Vmin=1.8V
No.of cell=12
Capacity=100Ah
Rate=10hr

R=0.03Ω/cell
Vmax=2.2V
Total internal resistance:
Rint=0.03×12= 0.36Ω
Max allowable current:
Imax = $\frac{100}{10}$ =10A
Max V=2.2×12=26.4V
Mi V=1.8×12=21.6V
Voltage across battery:
Vcharging=Vmax+ Imax× Rmax
26.4+10×0.3626.4+10×0.36
Vcharging=30V
Voltage drop:
Vresistance=110−30=80V
So, R = $\frac{V}{I}$ = $\frac{80}{10}$
R=8Ω

Find the p.d. Between A-B and B-C shown in the figure below.
Electrical circuits & components

Oct 2023



parallel resistance R_p) using the formula:

$$\frac{1}{R_p} = \frac{1}{10} + \frac{1}{4} + \frac{1}{20}$$
$$R_p = 2.5\Omega$$

The series resistor (2Ω) is added to the equivalent parallel resistance to find the total resistance R_{total}):

$$R_{total} = 2 + 2.5 = 4.5\Omega$$

The current in the circuit I) is calculated using Ohm's Law: $I = \frac{V}{R}$, where V is the voltage (24V).

$$I = \frac{24}{4.5} = 5.333 \text{ A.}$$

Drop in AB: The voltage drop across the 2Ω resistor V_{AB}) is calculated using Ohm's Law:

$$V_{AB} = I \times R = 5.333 \times 2 = 10.666 \text{ V.}$$

Drop in BC: The voltage drop across the parallel resistors V_{BC}) is calculated using Ohm's Law:

$$V_{BC} = I \times R_p = 5.333 \times 2.5 = 13.333 \text{ V.}$$

The following are the results of measurements taken at intervals over a half cycle of alternating voltage:
Time (t milliseconds) 0 0.45 0.95 1.5 2.1 2.5 3.1 3.9 4.5 5.0
Voltage (V volts) 0 20 36 40 37.5 33 32 31 20 0
Calculate the r.m.s. value, average value and frequency of the wave. (16)

Oct 2023

Time	0	0.45	0.45	1.5	2.1	2.5	8.1	8.9	4.5	6.0
Volts	0	20	84	40	22.5	33	32	31	30	0

1)RMS Value formula Vrms=$\sqrt{\sum V^2}$
V= voltage value
N= no. of value= 10
V^2= 0, 400,1296, 1600, 1406.25, 1089, 1024, 961, 400, 0
Average V^2 = $\frac{0+400+1296+1600+1406.25+1089+1024+961+400+0}{10}$
Vrms=$\sqrt{V2}$ = $\sqrt{817.625}$
Vrms = 28.59 v
2) Average Value:
Vavg =$\sum_{i=1}^{n} V$
Vavg =$\frac{0+20+36+40+37.5+33+32+31+20+0}{10}$
Vavg= $\frac{249.5}{10}$ = 24.95V
3)Frequency of wave
Half time in 5 millisecond = T/2
T= 5*2 = 10 millisecond
=10*10^{-3} second
=0.01 second
F= $\frac{1}{T}$ =$\frac{1}{0.01}$ = 100Hz

Ten thousand cubic millimetres of copper are (a) drawn into a wire 100 metres long, (b) rolled into a square sheet of 100mm side. Find the resistance of the wire and the resistance between opposite faces of the plate, if the resistance of the copper is 17 μΩmm or 1.7 x 10^-8 ohm-metres.

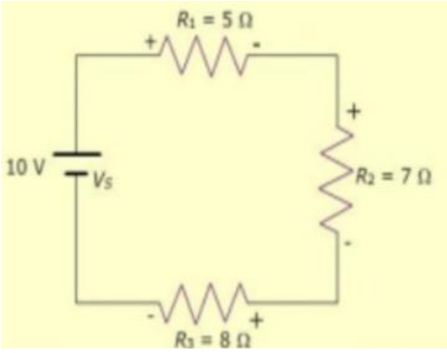
Oct 2023

Volume= 10000 mm^3
Volume= Area×Length
Or A= $\frac{V}{L}$ = $\frac{10\times103}{100\times103}$
= $\frac{1}{10}$ =0.1mm^2
Then R= $\frac{\rho L}{A}$
=$\frac{17\times10-6\times100\times103}{10-1}$ = 17×10^{-6}×10^6
=17Ω
(b)
Area of plate=100×100=$10^4$$mm^2$
Thickness of plate=$\frac{10\times103}{104}$ =1mm
This is the length in expression R = $\frac{\rho L}{A}$
∴R= $\frac{17\times10-6\times1}{104}$ =17×10^{-10}ohm

$=1.7\times10^{-3}\mu\Omega$

The resistors 5Ω, 7Ω and 8Ω are connected in series across a voltage source of 10 V. Find the voltage drop across each resistor and also the total power consumed by the circuit. (16)

Oct 2023



Since the resistor are connected in series, the current through each resistor are equal

Apply Kirchoff's law:

$V_s-IR_1-IR_2-IR_3 = 0$

Sub the known values in the above equation, we have 10-5l-7l-8l =0

20I= 10

$I=\frac{10}{20} = 0.5A$

We can apply Ohms law to find the voltage drop across each resistor.

$V_{R1}= R_1* I = 5\Omega * 0.5A = 2.5V$

$V_{R2}= R_2* I = 7\Omega * 0.5A = 3.5V$

$V_{R1}= R_3* I = 8\Omega * 0.5A = 4V$

Lets find the power consumed by each resistor using the formula $P= R* I^2$.

$P_{R1}= 5\Omega * (0.5A)^2 = 1.25W$

$P_{R2}= 7\Omega * (0.5A)^2 = 1.75W$

$P_{R3}= 8\Omega * (0.5A)^2 = 2W$

Total power consumed by the circuit= $P_{R1}+ P_{R2}+ P_{R3}$

Derive the formula for Total resistance of a circuit containing 3 resistors in
(a)Series (8)
(b) Parallel (8)

Sep 2023 **June 2023**

(a) Total Resistance of Resistors in Series

Circuit Configuration:

When resistors are connected end-to-end, forming a single path for current, they are said to be in series.

Derivation:

Let the three resistors have resistances R_1,R2,and R3 . According to Ohm's Law, the voltage drop across each resistor is given by:

- $V_1=I\cdot R_1$
- $V_2=I\cdot R_2$
- $V_3=I\cdot R_3$

where I is the current flowing through the circuit.

The total voltage V across the series combination is the sum of the individual voltage drops:

$V=V_1+V_2+V_3$

Substituting the expressions for V_1,V_2&V_3

$V = I \cdot R_1 + I \cdot R_2 + I \cdot R_3$
Factoring out I
$V = I \cdot (R_1 + R_2 + R_3)$
By Ohm's Law,
$V = I \cdot R_{total}$,
where R_{total} is the total resistance. Equating the two expressions for V:
$I \cdot R_{total} = I \cdot (R_1 + R_2 + R_3)$
Since $I \neq 0$, we can cancel I from both sides:
$R_{total} = R_1 + R_2 + R_3$

(b) Total Resistance of Resistors in Parallel
Circuit Configuration:
When resistors are connected across the same two points, providing multiple paths for current, they are said to be in parallel.
Derivation:
Let the three resistors have resistances R1R_1R1, R2R_2R2, and R3R_3R3. The total current III supplied by the source is the sum of the currents through each resistor:
$I = I_1 + I_2 + I_3$

According to Ohm's Law, the current through each resistor is given by:
- $I_1 = VR_1$
- $I2 = VR_2$
- $I3 = VR_3$

where V is the voltage across each resistor (same for all in parallel). Substituting these into the equation for total current:
$I = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$
By Ohm's Law, $I = \frac{V}{Rtotal}$
Equating the two expressions for I:
$\frac{V}{Rtotal} = V(1/R1 + 1/R2 + 1/R3)$
Since $V \neq 0$, we can cancel V from both sides:
$\frac{I}{\mathrm{Rtotal}} = \frac{1}{R} + \frac{1}{R2} + \frac{1}{R3}$
The total resistance R_{total} of three resistors connected in parallel is given by the reciprocal of the sum of the reciprocals of their individual resistances:

(a) Define Work, Power and Efficiency (6)
(b) A battery is charged with a constant current of 16 amperes for 11 hours after which time it is considered to be fully charged, its voltage per cell being recorded as 2.2V. Find its ampere hour efficiency if it is (10)
(i) Discharged at a rate of 16 amperes for 10 hours, and
(ii) 28 amperes for 4 hours.
In either case discharge was discontinued when the voltage per cell fell to 1.8 V.

Sep 2023 **Feb 2023**

(a) **Work:** is defined as the transfer of energy that occurs when a force is applied to an object and causes it to move in the direction of the force. Work (W) is calculated by multiplying the magnitude of the force (F) applied to an object by the displacement (d) of the object in the direction of the force. Mathematically, work is expressed as W = F * d. The SI unit of work is the joule (J).
Power: Power is the rate at which work is done or the rate at which energy is transferred or converted. It measures how quickly work is performed or how quickly energy is transformed.

Power (P) is calculated by dividing the amount of work done (W) by the time (t) taken to do that work. Mathematically, power is expressed as P = W / t. The SI unit of power is the watt (W).
Efficiency: Efficiency is a measure of how effectively a system or device converts input energy into useful output energy. It quantifies the ratio of useful output work or energy to the total input work or energy. Efficiency (η) is calculated by dividing the useful output work or energy (Wout) by the total input work or energy (Win) and multiplying by 100 to express it as a percentage. Mathematically, efficiency is expressed as η = (Wout / Win) * 100.

(b) Given:
I = 16 amps
t = 11 hrs
voltage per cell = 2.2 v
amphr efficiency = ?
condition
(i) discharge rate of 16 amp for 10 hrs

(ii) 28 amp for 4 hrs
(i) total input amp = 16×11 = 176
total output amp = 16×10 = 160

Amphr eff^n = $\frac{\text{Amphr of discharge}}{\text{Amphr of charge}}$

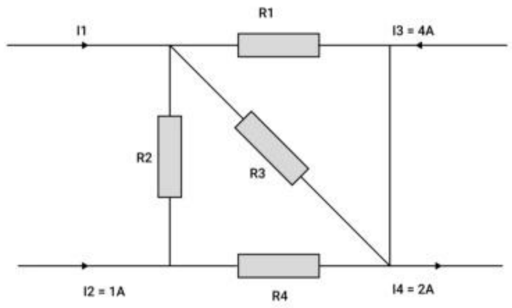
$= \frac{160}{176}$ = 0.91 or 91percentage
(ii) Total output = 28 × 4 = 112
Input = 16 × 11 = 176
Eff^n = $\frac{112}{176}$ = 0.63 or 63 percentage

(a) What is difference between EMF and PD of a battery. (6)
(b) Calculate the value of I1 in the following circuit. (10)

Sep 2023 **May 2023**

(a) The electromotive force (EMF) of a battery is the maximum potential difference that can be produced by the battery. The potential difference (PD) of a battery is the actual potential difference that is measured across the battery terminals. The PD of a battery is always less than or equal to the EMF of the battery.
The EMF of a battery is determined by the chemical reactions that take place inside the battery. The PD of a battery is determined by the resistance of the battery and the current that is flowing through the battery.
The EMF of a battery is a constant, while the PD of a battery can vary depending on the load that is connected to the battery.

(b)



By kirchoffs law:
$I_1+I_2+I_3-I_4=0$
$I_1+1+4-2=0$
$I_1=-3A$
current flow in opposite direction to that indicated by arrow.

(a) State Ohm's Law (3)
(b) State the limitations of Ohm's Law (3)
(c) If the resistance of a circuit is increased to 3 times and the applied Voltage is halved, what will happen to the circuit current? (10)

Sep 2023 | **May 2023**

(a) Ohm's law states that the current through a conductor is directly proportional to the voltage across it, and inversely proportional to the resistance of the conductor.
Mathematically, Ohm's law can be expressed as:

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

where:

- I is the current (in amperes)
- V is the voltage (in volts)
- R is the resistance (in ohms)

(b) The limitations of Ohm's law are:

- Ohm's law is only valid for a linear conductor. A linear conductor is a conductor whose resistance is constant.
- Ohm's law is only valid for a constant temperature. The resistance of a conductor changes with temperature.
- Ohm's law is only valid for a small range of voltages and currents. The resistance of a conductor can change significantly at high voltages and currents.

(c) If the reisitance of a circuit increased 3 times and the applied voltage halved, the circuit current will decrease by a factor of 6. This is because the current in a circuit is inversely proportional to the reisitance and directly proportional to the voltage.
The current in a circuit is calculated using the following formula:

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

where:
I is the current (in amperes)
V is the voltage (in volts)
R is the resistance (in ohms)
If the resistance is increased to 3 times, the new resistance will be

$$R'=3R$$

If the applied voltage is halved, the new voltage will be

$$V'=\frac{V}{R}$$

Substituting these values into the formula gives:

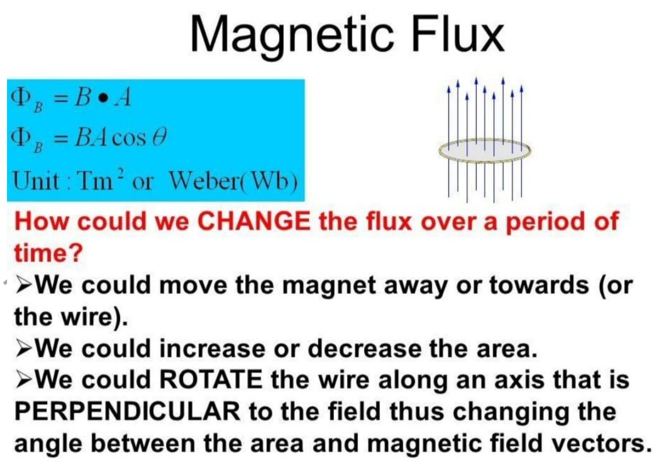
$$I=\frac{V}{R}=\frac{v/2}{3R}=\frac{V}{6R}$$

Therefore, the current in the circuit will decrease by a factor of 6.

(a) Describe the means by which the magnetic flux associated with a conductor may be changed. (6)
(b) Find the generated e.m.f./conductor of a 6-pole D.C. generator having a magnetic flux/pole of 64m Wb and a speed of 1000 rev/min. If there are 468 conductors, connected in six parallel circuits, calculate the total generated e.m.f. of the machine. Find also the total power developed by the armature when the current in each conductor is 50A. (10)

Oct 2023

(a) The magnetic flux associated with a charged conductor refers to the total magnetic field passing through a surface, typically perpendicular to the direction of the magnetic field. When a current flows through a conductor, it creates a magnetic field around it according to Ampere's law. The magnetic flux is a measure of the total magnetic field lines passing through a given surface. For a charged conductor, the magnetic flux is influenced by the current flowing through it and the geometry of the conductor.



(b) Given
P = 6 = A
$\phi = 64 * 10^{-3}$ wb
N = 1000 rpm
Z = 468
To find,
EMF
Power developed when current in each conductor is 50A
We know that E = $\frac{P*\varphi*NZ}{60A}$
E = $\frac{6*64*10^{-3}*1000*468}{60*6}$
E = 499.2V
Now
Current per conductor = 50A
Current in 6 parallel path
50 * 6 = 300A
So power developed = EMF X I

= 499.2 * 300
= 149.8 kW

(a) Discuss the open circuit and short circuit test performed for transformer.
(b) The primary and secondary windings of a 30 KVA, 6000/230 V, 1hp transformer have resistance of 10 Ω and 0.016 Ω respectively. The reactance of the transformer referred to the primary is 34 Ω. Calculate the primary voltage required to circulate full load current when the secondary is short circuited. What is the power factor on the short circuit?

Aug 2023

(a) Open Circuit Test:
The primary purpose of the open circuit test, also known as the no-load test, is to determine the core losses and exciting current when the transformer is under no-load conditions. To carry out open circuit test, proceed as follows:
- Connect the transformer to a variable AC voltage source.
- Keep the secondary winding open-circuited.
- Gradually increase the voltage until the rated voltage is reached.

- Record the input voltage, current, and power.

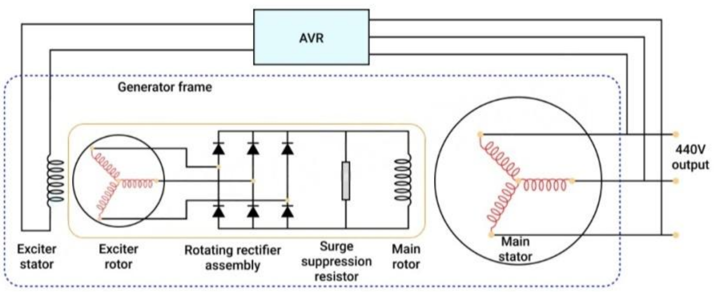
Short Circuit Test:
The short circuit test, also known as the impedance test or the full-load test, is conducted to determine the copper losses and leakage reactance of the transformer under full-load conditions. Short circuit test is described as follows:
- Connect the transformer to a variable AC voltage source.
- Short-circuit the secondary winding.
- Gradually increase the voltage until the rated current is reached.
- Record the input voltage, current, and power.

(b)
Transformation ratio,K= $\frac{230}{6000}$ = $\frac{23}{600}$
Equivalent resistance referred to primary, R_{01} = R1 +$\frac{R2}{K2}$
$10+0.016(600/23)^2=20.89\Omega$
Equivalent reactance referred to primary,,$X_{01}=34\Omega$
Equivalent impedance referred to primary, Z_{01}= $\sqrt{(R_{01})^2+(X_{01})^2}$
=√(20.89)2+(34)2= 39.904Ω
Full-load primary current,,$I_1 = \frac{\text{RatedKVA}\times 1000}{V1}$
= $\frac{30\times1000}{6000}$ =5A
Primary voltage required to circulate full load current when the secondary is short-circuited
$V_s = I_1 Z_{01}$
5×39.904=199.52V
Power factor on short circuit:
PF(Cosϕ)=($\frac{Ra}{Za}$)=($\frac{20.89}{39.90}$)
$\cos\varphi = 0.52$

(a) Sketch a schematic arrangement of a three phase alternator with star connection. (6)
(b) A 500V, 3-phase, star-connected alternator supplies a star-connected induction motor which develops 45kW. The efficiency of the motor is 88 percent and the power factor is 0.9 (lagging). The efficiency of the alternator at this load is 80 percent. Determine (10)
(i) The line current
(ii) The power output of the alternator
(iii) The output power of the prime-mover

Aug 2023 **Dec 2024**

(a)



(b) Given:

Motor output=45kW
ηm=88
cosϕ=0.9
ηA=80
ηm=$\frac{O/P}{I/P}$
Input=$\frac{45000}{88}$×100
=51.136kW
We know that
P=3VIcosϕ

(i)
Line current, I= $\frac{P}{3\times500\times0.9}$
= $\frac{51136.36}{\sqrt{3}\times500\times0.9}$ =65.6A
(ii)
Alternator O/P = Motor I/P=51136W
(iii)
ηA=80
I/P of Alternator = $\frac{51136}{80}$ ×100
Prime mover output= 63920W

(a) Describe the principle of variable-capacitance transducer.
(b) A coil of resistance 10 Ω and inductance 100mH is connected in series with two parallel capacitors each of value 100 μF across a 250 V, 50Hz supply. Determine (10)
(i) The circuit current
(ii) The total power factor
(iii) The power taken from the supply

Aug 2023

(a) Transducers based on the principle of changes in the capacitance are generally termed as capacitive transducers. These kinds of transducers are most common in linear displacement based applications. Other than displacement, many of the industrial variables such as pressure, level, moisture, etc. can be translated into an electrical signal by means of change in the capacitance.

PRINCIPLE OF A CAPACITIVE TRANSDUCER

The capacitive transducer is functioning similar to the working of a parallel plate capacitor. The capacitance is calculated as a function of area between two parallel plates, the distance between the plates and the dielectric medium in between the plates. It is expressed as:

C = $(A/\mathrm{d})\varepsilon o \varepsilon r$

Where,

A is the area of parallel plates

d is the distance between the plates

εo is the absolute permittivity of free space.

εr is the relative permittivity of free space.

The working principle of the capacitive transducer is based on the change in capacitance due to any of the change in area of the parallel plates, the distance between the plates or the permittivity of free space. Since the capacitance is a function of A, d and ε, i.e., C = f(A, d, ε), any variable which changes any one of the quantities, the capacitance of the parallel plate capacitor gets changed. Further, this change in capacitance can be further converted into the required electrical form.

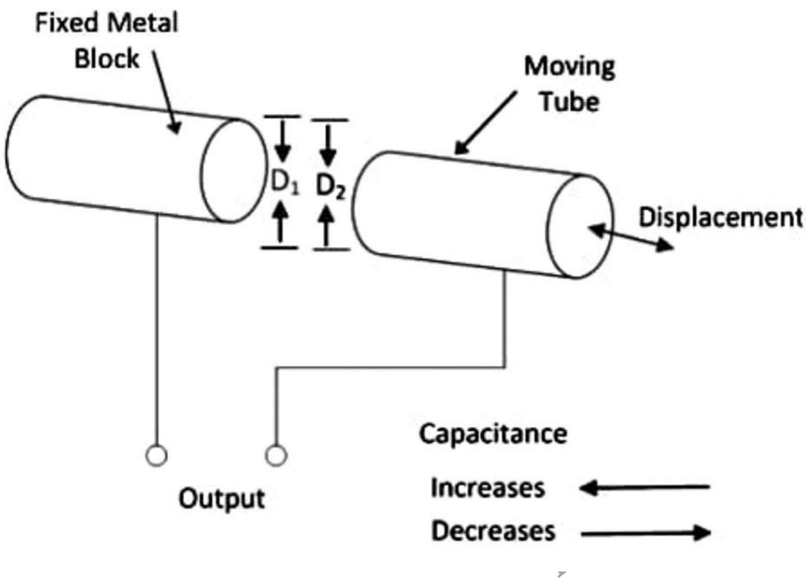
The capacitance is connected to voltage and charge by the expression:

$$Q = CV$$

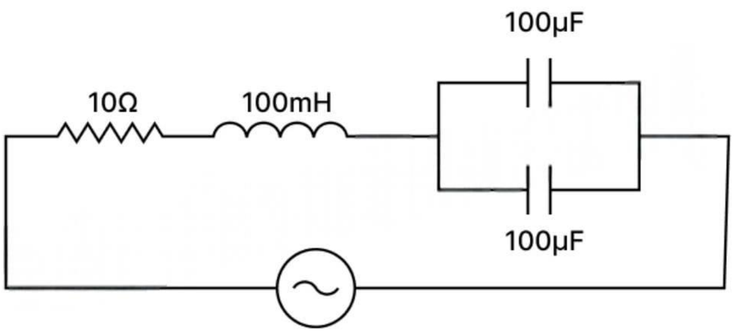
Where,

- Q is the charge in coulomb.
- C is the capacitance in farad.
- V is the voltage in Volts.

If the capacitance is affected by any of the above parameters, the output is transduced into an electrical form proportionally. In most of the cases, the changes are caused by means of physical variables such as pressure, displacement, force, thickness, etc. If there is change in dielectric medium between the parallel plates, there will be change in capacitance, and hence it can be used for the measurement of fluid level. Similarly, the change in dielectric medium due to change in the composition causes the change in absorption on moisture.



(b)



Given values

- **Resistance,** $R = 10\ \Omega$
- **Inductance,** $L = 100\ \text{mH}$

- **Capacitance,** $C = 100\ \mu F$ **(with two in parallel, total** $C = 200\ \mu F$**)**
- **Voltage,** $V = 250\ V$
- **Frequency,** $f = 50\ Hz$

Capacitive Reactance X_C**):**

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 200 \times 10^{-6}} = 15.91\ \Omega$$

$$X_L = 2\pi f L = 2\pi \times 50 \times 100 \times 10^{-3} = 31.41\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{10^2 + (31.41 - 15.91)^2} = \sqrt{100 + 240.28} = \sqrt{340.28} = 18.445\ \Omega$$

$$I = \frac{V}{Z} = \frac{250}{18.445} = 13.55\ A$$

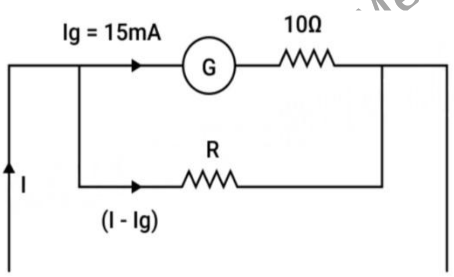
$$PF = \frac{R}{Z} = \frac{10}{18.445} = 0.542\ (\text{lagging})$$

Lagging because $X_l > X_c$
Power= I^2R
$13.55^2 \times 10 = 1836.025W$

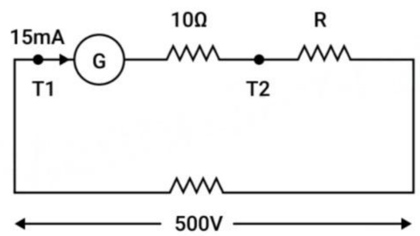
A moving-coil instrument has a resistance of 10 Ohms and requires a current of 15mA to give full-scale deflection. Calculate the resistance value of the resistor necessary to enable it to be used to measure (16)
(a) Currents upto 25A
(b) Voltages upto 500V

Jul 2023

(a)
Ig=15mA
For measuring I of 25A
Potential across galvanometer (V) = $15 \times 10^{-3} \times 10$
V=0.15V
Potential across shunt (v)=(I−Ig)R
$=(25-15\times10^{-3})R = 24.98R$
∴ Parallel potential is the same thus;0.15=24.98R



(b)For measuring voltage upto 500V



Potential across galvanometer (v)= I(R+Rg)
$=(15\times10^{-3})(10+R)$
$=0.15+(15\times10^{-3})R$
Potential across load =500V
∴ In Parallel voltage is same
$0.15(15\times10^{-3})R=500$
$15\times10^{-3}R=499.85$
$R=33323.3\Omega$

A 105V, 3kW d.c. shunt motor has a full-load efficiency of 82 percent. The armature and field resistances are 0.25Ω and 90Ω respectively. The full-load speed of the motor is 1000 rev/min. Neglecting armature reaction and brush drop, calculate the speed at which the motor will run at no load if the line current at no load is 3.5A. Calculate the resistance to be added to the armature circuit, in order to reduce the speed to 800 rev/min, the torque remaining constant at full-load value. (16)

Jul 2023

Given:
V = 105 V
On full load O/P = 3000W
$\eta_{FL} = 82$
$R_a = 0.25\ \Omega$
$R_{sh} = 90\ \Omega$
$N_{FL} = 1000$ rpm
$I_{LNL} = 3.5$ A
On no load:
$I_{sh} = \frac{V}{Rsh}$
$=\frac{105}{90} = 1.17A$
$I_{aNL} = I_{LNL} - I_{sh}$
$I_{aNL} = 3.5 - 1.17 = 2.33$ A
$E_{bNL} = 105 - (2.33*0.25) = 104.42V$
On Full Load:
$\eta_{FL} = \frac{O/P}{I/P}$ = 3000 * 100/82
$\eta_{FL} = \frac{O/P}{I/P}$ = 3660W
$I_{LFL} = \frac{Input\ power}{V} = \frac{3660}{105} = 34.86A$
$I_{aFL} = I_{LAL} - I_{SH}$
= 3660/105 = 34.86A
$I_{aFL} = I_{LAL} - I_{Sh}$
= 34.86 - 1.17 = 33.7A
$E_{bFL} = V - I_{aFL} * R_a$
$E_{bFL} = 105-(33.7*0.25)$
We know that, $E \propto N$
$\frac{EbFL}{EbNL} = \frac{NFL}{NNL}$
$N_{NL} = \frac{1000*104.42}{96.57}$
N_{NL} =1080 Rev/min
Suppose 'R' is the added resistance to reduced speed, then

E_{bL} =105-33.7(R+0.25)

$\frac{EbL}{EbFL} = \frac{800}{1000}$

$E_{bL} = \frac{800}{1000}$ *96.57

E_{bL} =77.26V

77.26 = 105 - 33.7(R + 0.25)

R = 0.57Ω

Find the length of manganese wire required to make a 15.7 ohm resistor, if the diameter is 0.315mm and the resistivity are 407 μΩ (16)

Jul 2023

Given:

R=15.7Ω

d=0.315mm

ρ=407μΩ ρ

Weknowthat:

$A = \frac{\pi}{4} \times d^2$

$= \frac{\pi}{4} \times 0.315^2$

$A = 0.078 mm^2$

$R = \rho \frac{l}{A}$

$l = \frac{R \times A}{\rho}$

$= \frac{15.7 \times 0.078}{407 \times 10-6}$

$l = 3.004 \times 10^3$m⌧m=3.0m (approx.)

The open-circuit voltage of a cell as measured by a voltmeter of 100 ohm resistance, was 1.5 V, and the p.d. When supplying current to a 10 ohm resistance was 1.25 V; measured by the same voltmeter. Determine the e.m.f. and internal resistance of the cell (16)

Jul 2023

Let E =e.m.f of cell and

R1 = internal resistance

With the voltmeter across the cell terminals only,

Current taken by voltmeter = $\frac{1.5}{100}$ = 0.015A

= 1.5 + 0.015R_1-----①

With voltmeter and resistor across the cell terminals,

Current taken by resistor = $\frac{1.25}{10}$ = 0.125 A

Current taken by voltmeter = $\frac{1.25}{100}$ = 0.0125A

Current supplied by cell

= 0.125 + 0.0125 = 0.1375A

Thus E = 1.25 + 0.1375R1 and E=1.25+ 0.1375R1----②

Solving and ① and ②

Thus E = 1.25 + 0.1375R_1 and

E = 1.5 + 0.015R_1

Subtracting ① and ②= 0.25 – 0.1225R_1

R1 = $\frac{0.25}{0.1225}$ = 2.04Ω and E = 1.5 + (0.015 * 2.04) = 1.5+0.031

Thus cell e.m.f = 1.531V

(a) Explain Fleming's Right hand rule. (6)
(b) A one-turn armature coil has an axial length of 0.4m and a diameter of 0.2m. It is rotated at a speed of 500 rev/min in a field of uniform flux density of 1.2T. Calculate the magnitude of the e.m.f. induced in the coil. (10)

Jul 2023 | **Mar 2025** | **Dec 2024**

(a) In electromagnetism Fleming's Right-Hand Rule is used to determine the direction of an **induced current** when a conductor moves through a magnetic field. It is particularly useful for understanding the working of **generators** and electromagnetic induction.
Position your right hand with the **thumb, forefinger, and middle finger** perpendicular to each other (forming an "L" shape with the fingers).

Each finger represents a different physical quantity:

- **Thumb** → Motion or force (direction of the conductor's movement).
- **Forefinger** (Index Finger) → Magnetic field direction (from North to South).
- **Middle Finger** → Induced current (conventional current direction from positive to negative).

Application of Fleming's right-hand rule:

- Determining the direction of current in a generator's windings (as mechanical energy is converted to electrical energy).
- Understanding electromagnetic induction in moving conductors within a magnetic field.
- Predicting current flow in dynamic electrical systems, such as alternators or electromagnetic braking systems.

(b)
Axial length =0.4m
Diameter =0.2m
Circumference =πd=3.14×0.2=0.628m
N=500 rev/min
Flux density =1.2T(B)
In one second, armature turns = $\frac{500}{60}$
In one second, coil side travels V= $\frac{500}{60}$×0.628 = 5.233m/sec
EMF=BLV
=1.2×0.4×5.23
EMF=2.513V

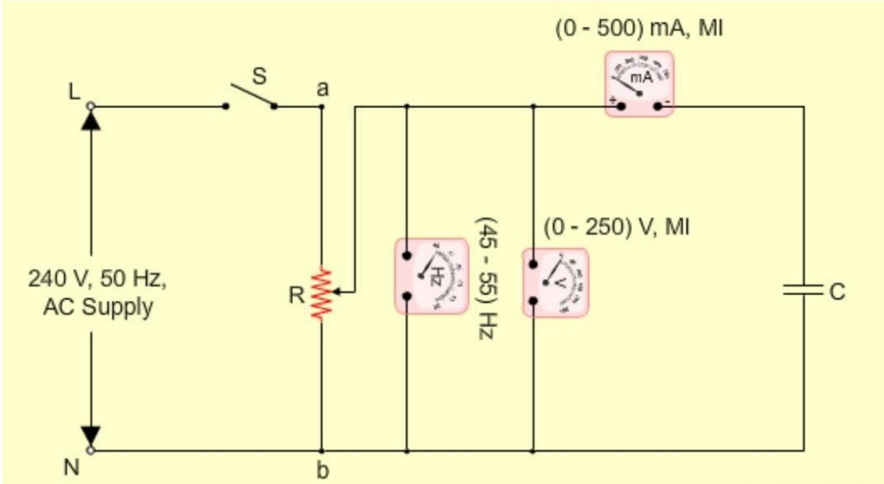
(a) Describe in detail the method used to measure the capacitance of a capacitor. (6)
(b) A circuit has a resistance of 3R and an inductance of 0.01 H. The voltage across its ends is 60V and the frequency is 50Hz. Calculate (10)
(i) The impedance
(ii) The power factor
(iii) The power absorbed

Jul 2023 | **Mar 2025** | **Mar 2025**

(a) Procedure

1. Connect the components as shown in the above image.
2. Switch ON the supply by closing the switch S and set the potential divider such that 50 V is applied across the capacitor.
3. Note down the readings of voltmeter and ammeter.
4. Calculate the impedance of the circuit using the formula Z= V/I. In this circuit, since there is no resistance connected, the impedance is equal to the capacitance. That is, Z=Xc

5. After calculating the capacitance Xc, record the result.
6. Calculate the capacitance Xc again using the formula Xc = 1/2pi fC and verify the results. (Use frequency meter to measure the frequency values)
7. Find the capacitance value for different values of capacitors by repeating steps 1 to 5.



(b) Given:

$R = 3\Omega, L = 0.01H, V = 60V, f = 50Hz, X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 0.01 = 3.14\Omega$

(i) $Z = \sqrt{R^2 + X_L^2} = \sqrt{3^2 + 3.14^2} = 4.34\Omega$

(ii) We know that $Cos\phi = \frac{R}{Z} = \frac{3}{4.34} = 0.69$

(iii) P = I²R

$I = \frac{v}{z} = \frac{60}{4.34} = 13.82A$

$\therefore P = 13.82^2 \times 3$

$P = 572.9W$

(a) Compare Direct current with Alternating current. (6)

(b) A four-pole generator has a flux of 12mWb/pole. Calculate the value of e.m.f. generated in one of the armature conductors, if the armature is driven at 900 rev min (10)

May 2023-2	Mar 2024	Sep 2024-1

a) Comparision of DC with AC

Direction of Current:
- DC: Electrons flow in one direction, maintaining a constant polarity.
- AC: Electrons periodically change direction, resulting in a reversal of polarity.

Voltage Polarity:
- DC: Voltage remains constant with a fixed polarity.
- AC: Voltage alternates, switching between positive and negative polarities.

Power Transmission:
- DC: Suitable for short-distance power transmission.
- AC: Efficient for long-distance power transmission due to the ability to change voltage levels using transformers.

Power Losses:
- DC: Power losses are more significant in long-distance transmission.
- AC: Power losses are comparatively lower over long distances.

Transmission Efficiency:

- DC: High-voltage direct current (HVDC) systems improve efficiency for long-distance transmission.
- AC: Better suited for local distribution.

Transformer Usage:
- DC: Transformers cannot be used for direct current; conversion to AC is required.
- AC: Transformers efficiently change voltage levels in AC systems.

Devices and Appliances:
- DC: Batteries, electronic devices, and some motors operate on DC.
- AC: Common in household appliances, lighting, and most electric motors.

Frequency:
- DC: Frequency is not applicable as it involves a constant flow.
- AC: Frequency represents the number of cycles per second (Hertz).

Safety:
- DC: Generally considered safer for low-voltage applications.
- AC: High-voltage AC can be more dangerous due to the potential for stronger shocks.

Generation:
- DC: Generated by batteries, solar cells, and certain types of generators.
- AC: Produced by most power plants for grid distribution.

Waveform Shape:
- DC: Has a constant, unidirectional waveform.
- AC: Waveform can vary (e.g., sinusoidal, square, triangular).

(b) In 1 revolution a conductor cuts

$4 \times 12 \times 10^{-3} = 0.048$Wb

Time of 1 revolution of the armature= $\frac{1}{900}$ minutes

$= \frac{60}{900}$ or $\frac{1}{15}$ seconds

$\therefore$ Rate of cutting flux $= \frac{\text{Flux cut per revolution}}{\text{time taken to complete a revolution}}$

Thus E = $\frac{0.048}{1/15}$

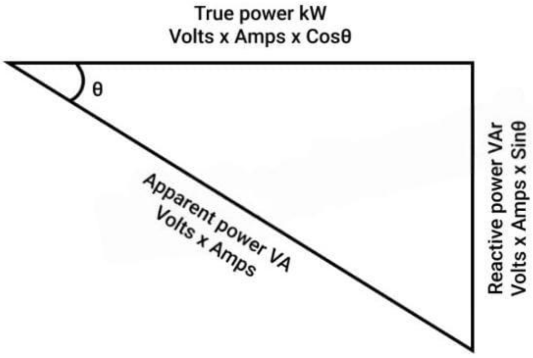
$= 0.048 \times 15$

$= 0.72$ volts/conductor

(a) Explain power factor with a.c. Sine wave and phasor diagram. (6)
(b) A circuit has a resistance value of 25 Ω and an inductance value of 0.3 H. If it is connected to a 230. 50Hz supply, find the circuit current, the power factor and the power dissipation. (10)

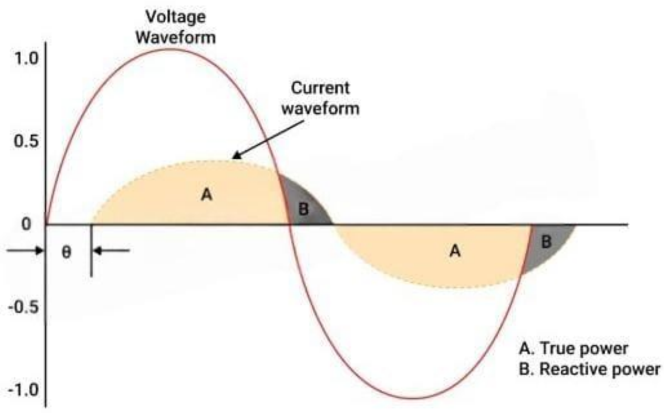
May 2023 - 2	Sep 2024-1	Mar 2024

(a) Power factor is a measure of the efficiency of an electrical system and is defined as the ratio of true power (real power) to apparent power. Mathematically, it is expressed as Power **Factor = True Power / Apparent Power**. The power factor is a dimensionless quantity and is often represented as a value between 0 and 1 or as a percentage. A typical power factor for ship systems is 0.8 lagging, indicating that the current waveform lags the voltage waveform by a certain angle (θ).



A low power factor on electrical systems results in increased reactive power, causing higher I2R heating, reduced overall system efficiency, and elevated energy costs. The inefficient use of apparent power due to a low power factor leads to higher currents, increased resistive heating in components, and diminished capacity for useful work, ultimately impacting the system's performance and contributing to higher operational expenses.

From the graph you can see that it is only the part of the current waveform that is in phase with the voltage that is actually able to do any work, however this current is causing I^2R heating and costing fuel to generate.



(b)

$X_L = \pi f L$

$= 2 * 3.14 * 50 * 0.3 = 94.2\ \Omega$

$$Z = \sqrt{25^2 + 94.2^2} = 97.5\Omega$$

$$I = \frac{230}{97.5} = 2.36A$$

Powerfactor $= \cos\phi = \frac{R}{Z} = \frac{25}{97.5} = 0.256 \text{ (lagging)}$

$$P = VI\cos\phi = 230 \times 2.36 \times 0.256 = 139W$$

or

$P = I^2R = 2.36^2 \times 25 = 139W$

(a) What is Kirchoff's current Law. (6)
(b) Calculate the value of I2 in the circuit, when I1 = -6A (10)

May 2023 - 2

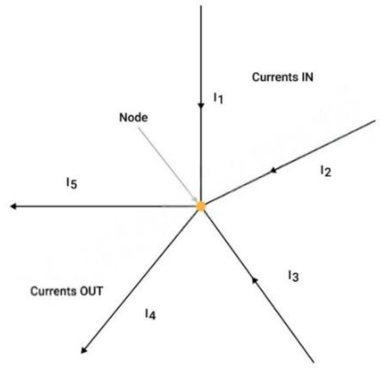
(a) 1. Kirchhoff's First Law or Kirchhoff's Current Law

According to Kirchhoff's Current Law,

The total current entering a junction or a node is equal to the charge leaving the node as no charge is lost.

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

The algebraic sum of every current entering and leaving the node has to be null. This property of Kirchhoff law is commonly called conservation of charge, wherein I(exit) + I(enter) = 0.



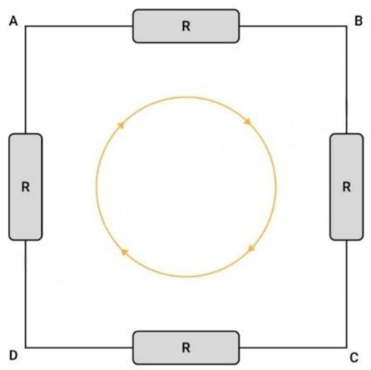
2. Kirchhoff's Second Law or Kirchhoff's Voltage Law

According to Kirchhoff's Voltage Law,

The voltage around a loop equals the sum of every voltage drop in the same loop for any closed network and equals zero.

$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$

The algebraic sum of every voltage in the loop has to be equal to zero and this property of Kirchhoff's law is called conservation of energy.



(b) Diagram for question

BY KIRCHOFF'S LAW

$I_1 + I_2 + I_3 = I_4$

$-6+I_2+4=2$

$I_2=2+6-4$

$I_2=4A$

(a) How does a moving coil ammeter measure large current? (6)
(b) A moving coil instrument with a coil resistance of 1.98 Ω, produces full scale deflection from a current of 10 mA. Determine the value of shunt required to extend the range upto 10 A. (10)

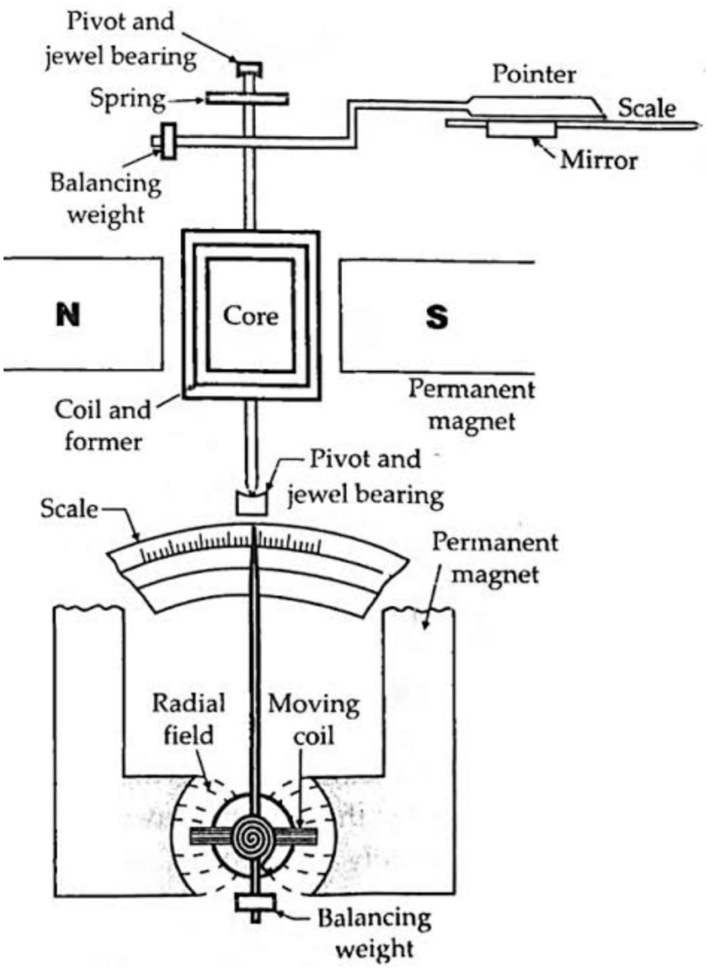
May 2023 - 2 | **Sep 2024 - 1** | **Mar 2024**

(a) A moving coil ammeter measures large currents through the use of a shunt resistor.

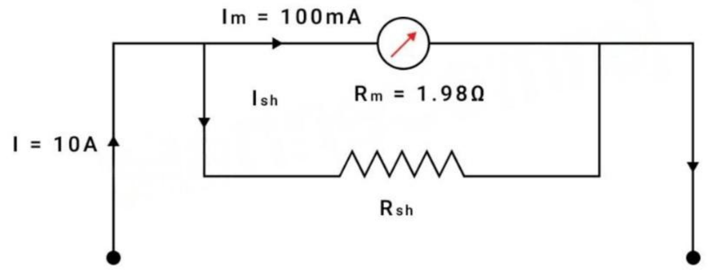
Basic Principle: A moving coil ammeter operates on the principle of a coil placed in a magnetic field. When current flows through the coil, it experiences a torque that causes it to move, deflecting a needle to indicate the current.

Shunt Resistor: To measure large currents, a shunt resistor, which is a low-resistance resistor, is connected in parallel with the moving coil. The shunt resistor allows the majority of the current to bypass the delicate moving coil.

Current Division: The current is divided between the shunt and the coil based on their resistances. Since the shunt resistor has a much lower resistance compared to the moving coil, most of the current flows through the shunt. As current flows through the circuit, the moving coil detects a small, proportional fraction of the total current (due to the shunt resistor). The needle deflection is proportional to this small current, but the scale is marked to show the total current, providing an accurate measurement.



(b)



Given:

I_m = 100mA = 0.1A, R_{sh} = 1.98 Ω,I = 10A

To find shunt resistance, R_s

$$R_s = \frac{I_m R_m}{I - I_m}$$

$$R_s = \frac{0.1 \times 1.98}{10 - 0.1}$$

$$R_s = \frac{0.198}{9.9}$$

$$R_s = 0.02\Omega$$

The shunt resistance, R_s, required is 0.02Ω.

(a) Name the various types of Capacitors. (6)
(b) A 500W, 100V bulb is to be connected across 250V, 50Hz mains. Find the value of the capacitor required to be connected in series. (10)

May 2023

(a) Various types of capacitor:
Ceramic Capacitors: Small and inexpensive capacitors made of ceramic materials. They have a wide range of capacitance values and are commonly used in various applications.

Electrolytic Capacitors: These capacitors use an electrolyte as one of their plates. They have high capacitance values and are used in applications requiring higher voltage and capacitance.

Film Capacitors: Constructed using a thin plastic film as the dielectric. They have good stability, high insulation resistance, and are used in AC and DC applications.

Tantalum Capacitors: Capacitors that use tantalum metal as the electrode. They have high capacitance per volume, excellent stability, and are commonly used in electronic devices.

Aluminum Capacitors: Also known as electrolytic capacitors, they use aluminum as the electrode. They have a high capacitance range and are commonly used in power supply applications.

Supercapacitors: Capacitors with extremely high capacitance values, capable of storing and releasing energy quickly. They are used in applications requiring rapid energy discharge.

Variable Capacitors: Capacitors with adjustable capacitance, used in tuning circuits for radios and other devices.

(b)

current taken by bulb = $\frac{500}{100} = 5A$

Impedance of lamp = $\frac{100}{5} = 20\Omega$

On 250V, impedance of the circuit is = $\frac{250}{5} = 50\Omega$

Impedance² = R² + X_C^2

Thus $X_c = \sqrt{50^2 - 20^2}$

$X_c = 45.8\Omega$

Again $X_c = \frac{1}{2\pi f C}$

$\therefore 45.8 = \frac{1}{2 \times 3.14 \times 50 \times C}$

$C = \frac{1}{2 \times 3.14 \times 50 \times 45.8}$

$C = 69.5\mu F$

(a) What are the routine maintenance carried out on lead acid batteries? (6)
(b) When a 10Ω resistor is connected across a battery, the current is measured to be 0.18A.
If similarly tested with a 25Ω resistor, the current is measured to be 0.08A. Find the e.m.f. of the battery and its internal resistance. Neglect the resistance of the ammeter used to measure the current. (10)

May 2023

a) Routine maintenance carried out on lead acid batteries:

Regular Inspection: Perform visual inspections of the battery to check for any signs of damage, corrosion, leaks, or loose connections. Look for bulging or swelling of the battery case, which could indicate internal issues.

Cleaning: Keep the battery and its terminals clean and free from dirt, debris, and corrosion. Ensure that the terminals are tight and secure.

Electrolyte Levels: For flooded lead-acid batteries, check the electrolyte levels regularly. If the battery is not maintenance-free, you may need to remove the cell caps and check the fluid levels. Add distilled water if necessary, but be careful not to overfill.

Charging: Lead-acid batteries should be kept fully charged to maintain their capacity and prolong their lifespan. Regularly charge the battery using a suitable charger that matches the battery's voltage and capacity. Avoid overcharging, as it can cause damage.

Equalization (for flooded batteries): Periodically perform an equalization charge to balance the individual cell voltages and ensure even charging. This process helps prevent stratification, where acid concentration varies within the battery.

Testing: Use a battery tester or a multimeter to check the battery's voltage and overall health. This can help identify any potential issues or determine if the battery needs replacement.

b)
Let E = EMF of battery
Let R_i = its internal resistance
Then $E = 0.18(10 + R_i)$ ----- ①
and $E = 0.08(25 + R_i)$ ----- ②
Equating ① and ②
$0.18(10 + R_i) = 0.08(25 + R_i)$
or
$1.8 + 0.18R_i = 2 + 0.08R_i$
$\therefore 2 - 1.8 = (0.18 - 0.08)R_i$
or
$0.2 = 0.1R_i$
or
$R_i = 2\Omega$
Substituting in E
$E = 0.18(10 + 2) = 0.18 \times 12 = 2.16V$

(a) What is self induction? (6)
(b) A coil of 800 turns is wound on a wooden former and a current of 5A is passed through it to produce a magnetic flux of 200 micro-webers. Calculate the average value of e.m.f. induced in the coil when the current is (i) switched off in 0.08 seconds (ii) reversed in 0.2 seconds.

May 2023

(a) Self-induction, or self-inductance, is a phenomenon in which a changing current in a coil of wire induces an electromotive force (EMF) in the same coil. This induced EMF opposes the change in current, creating a back electromotive force. It occurs due to the interaction between the magnetic field generated by the current and the coil itself. Self-inductance is quantified by the property called self-inductance, measured in henry (H). The effect of self-induction is most notable during sudden changes in current, causing a delay in the rise or fall of current in the coil. Self-induction is utilized in inductors and transformers, enabling energy storage, signal manipulation, and voltage/current transformation.

(b) (i)

$$E_{av} = \frac{N\phi}{t}$$

$$= \frac{800 \times 200 \times 10^{-6}}{0.08}$$

$$= \frac{16 \times 10^{4} \times 10^{-6}}{8 \times 10^{-2}}$$

$$E_{av} = 2 \text{ volts}$$

(ii) $E_{av} = \dfrac{N(\phi_1 + \phi_2)}{t}$

Here, $\phi_2 = -\phi_1$,

but is in the reverse direction. Thus flux change is from ϕ_1 to zero and then up again to ϕ_1 or a total change of $(\phi_1 + \phi_2) = 2\phi_1$ webers.

Thus $E_{av} = \frac{800[200\times10^{-6}]-[-200\times10^{-6}}{0.2} = \frac{800\times400\times10^{-6}}{2\times10^{-1}}$

$= \frac{32\times10^{4}\times10^{-6}}{2\times10^{-1}}$

= 1.6 volts

(a) Explain what is meant by phase difference between voltage and current values. (6)
(b) An inductance coil has a resistance of 19.5 Ω and when connected to a 220V, 50Hz supply, the current passing is 10A. Find the inductance of the coil. (10)

Jan 2025-1 | **Jul 2024** | **Feb 2024**

(a) In an AC circuit, the phase difference between voltage and current refers to the angle between their vectors. This angle signifies whether the current is lagging or leading the voltage. The phasor diagram visually represents this phase difference, indicating whether one alternating quantity is ahead (leading) or behind (lagging) another. A leading quantity reaches its maximum or zero values earlier than another, while a lagging quantity reaches them later. The phasor representation helps visualize electrical parameters and understand the timing relationship between voltage and current waveforms in the circuit.

(b)

Impedance $Z = \frac{V}{I} = \frac{220}{10} = 22\Omega$

The resistance R is 19.5Ω

Therefore reactance $X = \sqrt{Z^2 - R^2}$

$= \sqrt{22^2 - 19.5^2} = 10.15\Omega$

Also $X = 2\pi f L$

$\therefore L = \frac{10.15}{2\times3.14\times50} = \frac{0.1015}{3.14}$

$= 0.032H$

(a) Explain what is meant by the back e.m.f. of a motor. (6)
(b) A d.c. motor takes an armature current of 110 A at 480 V. The resistance of the armature circuit is 0.2 Ω. The machine has 6 poles and the armature is lap connected with 864 conductors. The flux per pole is 0.05 wb. Calculate (10)
(a) speed,
(b) the gross torque developed by the armature.

Apr 2023

(a) Back EMF is the electromotive force (EMF) that is generated in the armature of a motor by the rotation of the armature. It is proportional to the speed of the motor and the flux per pole. The back EMF opposes the applied voltage, which limits the current in the armature and the torque that the motor can produce.
The back EMF can be calculated using the following formula:
$E_b = K_e \varphi N$
where:
E_b is the back EMF in volts
Ke is the motor's electromagnetic constant
φ is the flux per pole in webers (Wb)

N is the speed of the motor in revolutions per minute (rpm) .The back EMF is an important factor in the operation of a motor. It limits the current in the armature and the torque that the motor can produce. The back EMF also helps to regulate the speed of the motor.

(b) Given

A = P (for lap wound)

I_A = 110A

V = 480V

ϕ = 0.05wb

Z = 864

R_A= 0.2 Ω

N = ?

$E_B = V - I_a R_a$

458 = 480 - (110 * 0.2)

$458 = \frac{0.05*6*N*864}{60*6}$

∴ N = 636.1 rpm

$T_A = \frac{P\varphi\, IZ}{2\pi A} = \frac{6*0.05*110*854}{2\pi A}$ = 756.3 Nm

(Or)

$T_A = 9.55 * \frac{EB*IA}{N}$

= 9.55 * (458 *110)/636.1

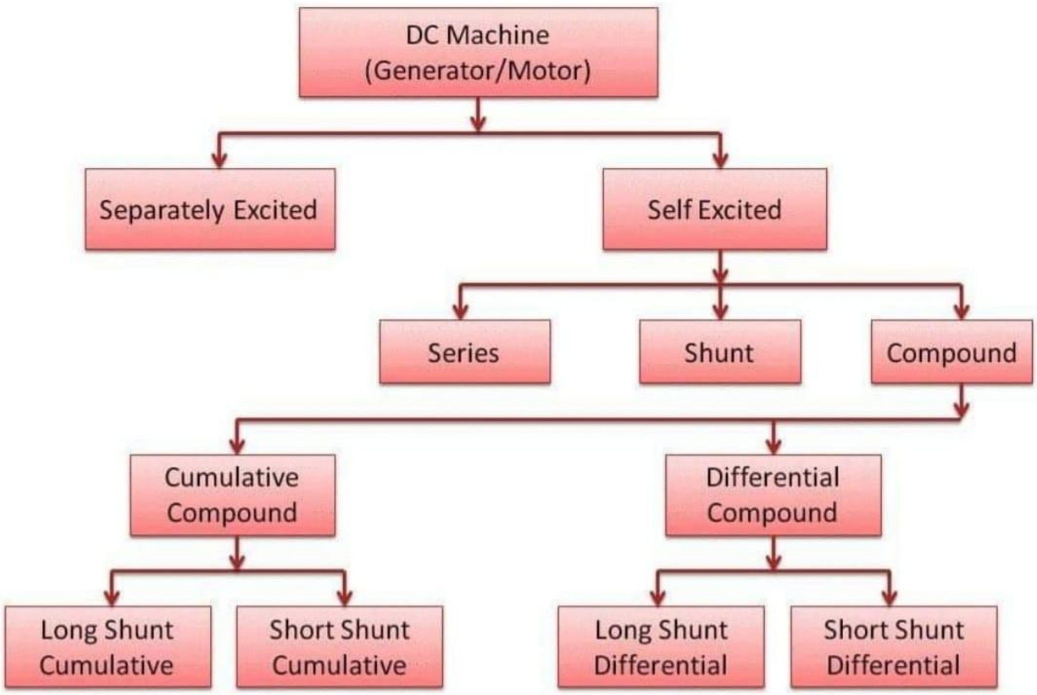
=756.37 Nm

(a) List the different combinations of motor-generators that are often made, to suit load conditions. (6)

(b) A diesel engine has a measured indicated power of 7.5 kW and a mechanical efficiency of 85 percent. It drives a generator which supplies a lamp load at 110V. How many 60W lamps can be supplied, if the efficiency of the generator is measured to be 88 percent? Find the total load current. (10)

Apr 2023

(a)



(b) Output of the engine = input × efficiency

$7.5 * \frac{85}{100}$ = 6.375kW

At the coupling between the engine and generator, it can be assumed that there is no loss of energy, so the power input to the generator must be the power output of the engine as follows

Output of engine = input to gen = 6.375kW

∴ Gen output = input* efficiency

$6.375 * \frac{88}{100}$ = 5.61kW

No. of lamps $= \frac{Gen\ output}{\text{load of lamp}}$

$= \frac{5610}{60}$ = 93.5

We say 93 lamps

Load current= $\frac{GEN\ POWER\ OUTPUT}{VOLTAGE}$

$= \frac{5610}{110}$ = 51A

(a) Describe the measures to be taken and the effect on various outputs when running a 60Hz system on a 50Hz supply (6)
(b) A series circuit consists of a capacitor of 50μF and a coil of inductance 1.5H and resistance of 300 ohms. Find the total impedance when working on a 50Hz supply. Find whether the current leads or lags the voltage (10)

Mar 2023 **Sep 2022**

(a) The basic, RPM is in direct proportion to Hz. If you decrease the power supply frequency, the motor will slow down. On the contrary, if you increase the frequency, the motor will speed up. The RPM change is proportional to the Hz change. 60Hz motor will run 20% slower on 50Hz power supply This also results in 20% less power.

Basically, running the electric machine slower usually means it will be demanding less power. That's good, as the motor also decrease 20% of its power, and the cooling fan is slow down too. But the critical factor here is the V/Hz ratio. It goes up 20%! Not good. This means that during parts of every power line cycle the magnetic structure of the motor will probably be overloaded.

The only recourse here is to correct the V/Hz with the variable value that is easy to change – V the voltage. Lower the voltage with a transformer to correct the V/Hz ratio.

(b) Given,
L=1.5H
so, X_L=2πfL =2π×50×1.5= 471Ω

C = 50μF

So, $x_C = \frac{1}{2\pi fL} = \frac{1}{2\pi\times50\times50\times10^{-6}}$ =63.70 Ω

Total reactance, $X = X_L - X_c$ = 471 - 63.70 = 407.30 Ω

Impedance, $Z = \sqrt{R^2 + X^2} = \sqrt{300^2 + 407.3^2}$ = 506 Ω

Since the inductive reactance is more, the circuit is inductive, so the current lags with the voltage.

(a) Describe the normal criteria used for setting thermal protection relays and their advantage compared to magnetic types (6)
(b) A series motor runs at 600 r/min when taking 110A from a 230V supply. the resistance of the armature circuit is 0.12Ω and that of series winding is 0.03Ω. the useful flux per pole is 110A is 0.024 wb and that for 50A is 0.0155wb. Calculate the speed when the current has fallen to 50A (10)

Mar 2023 **Sep 2022**

(a) Thermal protection relays are designed for sustained overcurrent protection, typically set between 105-120% of the full load current with a time delay. They are not intended for momentary overcurrents.

The overcurrent setting depends on the following:

- The electrical system's maximum continuous load capacity determines the relay settings to ensure the system operates without tripping under normal conditions.
- The relay settings are influenced by the insulation class and its capacity to withstand elevated temperatures.
- The amount of power consumption and heat generated during normal operation is evaluated to set the relay accurately.
- The relay takes into account the cooling mechanism in place to ensure that heat dissipation during operation is factored into the thermal protection settings.

Advantages of Thermal relays over Magnetic relays:

- Thermal relays provide a time delay, preventing tripping from momentary overcurrents that might not cause actual damage. Magnetic relays respond much faster.
- Thermal relays operate based on the heat generated by an overcurrent, offering a more accurate reflection of the actual thermal stress on the system. Magnetic relays respond to the magnitude of the current, irrespective of heat generation.
- Thermal relays are more economical because they use bimetals instead of more expensive magnetic solenoid coils.
- Thermal relays are effective for sustained overcurrents, providing protection that is independent of other factors like the system voltage or magnetic field fluctuations.

(b) Given,
Speed = 600rpm
Voltage = 230V
Current = 110A
Resistane,
Armature Ra = 0.12Ω
Series winding Rs = 0.03Ω
Flux per pole,
ϕ_{110} = 0.024wb
ϕ_{50} = 0.0155wb
To find speed at 50A
$E_{b110} = V_t - (I_A R_a + I_S R_S)$ = 230-110(0.12 +0.03) = 213.5V

$E_{b50} = V_T - (I_A R_A + I_S R_S) = 230 - 50(0.12 + 0.03) = 222.5V$

We know, $E = \phi$ PNZ/60A

So, $E_B \, \alpha \phi$ N

$$\frac{Eb110}{E650} = \frac{\varphi 110\, N110}{\varphi 50\, N50}$$

$$\frac{213.5}{222.5} = \frac{0.024 \times 600}{0.0155 * N50}$$

N_{50} = 968rpm

(a) Show graphically the effect of a.c. Current due to pure inductive load. (6)
(b) A 220V, 50Hz supply is applied to a choke-coil of negligible resistance and the circuit current is measured to be 2.5A. Find the inductance of the coil and the power dissipated. (10)

Feb 2023

(a)

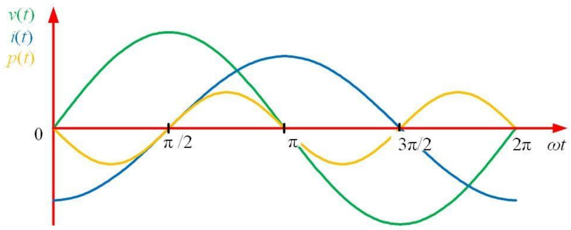


Figure 3: Current, voltage and power waveforms.

(b) Since $Z = \frac{V}{I}$

Then, $Z = \frac{220}{2.5} = 88\Omega$

Now $R = 0$

$\therefore X_L = Z$ or $X_L = 88\Omega$

So, L = $\frac{X_L}{2\pi F} = \frac{88}{2 \times 3.14 \times 50} = \frac{0.88}{3 \cdot 14}$ Or $L = 0.28H$

Also as $R = 0$, $\cos\phi = \frac{0}{88} = 0$ $\therefore = 220 \times 2.5 \times 0 = 0$

Alternatively since $P = I^2 R$ then $P = 2.5^2 \times 0 = 0$ The circuit has choke-coil. So, the Circuit is purely Inductive. Hence Power is Zero.

(a) Explain mutual induction with the help of two insulated coils (6)
(b) A coil of 800 turns is wound on a wooden former and a current of 5A is passed through it to produce a magnetic flux of 200 micro-webers. A secondary coil of 2000 turns is wound on it. Find the emf induced in the secondary coil when the current is switched off in 0.08sec.

Jan 2023

(a) Mutual inductance is a fundamental principle of electromagnetism. When two coils are placed near each other, the magnetic field generated by a current in the first coil can induce a voltage in the second coil. This effect occurs due to the changing magnetic flux that links the two coils, in accordance with Faraday's law of electromagnetic induction. Mutual inductance

M is a measure of how effectively a change in current in one coil induces a voltage in another coil, and it is given by:

$$V_2 = M\frac{dI_1}{dt}$$

- V_2 is the **induced voltage in the secondary coil** (in volts),
- M is the **mutual inductance** between the two coils (in henries),
- $\frac{dI_1}{dt}$ is the **rate of change of current** in the primary coil (in amperes per second).

The mutual inductance depends on factors like the number of turns in each coil, their proximity, the core material, and how well the magnetic flux is linked between them. This principle is widely used in transformers, wireless charging systems, and many electrical devices.

(b) The induced EMF in the secondary coil is given by $E_{av} = -N\frac{\phi_2 - \phi_1}{t}$.

$$E_{av} = -2000\,\frac{0 - 200\times10^{-6}}{0.08}$$

$$E_{av} = -2000\,\frac{-200\times10^{-6}}{0.08}$$

$$E_{av} = \frac{2000\times200\times10^{-6}}{0.08}$$

$$E_{av} = \frac{0.4}{0.08}$$

$$E_{av} = 5$$

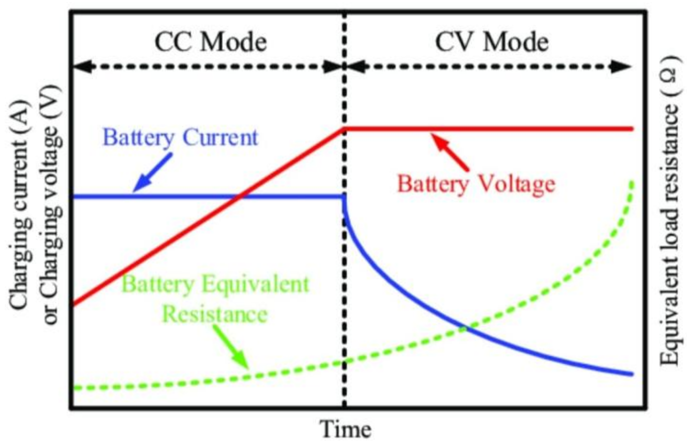
The induced voltage in the secondary coil is 5 V.

(a) Compare constant current method and constant voltage method of charging batteries (6)

(b) A 24V emergency battery is to be charged from the 110V ship' mains when the e.m.f per cell has fallen to a minimum value of 1.8V. The battery consists of 12 cells in series, has a capacity of 100Ahr at a 10 hr rate and the internal resistance is 0.032/cell. If charging continues until the voltage per cell rises to 2.2V, find the values of the variable resistor needed to control the charging. The charging current can be assumed to be equal to the maximum allowable discharge current (10)

Feb 2023 | **Feb 2024** | **Jul 2024** | **Jan 2025**

(a)



- The constant voltage charging is more rapid than the constant current charging. The time of charge in a constant voltage system as compared to the constant current system is almost reduced to half.
- In a constant voltage charging method of battery, the charging current from discharged to fully charged condition decrease.
- The current control mode is used for constant battery charging.
- The constant current charging is more efficient than the consonant voltage charging as in case of constant voltage charging the charging current may be excessive which causes heating of the battery during charging.
- The practical charging method uses two types of sources. The constant current charging at the start where the battery is relatively empty.* Once the battery reaches a certain voltage near the maximum voltage then constant voltage charging is accomplished.

(b)

24 V battery charged by 110 V main
V_{min} = 1.8 V
Number of battery = 12
Capacity = 100 Ah
Rate = 10 hr
R = 0.03 Ω/cell
V_{max}= 2.2V

Total internal resistance:
R_{int} = 0.03*12 = 0.36 Ω
Max allowable current:
$I_{max}= \frac{100}{10}$ =10A
Max V=2.2×12=26.4V
Min V=1.8×12=21.6V
Voltage across battery:
$V_{charging}=V_{max}+I_{max}\times R_{max}$
26.4+10×0.3626.4+10×0.36
$V_{charging}$=30V
Voltage drop:
$V_{resistance}$ =110−30=80V
So,R= $\frac{V}{I} = \frac{80}{10}$
R=8Ω

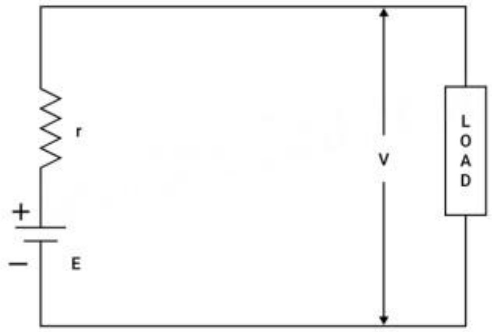
(a)What are condition under which cells are connected in Series, Parallel, Series & Parallel (6)
(b) The total resistance of a battery of series connected cell is 0.15 Ω. The resistance of a connected load is 0.6 Ω and the terminal voltage at this load is 12 V. Calculate the power loss in the battery (10)

Jan 2023

(a) Connected in series to increase voltage, connected in parallel to increase current, connected in series and parallel to increase voltage and current.
In series circuit electrons travel only in one path. Here the current will be the same which passes through each resistor. The voltage across resistors in a series connection will be different. Series circuits do not overheat easily. The design of series circuit is simple compared to parallel circuits.

In parallel circuit electrons travel through many branches in it. In this case, the voltage remains the same across each resistor in the circuit. Here the current in the circuit is divided among each branch and finally recombines when the branches meet at a common point. A parallel circuit can be formed in many ways, which means cells can be arranged in different forms. Parallel circuits can be used as a current divider.

(d) Given:
Terminal voltage (V) = 12V
Internal resistance (r) = 0.15Omega
Load resistance (R) = 0.6 Ω



Current, I = V/R = 12/0.6 =20Amps
Power loss in the battery = 1^2r
= $20^2 * 0.15$ = 60W

(a) Describe the effect of running an induction motor on reduced voltage.
(b) A motor takes a current of 60 amperes at 230 volts, the power input being 12 kW. Calculate the power component and the reactive component of the input current. (10)

Dec 2022 **Jan 2025**

(a) 1. Reduced Starting Torque:
The starting torque of an induction motor is proportional to the square of the voltage. When the voltage is reduced, the starting torque decreases significantly. This can result in the motor struggling to start or taking a longer time to reach full speed, especially under heavy load conditions. This can also cause mechanical stress and overheating.

2. Higher Current Draw:
To produce the same mechanical output at reduced voltage, the motor will draw more current. This increased current can lead to overheating of the windings and other electrical components, potentially damaging the insulation and leading to a shorter lifespan or even motor failure.

3. Reduced Efficiency:
When running at reduced voltage, the motor operates at a lower efficiency. The motor will consume more power for the same output, resulting in energy wastage. This inefficiency is caused by increased copper losses (I^2R losses) due to higher current.

4. Excessive Heating:
The higher current draw at reduced voltage increases the I^2R losses in the motor windings. This leads to excessive heating, which can damage the motor's insulation, reduce its lifespan, and in extreme cases, cause winding failure.

5. Reduced Speed:

The motor may run at a slightly lower speed than its rated speed due to the lower voltage. In induction motors, the speed is determined by the frequency of the supply, but running at reduced voltage may cause a small reduction in speed, particularly under load.

6. Vibration and Noise:
Reduced voltage can lead to unstable or uneven motor performance, resulting in increased vibration and noise. This happens because the motor is not able to maintain steady torque under reduced voltage conditions, leading to mechanical stress and potentially damaging motor components over time.

7. Risk of Stalling:
If the motor is running under heavy load, reduced voltage may not provide enough torque to sustain rotation, causing the motor to stall. A stalled motor under load draws a large current, which can cause overheating and eventual burnout of the windings.

(b) Given:
I=60amps
V=230V
P=12kW
1. Calculate the Power Factor: The Power Factor (PF) is calculated using the formula
$PF = \frac{\text{Pinput}}{V \times I}$
Where,

- **P** is the power input
- **V** is the voltage
- **I** is the current

$PF = \frac{12000}{230 \times 60} = \frac{12000}{13800} = 0.87$
2. Calculate the power component of the current: The power component of the current
$I_p = I \times PF$
$I_p = 60 \times 0.87 = 52.2A$

3. Calculate the Reactive Component of the current: The reactive component of the current I_q is calculated using the Pythagorean theorem in the context of power triangle
$I_q = \sqrt{I^2 - I_p^2} = \sqrt{60^2 - 52.2^2}$
$= \sqrt{3600 - 2724.84}$
$= \sqrt{875.16}$
$= 29.58A$
The power component for the input current is 52.2A and the reactive component is 29.58A.

(a) Explain how fluorescent tubes power factor is improved. (6)
(b) A fluorescent lamp taking 80-watt 0.7power factor lagging from a 230v, 50-Hz supply is to be connected to unity power factor. Determine the value of the correcting approach require (10).

Dec 2022 | Oct 2024 | May 2024

(a) Fluorescent tube power factor can be improved by using power factor correction techniques such as adding capacitor banks or using electronic ballasts. These methods help offset the reactive power consumed by the fluorescent tubes, resulting in a higher power factor. Capacitor banks store energy and release it to counteract the inductive reactive power, while electronic ballasts regulate the power delivered to the tubes more efficiently. These measures reduce power losses, improve energy efficiency, and optimize the utilization of the electrical system's capacity.

(b) Power of the tube = 80 watts
Supply voltage = 230 V
$\cos\phi = 0.7$
$\sin\phi = 0.714$
$P = VI \cos\phi = 80$
$\therefore I = \frac{80}{(230 * 0.7)} = 0.4969A$
current through the capacitor = reactive component of line current
$= I \sin\phi$
$= 0.4969 * 0.714$
$I_C = 0.3548$ A
Also, Voltage $V = I_C * X_C$
$\therefore X_C = \frac{V}{I}{}_c = \frac{230}{0.3548} /= 648.25\ \Omega$
$\therefore X_C = \frac{1}{2\pi fC} = 648.25b\ \Omega$
$\therefore C = \frac{1}{(648.25 * 2 * 3.14 * 50)} = 4.912*10^{-6}$ Farads
Capacitor to be added = 4.912 μF

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a) Describe the normal criteria used for setting thermal protection relays and their advantage compared to magnetic types.
(b) Calculate the r.m.s. value, the form factor and peak factor of a periodic voltage having the following values for equal time intervals changing suddenly from one value to next: 0, 5, 10, 20, 50, 60, 50, 20, 10, 5, 0, -5, -10, V etc. What would be the r.m.s. value of a sine wave having the same peak value?

Dec 2022

(a) Thermal protection relays are designed for sustained overcurrent protection, typically set between 105-120% of the full load current with a time delay. They are not intended for momentary overcurrents.

The overcurrent setting depends on the following:

- The electrical system's maximum continuous load capacity determines the relay settings to ensure the system operates without tripping under normal conditions.
- The relay settings are influenced by the insulation class and its capacity to withstand elevated temperatures.
- The amount of power consumption and heat generated during normal operation is evaluated to set the relay accurately.
- The relay takes into account the cooling mechanism in place to ensure that heat dissipation during operation is factored into the thermal protection settings.

Advantages of Thermal relays over Magnetic relays:

- Thermal relays provide a time delay, preventing tripping from momentary overcurrents that might not cause actual damage. Magnetic relays respond much faster.
- Thermal relays operate based on the heat generated by an overcurrent, offering a more accurate reflection of the actual thermal stress on the system. Magnetic relays respond to the magnitude of the current, irrespective of heat generation.
- Thermal relays are more economical because they use bimetals instead of more expensive magnetic solenoid coils.
- Thermal relays are effective for sustained overcurrents, providing protection that is independent of other factors like the system voltage or magnetic field fluctuations.

(b)

RMS = Root Mean Square Hence, mean value of V^2:

$$V^2 = \frac{0^2 + 5^2 + 10^2 + 20^2 + 50^2 + 60^2 + 50^2 + 20^2 + 10^2 + 5^2}{10}$$

$$V^2 = \frac{0 + 25 + 100 + 400 + 2500 + 3600 + 2500 + 400 + 100 + 25}{10} \quad V^2 = \frac{9650}{10} = 965$$

$$\therefore RMS \text{ value} = \sqrt{965} = 31 \text{ V}$$

Average Value: $$\text{Average value} = \frac{0 + 5 + 10 + 20 + 50 + 60 + 50 + 20 + 10 + 5}{10}$$

$$\text{Average value} = \frac{230}{10} = 23 \text{ V}$$

Form Factor: $$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{31}{23} = 1.35$$

Peak Factor: $$\text{Peak factor} = \frac{\text{Maximum value}}{\text{RMS value}} = \frac{60}{31} = 1.94 \approx 2$$

RMS value of a sine wave with the same peak value:

$$\text{RMS}_{\text{sine}} = \frac{\text{Max value}}{\sqrt{2}} = \frac{60}{\sqrt{2}} = 42.42 \text{ V} \approx 42.2 \text{ V}$$

(a) Explain the Speed-Current Characteristics of D.C motor. (6)

(b)A 4-pole, 32 conductor, lap-wound d.c. shunt generator with terminal voltage of 200 volts delivering 12A to the load has Ra 2 and field circuit resistance of 200 ohms. It is driven at 1000 rpm. Calculate the flux per pole in the machine. If the machine has to be run as a motor with the same terminal voltage and drawing 5A from mains, maintaining the same magnetic field, find the speed of the machine. (10)

Nov 2022

(a) SPEED - CURRENT CHARACTERISTICS.

Since the speed of the DC motor is given by:

N= k(E/Φ) , where k= proportionality constant.

N = k{(V - IR)/Φ}

The resistance of the armature is minimal so voltage drop (IR) can be neglected and supply voltage is constant. So speed is inversely proportional to flux.

Now, in the DC series motor, the flux is produced by the armature current flowing in the field winding. So, the flux produced is directly proportional to the armature current. Hence, the speed of the series motor becomes inversely proportional to the armature current.

The curve between them is a rectangular hyperbola.

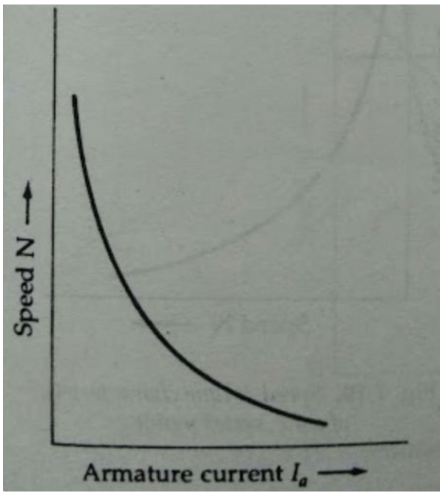


Fig. Speed - current characteristics

Thus, when the armature current is low the speed will be very large. Therefore, at no load or light load, there is a possibility of dangerously high speed, which may damage the rotor. Hence, the DC series motor should never be run at no load.

(b) Given:

P = 4

A = P (lap)

Z = 32

V = 200V

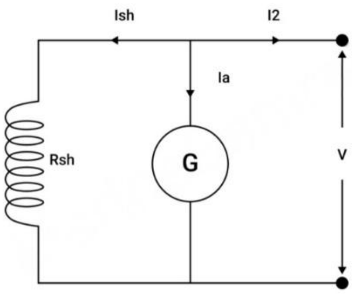
I_L = 12A

R_a = 2Ω

Rsh = 200 Ω

N =1000 rpm

When running as a generator, shunt current



Ish = $\frac{V}{Rsh} = \frac{200}{200}$ = 1 A

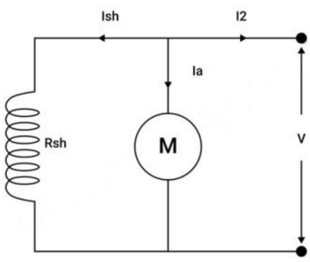
Armature current, Ia = I_L+I_{sh} = 12+1 = 13A

EMF induced, E_b = V+Ia Ra = 200+ (13 × 2) = 226V

$E_b = \frac{\phi ZNP}{60A}$

$\varphi = \frac{226\times60}{32\times1000}$ = 0.423 wb

When running as a motor, Armature current



$I_a = I_L - I_{sh} = 5-1 = 4$ A

EMF induced, $E_1 = V - IaRa = 200 - (4 \times 2)$

E = 192 V

$\therefore$ Speed N = $\frac{Eb * 60}{\phi Z}$

$= \frac{60 * 192}{0.423 * 32} = 850$ rpm

(a) State the relationship between impedence, voltage and current. (6)
(b) The filament of a 230V lamp takes a current of 0.261A when working at its normal temprature of 2000°C. The temperature coefficient of the tungsten filament material can be taken as 0.005 Ohms/Ohms at 0° C/C. Find the approximate current which flows at the instant of switching on the supply of the cold lamp, which can be considered to be at a room temperature of 20°C (10)

Nov 2022	Apr 2025 - 1	Aug 2024	May 2024 - 2	Aug 2022

(a) Relationship between Impedance, Voltage and Current.
Impedance (Z): is the total opposition that a circuit presents to the flow of alternating current. It includes both resistance (opposition to current flow that dissipates energy as heat) and reactance (opposition to current flow due to inductors and capacitors). Impedance is measured in ohms (Ω).
Voltage (V): Voltage is the electrical potential difference that drives the current through the circuit. It is measured in volts (V).
Current (I): Current is the flow of electrical charge through the circuit. It is measured in amperes (A).
The Relationship is expressed by a form of Ohm's Law:
V = I * Z
This equation states that the voltage across a circuit is equal to the current flowing through it multiplied by the impedance of the circuit.

(b) Given:
Voltage = 230V
Current = 0.261A
Temperature = 2000°C
Temperature co-efficient = 0.005
To find:
current at 20°C
Resistance of lamp at 2000°C
Rhot= $\frac{V}{I}$
$= \frac{230}{0.261}$
=881.2Ω
Resistance, Ro $R_{hot} = Ro(1+\alpha T_{hot})$
$881.2 = R_o(1+(0.005 \times 2000))$
Ro=80.1Ω
Resistance at 20°C
$R_{20} = R_o(1+\alpha T_{cold})$
=80.1(1+0.005×20)
=88.11Ω
Current at 20°C

$I_{20} = \frac{v}{R20}$

$= \frac{230}{88.11} = 2.61A$

The power component fo the input current is 52.2A and the reactive component is 29.58A

(a) Explain the effect of changing current and its associated magnetic flux on the induced e.m.f (6)

(b) A d.c. generator gave the following O.C.C. when driven at 1000 rev/min.

Field Current (A) 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6

Armature Voltage (V) 32, 58, 78, 93, 104, 113, 120, 125

If the machine is run as a shunt generator at 1000 rev/min, the shunt-field resistance being 100Ω, find

(i) the O.C. voltage

(ii) the critical value of the shunt-field resistance,

(iii) the O.C. voltage if the speed was raised to 1100 rev/min, the field resistance being kept constant at 100Ω.

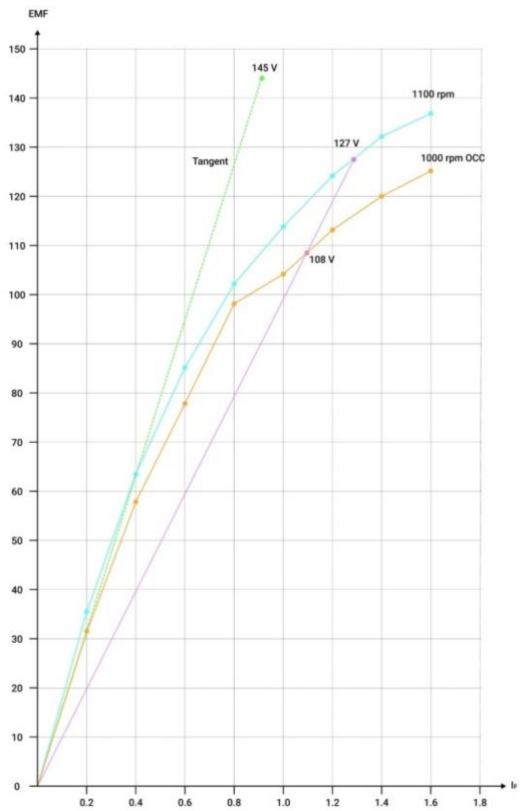
Dec 2022

(a) When the current through a conductor changes, it produces a magnetic field around it. This changing magnetic field induces an electromotive force (emf) in any nearby conductor, according to Faraday's law of induction. The emf produced is directly proportional to the rate of change of magnetic flux through the conductor, which is a measure of the strength and extent of the magnetic field lines passing through it.

Increasing the current through a conductor results in a stronger magnetic field, which leads to a larger magnetic flux and a higher induced emf. Conversely, decreasing the current weakens the magnetic field, reduces the magnetic flux, and lowers the induced emf.

Similarly, changing the magnetic flux around a conductor also induces an emf, according to Lenz's law. If the magnetic flux through a conductor increases, the induced emf opposes this increase, whereas a decrease in magnetic flux causes an emf that opposes this decrease.

(b)



(i) The O.C voltage

The 1000 rev/min OCC is plotted against field current armature voltage and cut by the 100 Ω field voltage drop line which is plotted by drawing a straight line through any deduced point and the origin. Thus considering a I_F value of 1 A, then field voltage line would be
1×100=100V
Join this point to the origin.
The point intersection at 108 V is the answer required.

(ii) The tangent is drawn to the 1000 rev/min OCC. The critical resistance
R_C is determined by taking any voltage value on this tangent and dividing by the current.
Thus Ra=$\frac{145\ v}{0.9A}$ =161.1Ω
The critical resistance for this speed is 161 Ω.

(iii) The 1100 rev/min OCC is obtained by multiplying the original 1000 rev/min values by 11/10=1.1

I_F	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
EMF 1000 rpm	32	58	78	93	104	113	120	125
EMF 1100 rpm	35.2	63.8	85.8	102.3	114.3	124.3	132	137.4

This 1100 rev/min characteristic when plotted is cut by the 100 Ω field voltage drop line at 127 volts.

(a) Explain about the various speed control methods of DC series motors. (6)
(b) The Armature circuit resistance of an 18.65KW 250V series motor is 0.1Ω. The brush voltage drop is 3V and series field resistance is 0.05Ω. When the motor takes 80A speed is 600 r.p.m. Find the speed when the motor is 100 A.

Nov 2022

(a) The speed of the DC series motor can be controlled by following two methods. They are
Flux control method.
Variable Resistance in series with Motor
1. Flux control method: In this method, flux variation can be achieved in four different ways. They are,

- Field diverter method.
- Armature diverter method.
- Tapped field control method.
- Paralleling field coils method

Field diverter method:

In this method, variable resistance Rx is connected in parallel with the series field winding of the motor. Here, variable resistance is known as diverter. Field flux can be decreased by reducing field current. Field current can be reduced by lowering the resistance value in the diverter. Hence the speed of the motor increased by decreasing field flux in the field winding. The circuit diagram of this method is shown in the image given below.

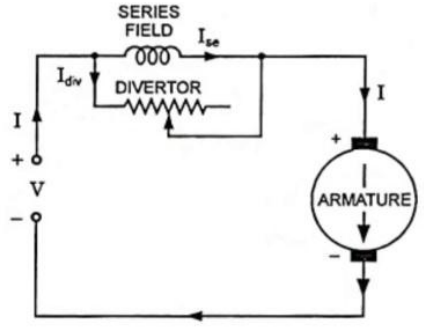
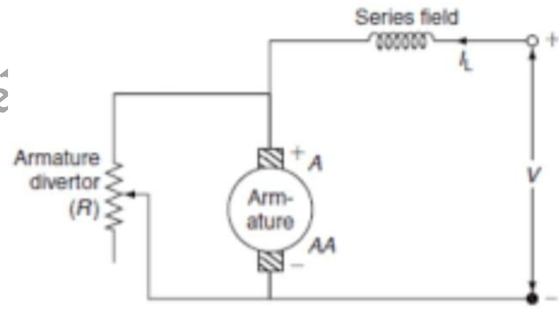


Fig. 1.72 (a) Field Divertor Method of Speed Control For DC Series Motors

Armature diverter method:
In this method, diverter Rx is connected across the armature winding of the motor. This method is used to control speeds below the rated value. If you decrease the resistance value in the diverter, the total parallel resistance of the diverter and armature decreases. So, the total current in the motor increases. This current is passing through the field winding of the motor. So, the field flux increases. Hence, the speed of the motor decreased. The circuit diagram of this method is shown in the image given below.



Tapped field control method:
In this method, field flux can be controlled by varying the number of turns in the field winding. Here field winding is provided with a number of taps. If you connect the whole field winding in the circuit, the motor runs at normal speed. The flux in the field winding decreases by changing the number of taps in the field winding. Thereby, the field flux decreases and hence, the speed of the motor increases. The circuit diagram of this method is shown in the image given below.

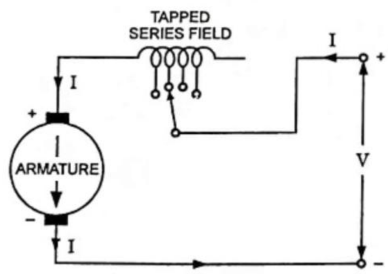


Fig. 1.72 *(b) Tapped Field Control For DC Series Motors*

(d) Paralleling field coils method:
In this method, the field coils are regrouped to achieve several speeds. This is mostly applied in the case of fan motors. In the circuit diagram shown below, we can see that three speeds can be easily achieved for a four-pole motor by using this method.
2. Variable Resistance in series with Motor:
By increasing the resistance in series with the armature will lead to a drop in the potential difference across the armature terminals. A voltage drop across the armature will decrease the speed of the motor. Also, it is to be noted that, due to the flow of full motor power through this resistance, there will be a considerable power loss.

(b) Given:

V= 250 V

brush drop = 3V = V_b

R_a= 0.1 Ω

$R_f = 0.05\ \Omega$

$N_1 = 600$ rpm

R = Ra + Rf

When motor takes 80 A, back EMF

$E_{b1} = V - I_a(R_a+R_f) - V_b$

= 250 - 80(0.1+0.05)

$E_{b1} = 235$ V

When motor takes 100 A, back EMF

$E_{b2} = V - I_a(R_a+R_f) - V_1 = 250 - 100(0.1 + 0.05) - 3$

$E_{b1} = 232$ V

Noω, ϕ ∝ Iα

also, $\frac{N2}{N_1} = \frac{Eb2}{Eb1} * \frac{\varphi 1}{\varphi 2} = \frac{Eb2}{Eb1} * \frac{Ia1}{Ia2}$

$\frac{N2}{600} = \frac{232}{235} * \frac{80}{N2}$

$N_2 = 474$ rpm

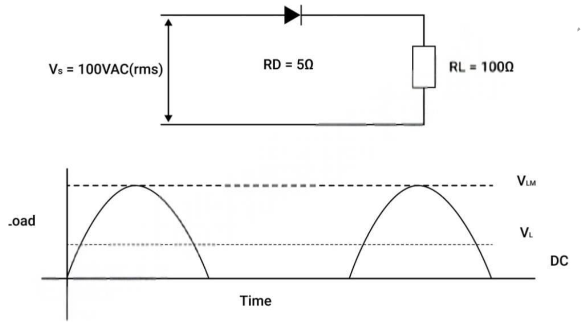
Speed at 100 rpm = 474 rpm

(a) Explain about non-linear resistors with some examples and illustration on how they differ from linear resistor. (6)
(b) A Diode half-wave rectifier supplies a resistive load of 100Ω from a 100V AC R.M.S. voltage source. The diode is a resistance of 5Ω during conduction state. (10)
Calculate
(i) The DC output voltage
(ii) DC average load current.

Nov 2022

(a)
An electrical circuit having a linear component, such as a linear resistor (or inductor, capacitor), as its component is called a linear circuit. A linear circuit is an electric circuit in which the output voltage and current of a linear circuit are linear functions of its input voltage and current.
Non-linear circuits having non-linear resistors, connected individually or in series or parallel combinations, change with time or with the level of voltage or current in the circuit
Linear circuits obey superposition theorem. They are governed by linear differential equations. They can be analyzed with Fourier Analysis and Laplace Transform and with scientific calculators.
Non-linear circuits do not normally have closed form solutions. Non-linear circuits can be analyzed using approximate numerical methods.
The behavior of resistors in linear circuit can be specified by a single number or a straight line on a graph.
The behavior of non-linear resistors is specified by its detailed transfer function, given by a curved line on a graph.

Linear resistors obey Ohm's Law. The current through the linear resistor is inversely proportional to its resistance value, provided the temperature is constant. Its V-I curves are straight lines.
There are some elements which do not obey Ohm"s Law. Their V- I curves are not straight lines i.e., the V-I curves are non-linear. Such resistors are called nonlinear elements.
Filaments of incandescent lamps are typical examples of non-linear elements. Diodes, thermistors and varistors also have non-linear V-I curves.



(b) Given,

V_{RMS} = 100V AC

R_D = 5Ω

R_l = 1000Ω

(i) The DC output voltage:

$V_{rms} = \frac{V_m}{\sqrt{2}}$

$V_m = V_{RMS} \times \sqrt{2} = 100 \times 1.4142 = 141.4V$

$$V_{DC} = \frac{V_m}{\pi(R_L + R_D)} \times R_L = \frac{141.4 \times 100}{\pi(100+5)} \; V_{DC} = 42.87V$$

(ii) DC average load current:

$$I_{AV} = \frac{V_{DC}}{R_L} = \frac{42.87}{100}$$

I_{AV} = 0.428amp

(a) Explain the factors which govern the variation of resistance of conductors. (6)
(b) A 2-core cable, each core of which is 300 m long and of uniform cross-sectional area of 150 mm2 is fed from one end at 240V. A load of 200A is taken off from the centre of the cable and a load of 100A from the far end. Calculate the voltage at each load. A single-core cable of similar material 880 m in length and of uniform cross-sectional area of 50mm2 has a resistance of 0.2192. (10)

Oct 2022

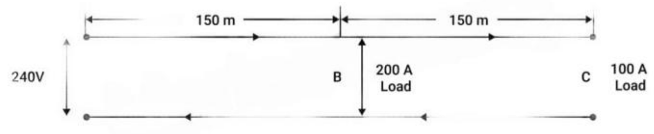
(a) The resistance of a conductor is determined by the following factors:
• The length of the conductor: The longer the conductor, the greater the resistance.
• The cross-sectional area of the conductor: The larger the cross- sectional area, the lower the resistance.
• The type of material: The resistivity of different materials varies.
• The temperature: The resistance of most materials increases with temperature.
The resistance of a conductor can be calculated using the following equation:

$$R = \frac{Þ L}{A}$$

where:
R is the resistance in ohms
Þ is the resistivity of the material in ohm- meters
L is the length of the conductor in meters
A is the cross-sectional area of the conductor in square meters
The resistivity of a material is a measure of how difficult it is for current to flow through the

material. The resistivity of different materials varies widely. For example, the resistivity of copper is 1.68 x 10-8 ohm meters, while the resistivity of iron is 10.0 x 10-8 ohm-meters.

(b)



Given:
l = 300m
A = 150 mm^2
V = 240 V
A single core cable of similar material with 880 m long and 50 m^2 area has resistance 0.2190
We know that R = $\frac{\rho l}{A}$
i.e., R ρ l ; Rρ $\frac{1}{A}$
∴ the resistance of 880 m wire,
0.219 = $\frac{\rho * 880}{50 * 10{-}6}$ =1.244 * 10 $^{-8}$ Ωm
Hence the resistance of 150 m long 150 m m ^{2} wire is
R=$\frac{1.244 * 10{-}8 * 150}{150 * 10{-}6}$
=0.0124Ω
Total current in the wire (AB) = 200 + 100 =300A
Total resistance in the wire (AB) = 2 * 0.0124= 0.0248Ω
Voltage drop in length of (AB) = IR = 300* 0.0248= 7.44V
Voltage in 200 A load = 240 V -7.44 V = 232.56V
Voltage drop in section BC = 1/3 of AB(since the current is 1/3 rd)
= 1/3 * 7.44
= 2.48V
∴ Voltage in 100 A load = 232.56 - 2.48 = 230.08V

(a) Explain and describe why and how space heaters are fitted to motors. (6)
(b) Give a clear explanation of the following effects in a three phase induction motor,
(i) the production of rotating field,
(ii) the presence of an induced rotor current,
(iii) the development of torque.
A 4-pole, 250V motor has its armature removed in order to test the continuity of the field windings which are connected in series and consist of 2000 turns each. What is the average e.m.f. induced when the current is switched off, if the flux falls from 0.026Wb to 0.001 Wb in 0.2s? (10)

Oct 2022

(a) Space heaters are fitted to motors in order to prevent moisture from condensing inside the motor when it is not in use. This can be a problem in environments where the humidity is high, as the moisture can short out the motor's winding and cause it to fail. Space heaters work by providing a low-level heat source that is sufficient to keep the temperature inside the motor above the dew point, thereby preventing moisture from condensing on the windings.
Space heaters are typically fitted to the exterior of the motor, either on the housing or on the end bells. They may be in the form of heating elements, such as resistance wire or cartridge heaters, or they may be heated air blowers. The heaters are controlled by thermostats or

temperature sensors that turn them on and off as needed to maintain a consistent temperature inside the motor.

(b) (i) The production of rotating field: In a three phase induction motor, the stator winding is supplied with a three phase AC voltage. This causes a rotating magnetic field to be produced in the stator. The direction and speed of the rotating field is determined by the phase sequence and frequency of the AC voltage.
(ii) The presence of an induced rotor current: When the rotating field of the stator cuts the conductors of the rotor, an induced current is generated in the rotor. This induced current creates a magnetic field in the rotor, which interacts with the magnetic field of the stator.

(iii) The development of torque: The interaction between the magnetic field of the stator and the magnetic field of the rotor causes a torque to be developed in the rotor. The magnitude of the torque is determined by the strength of the magnetic fields, the speed of the rotor, and the angle between the magnetic fields. The direction of the torque is determined by the direction of the magnetic fields and the direction of rotation of the rotor.
From Faraday's law, E_{av}

$$E_{av} = \frac{N(\Phi 1-\Phi 2)}{t}$$

$$E_{av} = \frac{2000\times 4\times(0.026-0.001)}{0.2}$$

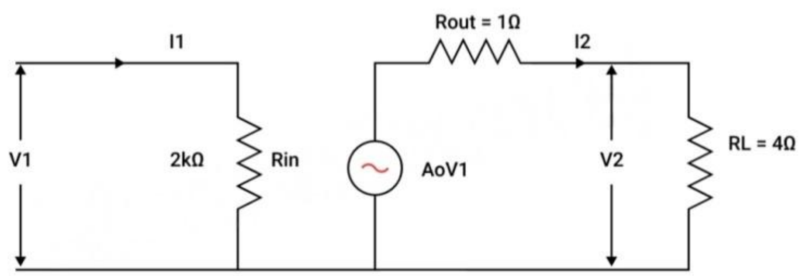
Induced EMF = 1000V = 1kV

(a) Explain the term bandwidth and describe the relationship between gain and badwidth (6)
(b) (b) An amplifier has an open-circuit voltage gain of 1000, and input resistance of 20000 and and an output resistance of 1.00. Determine the input signal voltage required to produce an output signal current of 0.5A in a 4.0Ω resistor connected across the output terminals. If the amplifier is then used with negative series voltage feedback so that one tenth of the output signal is fed back to the input, determine the input signal voltage to supply the same output signal current.

Oct 2022

(a) Bandwidth is the range of frequencies that a system can transmit or receive. It is usually measured in hertz (Hz). The higher the bandwidth, the more frequencies can be transmitted or received.
Gain is the ratio of the output power of a system to the input power. It is usually expressed in decibels (dB). The higher the gain, the more powerful the output signal.
The relationship between gain and bandwidth is that the higher the gain, the lower the bandwidth. This is because a system with high gain will amplify all frequencies, including noise. The noise will be amplified along with the desired signal, which will reduce the signal-to- noise ratio.

(b)



A_0 = 1000 Current gain, $A_1 = I_2/I_1$
Current gain, $A_1 = A_0R_{in} / R_{out} + R_L$
= 1000* 2000/ 1 + 4b = 4 * 10^5
$I_1 = I_2 / A_i$ = 0.5/4 * 10^5 = 1.25 * 10^{-6}
Now, $V_1 = I_1$ Rin = $(1.25\times10^{-6}) \times 2000$
= 2.5 * 10^{-3} = 2.5mV
With feedback,
A = Ao*RL / (Rout + RL)
A = (1000 * 4)/(1 + 4) = 800
$R_{if} = R_{in}(1 + \beta A)$
$R_{if} = 2000 \times (1+ 1/10 \times 800)$
R_{if} = 162000 Ω = 1.62×10^5
$V_1 = I_1R_{if} = (1.25 \times 10^{-6}) \times (1.62 \times 10^5)$
V_1 = 0.202V

---

a) Describe the effect of running an induction motor on reduced voltage. (6)
(b) A 90V d.c. generator is used to charge a battery of 40 cells in series, each cell having an average e.m.f.of 1.9 V and an internal resistance of 0.00252. If the total resistance of the connecting cells is 12, calculate the value of the charging current. (10)

Aug 2022 | **Apr 2025-1** | **Aug 2024** | **May 2024-2**

(a) Running an induction motor on reduced voltage has several effects, including:

- When the voltage supplied to the motor is reduced, the current drawn by the motor increases to maintain the power requirement (P = VI). Higher current can lead to several issues.
- The increased current results in higher losses in the motor windings, leading to elevated temperatures.
- Overheating is a major concern as it can damage the insulation, winding, and other components of the motor.
- Lower voltage leads to reduced starting torque, affecting the motor's ability to accelerate and start rotating properly. This can result in difficulties in starting heavy loads or moving the motor from a standstill.
- The pullout torque, which is the maximum torque the motor can deliver without stalling, is significantly reduced under reduced voltage conditions.
- Operating the motor at reduced voltage results in lower efficiency. Motors are designed to operate optimally at their rated voltage, and deviating from this value can lead to inefficiencies in power consumption.
- The combination of increased current, overheating, and reduced performance can contribute to a shortened overall lifespan of the motor. Continuous operation at
- reduced voltage accelerates wear and tear on the motor components.
- Induction motors are sensitive to voltage sags or fluctuations. A significant drop in voltage, even for a short duration, can cause a motor to stall or operate erratically.

(b) Given:
Generator voltage = 90V
Number of cells in series 40
Average EMF of each cell = 1.9V
Internal resistance = 0.0025Ω
Total resistance = 1 Ω
To find

Charging current, I

EMF of the battery, E_b = 40 * 1.9 = 76V Internal resistance, R_i = 40 * 0.0025 = 0.1 Ω

Total resistance, R = 1 + 0.1 = 1.1 Ω

We know,

$V_{charging} = V_{gen} - E_b$

= 90 -76

= 14

Then, I = $\frac{V}{R}$

= $\frac{14}{1.1}$

= 12.72A

A 4-pole lap wound D.C shunt generator has an open e.m.f of 250V when the flux per pole is 0.08 Wb and the speed is 10 rev/sec/ The speed of the generator is reduced to 10% and the flux per pole is increased by 5% when the generator supplies a load of 100A. Determine the terminal voltage, if the armature resistance is 0.060 and the new total field circuit resistance is 2002. (16)

Aug 2022

Given:

P = 4

A = P(lap)

I_L = 100A

R_a = 0.06Ω

R_{sh} =200ϕ

To find

(i) Terminal voltage, V_T

ϕ = 0.08wb

n = 10rps

A = P

E_a = 250V

$E_b = \frac{\phi ZNP}{A} = \phi Zn$

250 =.08*10*Z

Number of conductors, $Z = \frac{250}{(0.08 * 10)}$ = 312

Now, speed is reduced to 10 n =0.1 × 10 = 1 rps

Flux per pole is increased by 5

ϕ = 1.05 * 0.08 = 0.084wb

New induced emf, $E_g = \phi * Zn$

= 0.084 * 312 * 1

= 26.2V

Also, $I_a = I_L + I_{sh}$

$I_a = I_L + \frac{VT}{Rsh} = 100 + \frac{VT}{200}$ ---①

But, $V_T = E_g - I_a * R_a$ ----②

Substuting in ① in ②

V_T = 26.2 - (100 + V_T/200) * 0.06

= 26.2 - 6 - V_t/3000

V_T = 20.2/1.0003

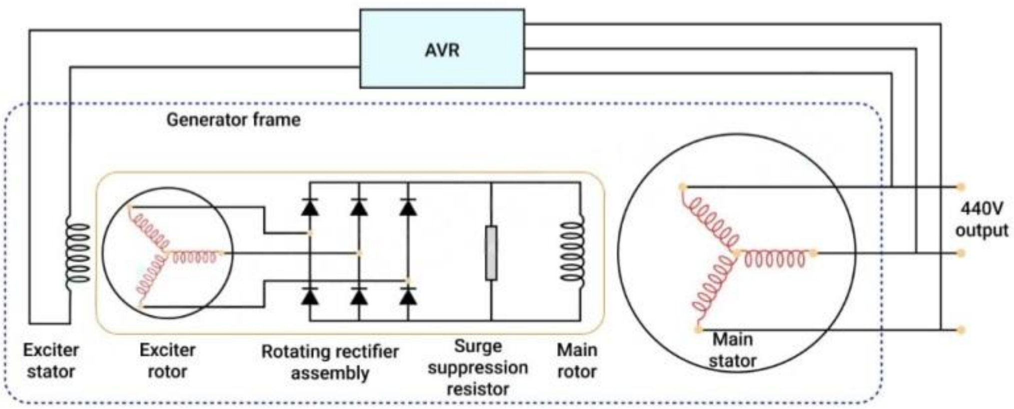
(Since Vr/30000 is very small, neglect the value)

V_T = 20.2V

(a) Describe the basic principles a self-excited generator. (6)
(b) The armature resistance of a 200 V, Shunt motor is 0.4 ohms and the no-load armature current is 2A. When fully loaded and taking an armature current of 50 A, the speed is 1200 rev/min. Find the no-load speed and state the assumption made in the calculation.

Apr 2025-1	Aug 2022	Aug 2024	May 2024-2

(a) The basic principles of a self-excited generator:
When the generator is first started, there is a small amount of residual magnetism in the rotor winding. This residual magnetism is due to the fact that the rotor winding is made of ferromagnetic material, which retains a small amount of magnetism even when there is no current flowing through it. The prime mover (usually a diesel engine or a turbine) rotates the rotor of the generator. As the rotor rotates, the residual magnetism in the rotor winding induces an electromotive force (EMF) in the stator winding. The EMF induced in the stator winding is proportional to the speed of rotation of the rotor and the strength of the residual magnetism.
The EMF induced in the stator winding is fed to the automatic voltage regulator (AVR). The AVR rectifies the AC voltage from the stator winding and uses it to excite the rotor winding. The DC current from the AVR flows through the rotor winding, creating a magnetic field. This magnetic field interacts with the residual magnetism in the rotor winding, creating a stronger magnetic field. The stronger magnetic field induces a higher EMF in the stator winding
The process of self-excitation continues until the generator reaches its rated voltage. At this point, the AVR reduces the excitation current to maintain the generator voltage at the desired level.



(b) Given:
Armature resistance: $R_a = 0.4\Omega$
Voltage: V = 200V
No-load armature current: $I_{ao} = 2A$
Full load current: $I_a = 50A$
Full load speed : N = 1200rpm
To find:
No-load speed : No
On No-load: E_o V- I_{ao} R_a = 200- (2*0.4) = 199.2V
On full-load: $E_a = V – I_a R_{ao}$ = 200- (50*0.4) = 180V
We know, E = $\frac{\phi * PNZ}{60}$
So, N = $\frac{60E}{\phi\ PZ}$
Then, N_o = $\frac{60Eo}{\phi PZ}$

For the Shunt motor, the field is unaffected by the loading of the armature.

So, $\phi = \phi o$

$\frac{No}{N} = \frac{Eo}{E}$

$N = N \times \frac{Eo}{E}$

$= 1200 \times \frac{199.2}{180} = 1328 rpm$

A 3 phase induction motor which is wound for 4 pole, when running full load develops a useful torque of 100Nm, also rotor emf is observed to make 120 cycles/ min. It is knows that the torque lost on account of friction and core loss is 7Nm. Calculate the shaft power output, rotor cu loss, Motor Input and Efficiency (4 x 4) (10)

Jul 2022

Given:

Shaft torque, T_{sh} = 100 Nm

Rotor frequency, f_r = 120/60 = 2 Hz

Assume supply frequency is 50 Hz, ∴fs = 50 Hz

Slip = $\frac{fr}{fs} = \frac{2}{50}$ = 0.04

Synchronous speed = $N_s = \frac{120f}{p}$

$= \frac{120 \times 50}{4}$ = 1500 rpm

Rotor speed = $N_r = (1 - S) * N_S$

= (1 -0.04) × 1500

= 1440 rpm

Rotor's radian speed, $\omega_r = \frac{2\pi Nr}{60}$

$= \frac{2 * 3.141 * 1440}{60}$ = 150.7 rad/sec

(i) Shaft power output, $P_{out} = T_{sh} * \omega_r$

= 100 * 150.7 = 15070 W

P out =15.07 kW

Gross torque, $T_g = T_{sh} + T_{loss}$ = 100 + 7 = 107 Nm

But $T_g = \frac{Pm}{Wr}$

Rotor gross output power $P_m = T_g * \omega_r$

= 107 *150.7

= 16.12kW

Rotor input power, $P_2 = \frac{Pm}{(1-S)}$

$= \frac{16.12}{(1-0.04)}$ = 16.79 kW

(ii) Rotor C_u loss = $S \times P_2$ = 0.04 × 16.79

Rotor C_u loss = 0.67 kW

(iii) Motor power input, $P_{in} = P_2$ + stator C_u loss

P_{in} = 16.79 + 0.7 (Assume stator C_u loss= 0.7 kW)

Pin = 17.49 kW

(iv)Efficiency, $\eta = \frac{Pout}{Pin}$

$= \frac{15.07}{17.49} * 100$

η = 86.16

(a) Give a brief outline about general maintenance of transformers (4)
(b) Explain about transformer rewinding and testing of transformer oil (4)
(c) A why jacketed fuel pipes are employed, 1100/220V, 50Hz, single-phase transformer has a leakage impedance of (0.1 + j0.40) ohm for the H.V winding and (0.006 + j0.015) ohm for the L.V winding. Find the equivalent winding resistance, reactance and impedance referred to the H.V and L.V sides (8)

Jul 2022

(a) General Maintenance - Transformers

- The insulation resistance should be measured with megger periodically. All the windings to earth need to be meggered individually. Meggering between windings is also essential.
- Polarisation Index (P.I) value (I.R value at 10 min divided by I.R. value at one minute) of the winding insulation shall be checked.
- Connection points should be checked for tightness observing for any hot spots.
- The D.C resistance value of the windings should be measured in all taps.
- All the parts including windings shall be cleaned and inspected for any signs of physical damage or spot heating.
- Gaskets in the covers shall be checked and must be securely placed back.

(b)

Transformer Rewinding:

Transformer rewinding is the process of removing the damaged or burnt windings of a transformer and replacing them with new windings using copper or aluminium wire. It is done when the transformer windings get short-circuited, overheated, or aged. Proper insulation, correct turns ratio, and tight winding are essential to restore the transformer's performance.

Testing of Transformer Oil:

Transformer oil is tested to ensure its dielectric strength, moisture content, acidity, and insulating properties are within safe limits.

Common tests include:

- BDV (Breakdown Voltage) Test: Checks the oil's ability to withstand high voltage without breaking down.
- Moisture Content Test: Water in oil reduces insulation; measured using a Karl Fischer titrator.
- Acidity Test: Detects oil degradation by measuring acidic content.
- Interfacial Tension & Flash Point Tests are also conducted for safety and quality control.

(c) Given:

$R1= 0.1\Omega$, $X1=0.4\Omega$, $V1=1100V$

$R2=0.006\Omega$, $X2=0.015\Omega$, $V2=220V$

Turns ratio, $K= \frac{V2}{V1} = \frac{220}{1100} = \frac{1}{5} = 0.2$

(i)

Referred to HV side(primary)

Equivalentresistance, $R_{01}= R_1+R_2' = R_1+ \frac{R2}{k2}$

$R_{01}= 0.1+ \frac{0.006}{(0.22)} = 0.1+0.15$

$R_{01}=0.25\Omega$

Equivalentreactance, $X_{01}= X_1+X_2' = X_1+(\frac{X2}{k2})$

$X_{01}=0.4+ \frac{0.015}{(0.22)} =0.4+0.375$

$X_{01}=0.775\Omega$

Impedance, $Z_{01}= \sqrt{R201} + X201$

$=\sqrt{0.252} + 0.7752$

$Z_{01}= 0.8143\ \Omega$

Refering to the LV sode(secondary)

Resistance, $R_{02} = R_2 + R_1 = R_2 + R_1 * K^2$

$=0.006+0.1* (0.2)^2$

$R_{02} = 0.01\ \Omega$

Reactance , $X_{02} = X_2 + X_1 = X_2 + X_1 * K^2$

$=.015+ 0.4*(0.2)^2$

$X_{02} = 0.031\ \Omega$

Impedence, $Z_{02} = \sqrt{R202} + X202$

$Z_{02}= \sqrt{0}.012 + 0.0312$

$Z02= 0.0326\ \Omega$

---

a) Explain about Single Phasing Protection for poly phase motor (6)
(b) A 440V, 10Kw, 0.8 p.f, 3phase load is supplied as shown. Calculate short circuit fault current at the load and at the main switch board (10)

Jul 2022

(a) Effects of Single Phasing on 3 phase Induction Motors

- Single phasing is a particular case of unbalance.
- Single phase is often the cause of damage to the motor and its effects are far more
- Serious than those of practical values of unbalanced supply voltages

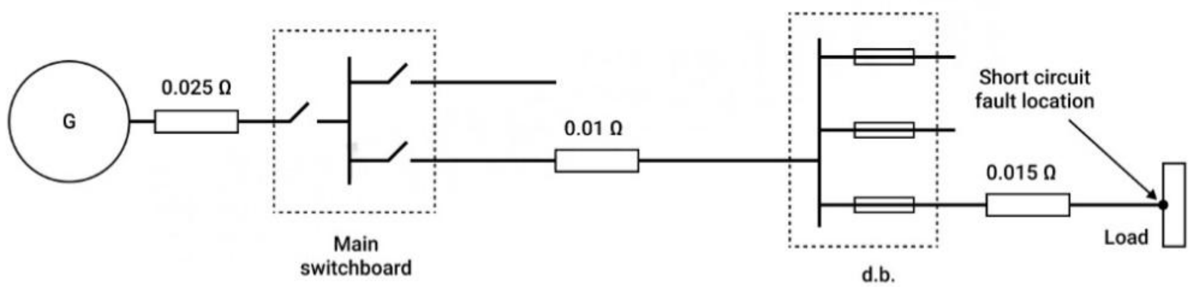
Single phasing is the operation of a poly phase induction motor, when one of the supply lines to the motor is severed or dead. Single phasing is also referred as „Open Phasing" or „Phase Failure" and a peculiar case of unbalanced supply voltage.
Single phasing may be caused by the blowing off of a fuse somewhere in the system through an earth fault. Loose contacts or burning out of a contact in control equipment will also result in phase failure
The usual cause of blow-outs in induction motors is single- phasing.

- A stationary motor will not start with one line broken.
- In fact, due to heavy standstill current, it is likely to burn-out quickly unless it is immediately disconnected.

Protection of poly phase from single phasing:

- Fuse
- Overcurrent relay
- Thermistor
- Current transformer

(b)



Suppose now a short-circuit fault occurs at the load terminals.
The total impedance is:
Z_F=0.025+0.01+0.015=0.05Ω
and the prospective short-circuit fault current is
IF=V/Z_F = 440V/0.05Ω
=8800A
For a short-circuit at the main switchboard 440V, the fault level is
440V/0.025Ω=17,600A
So, the prospective fault current level at MSB is 17600A

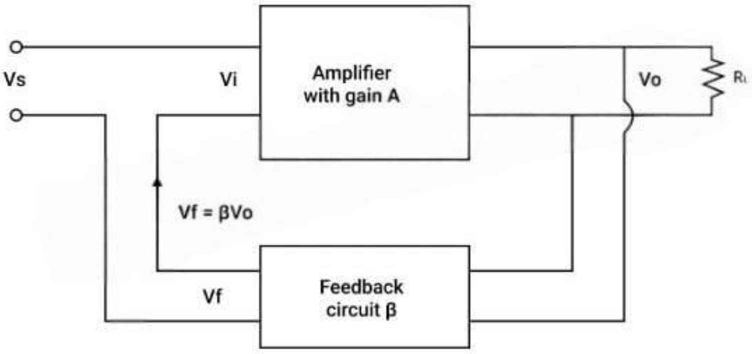
Control system

- **Notes:**

With the aid of a block diagram, briefly describe the effect which negative voltage feedback has on an amplifier and state the advantages resulting from the use of negative feedback. (16)

Oct 2024

Block Diagram and Effects of Negative Voltage Feedback on an Amplifier:



Effect of Negative Voltage Feedback:
Negative voltage feedback in an amplifier involves feeding a portion of the amplified output back to the input in the opposite phase. This is achieved through a feedback network. The primary effects of negative voltage feedback on an amplifier are as follows:

- **Stabilization of Gain:** Negative feedback stabilizes the gain of the amplifier, ensuring that it remains relatively constant over varying conditions. This is particularly beneficial in maintaining consistent amplification in practical applications.
- **Increased Input Resistance:** The input resistance of the amplifier circuit is effectively increased when negative feedback is applied, depending on the specific feedback configuration. This enhances the amplifier's interaction with the input signal source.
- **Decreased Output Resistance:** Negative feedback reduces the output resistance of the amplifier for various feedback configurations. This improvement contributes to better interfacing with subsequent stages in a system.
- **Stable Operating Point:** The operating point of the amplifier remains stable with the application of negative feedback. This stability is crucial for the reliable and consistent performance of the amplifier.

Advantages Resulting from Negative Feedback:

- **Gain Stabilization:** Negative feedback helps maintain a stable and consistent gain in the amplifier, preventing variations due to changes in operating conditions.
- **Increased Input Resistance:** The input resistance is enhanced, allowing for better matching and interaction with signal sources.
- **Decreased Output Resistance:** The reduced output resistance facilitates improved coupling with subsequent stages in a system.
- **Stable Operating Point:** The operating point of the amplifier remains stable, contributing to overall circuit reliability.

Disadvantage:
Reduction in Gain: The primary disadvantage of negative feedback amplifiers is a reduction in gain. While stability is achieved, there is a trade-off with reduced amplification. However, this is often an acceptable compromise in many applications.

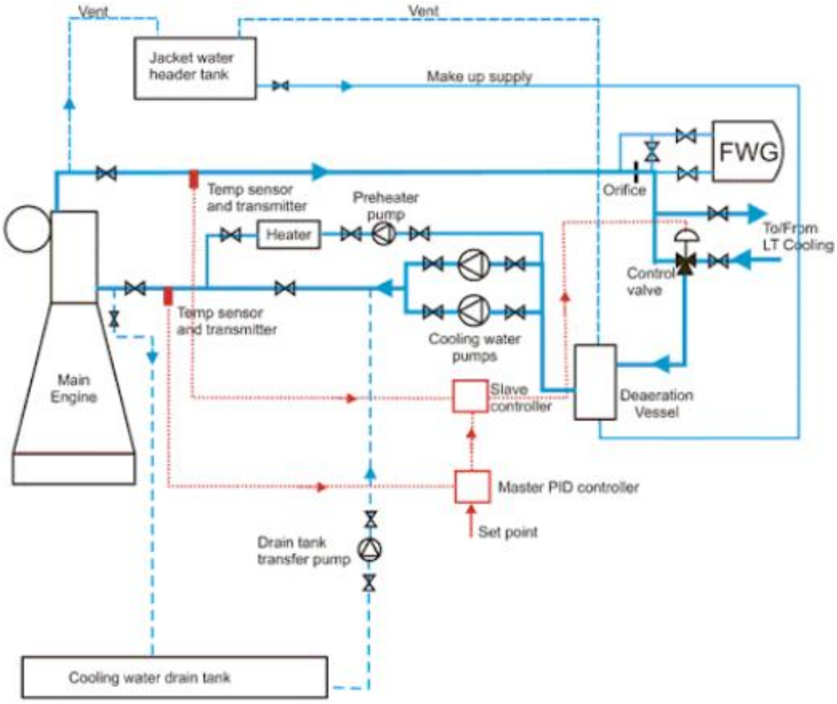
Applications of Negative Feedback Amplifiers:

- Electronic Amplifiers
- Regulated Power Supplies (RPS)
- Large Bandwidth Amplifiers

Explain with a simple line sketch, a main engine jacket cooling automatic control system capable of maintaining the jacket water temperature within close limits during wide changes in engine load. (16)

Apr 2023

A temperature-controlled HT (high-temperature) circulating system is a good example of a control system that can be enhanced by the inclusion of cascade control. The system involves two controllers in cascade, each equipped with its own temperature sensor.



- The first controller (outer loop) regulates the temperature of the water outlet and utilizes a PI (proportional-integral) controller.
- The control valve is located far from the outlet, where it accurately measures the temperature.
- The error term of this first PI controller is the difference between the desired HT temperature and the measured temperature at the outlet.
- Instead of directly controlling the valve, the first PI controller sets the input for the second P (proportional) controller.
- The second controller (inner loop) compares the inlet temperature of the system with the output from the first controller.
- The second controller sends a signal to the control valve based on this comparison.
- The proportional and integral terms of the two controllers are designed to be different. The outer PI controller has a longer time constant, considering the entire system's thermal mass, while the inner loop responds more quickly.
- This cascade control configuration allows each controller to be tuned to match the specific characteristics of the part of the system it controls, optimizing the overall system response. The outer loop addresses slower changes in the system, while the inner loop provides rapid adjustments, resulting in a more robust and efficient temperature control system.

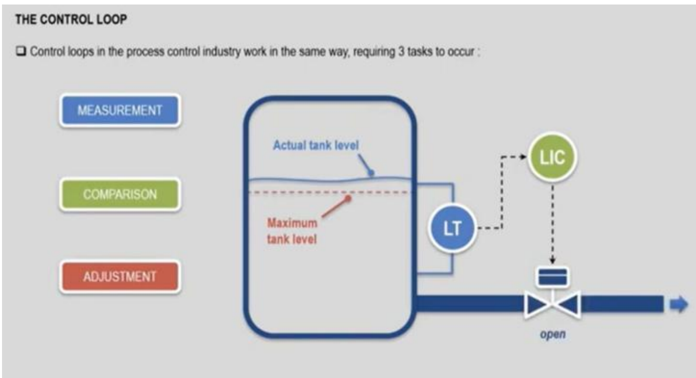
ALTERNATE METHOD:

Combination of cascade and split range control. Cascade control is where the output from a master controller is used to adjust automatically the desired value of a slave controller. The master controller obtains an outlet temperature reading from the engine which is compared with a desired value. Any deviation acts to adjust the desired value of the slave controller. The slave controller also receives a signal from the water inlet temperature sensor which it compares with its latest desired value. Any deviation results in a signal to two control valves arranged for split range control. If the cooling water temperature is high, the Low temp water valve is opened to admit more cooling water to the cooler. If the cooling water temperature is low, then the sea water valve will be closed in. If the sea water valve is fully closed, then the steam inlet valve will be opened to heat the water. Both master and slave controllers will be identical instruments and will be two-term (P+I) in action.

Explain the meaning of the following terms with reference to automatic control system:
(a) Control loop (4)
(b) Transmitter (4)
(c) Controller (4)
(d) Desired value (4)

Dec 2022

(a) A control loop is a continuous feedback loop that allows a controller to adjust a process or system to maintain a desired output or set point. It consists of four components: a process or system, a sensor or measuring device, a controller, and an actuator. The sensor measures the output of the process or system and provides feedback to the controller. The controller then makes decisions on how to adjust the system through the actuator. The loop operates continuously, with the sensor providing feedback, the controller making adjustments, and the process responding to these adjustments. The control loop is essential for precise and efficient regulation of complex processes and systems.



(a) In an automatic control system, a transmitter is a device that converts a physical variable, such as temperature or pressure, into an electrical signal that can be transmitted to a controller or monitoring system. The transmitter typically consists of a sensing element, signal conditioning circuitry, and a transmitter circuit. The sensing element detects the physical variable and converts it into an electrical signal. The signal conditioning circuitry filters and amplifies the signal to make it suitable for transmission. The transmitter circuit transmits the signal to the controller or monitoring system, where it can be analyzed and used for control or monitoring purposes. Transmitters are critical components of automatic control systems, as they allow for accurate and reliable measurement of physical variables.

(c) A controller is a device that receives input signals from sensors, compares them to a desired setpoint or reference value, and then generates output signals to control the system or process being monitored. The controller may use different types of control algorithms, such as proportional-integral-derivative (PID) or fuzzy logic, to make decisions about the appropriate output signal. The output signal is typically sent to an actuator, such as a valve or motor, which then adjusts the system or process being controlled. Controllers are critical components of automatic control systems, as they allow for precise and efficient regulation of complex processes and systems. The effectiveness of a controller depends on the accuracy and reliability of the input signals and the control algorithm used.

(d) The desired value is the target or reference value that the system or process is intended to achieve or maintain. It is typically set by an operator or a control engineer based on the desired outcome of the system or process. The desired value serves as the set point for the controller, which compares it to the measured value provided by a sensor, and generates output signals to adjust
the system or process accordingly. The effectiveness of the control system depends on how well the desired value is set, as well as the accuracy and reliability of the sensors, controllers, and actuators
used to regulate the system or process. The desired value is a critical component of automatic control systems, as it allows for precise and efficient regulation of complex processes and systems.

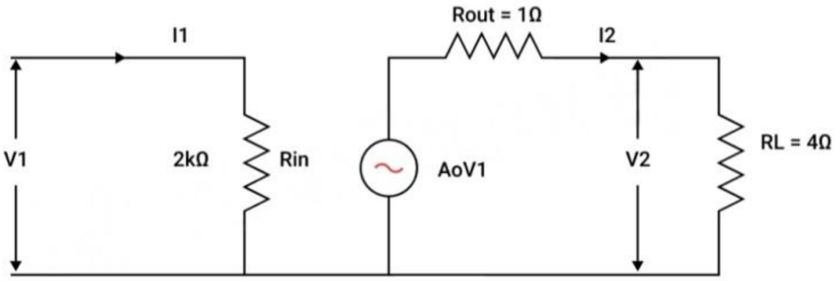
(a) Explain the term bandwidth and describe the relationship between gain and badwidth (6)

(b) (b) An amplifier has an open-circuit voltage gain of 1000, and input resistance of 20000 and and an output resistance of 1.00. Determine the input signal voltage required to produce an output signal current of 0.5A in a 4.0Ω resistor connected across the output terminals. If the amplifier is then used with negative series voltage feedback so that one tenth of the output signal is fed back to the input, determine the input signal voltage to supply the same output signal current.

Oct 2022

(a) Bandwidth is the range of frequencies that a system can transmit or receive. It is usually measured in hertz (Hz). The higher the bandwidth, the more frequencies can be transmitted or received.
Gain is the ratio of the output power of a system to the input power. It is usually expressed in decibels (dB). The higher the gain, the more powerful the output signal.
The relationship between gain and bandwidth is that the higher the gain, the lower the bandwidth. This is because a system with high gain will amplify all frequencies, including noise. The noise will be amplified along with the desired signal, which will reduce the signal-to- noise ratio.

(b)



$A_0 = 1000$ Current gain, $A_1 = I_2/I_1$
Current gain, $A_1 = A_0 R_{in} / R_{out} + R_L$
$= 1000 * 2000 / 1 + 4b = 4 * 10^5$
$I_1 = I_2 / A_i = 0.5/4 * 10^5 = 1.25 * 10^{-6}$
Now, $V_1 = I_1$ Rin $= (1.25 \times 10^{-6}) \times 2000$

$= 2.5 * 10^{-3} = 2.5mV$

With feedback,

$A = Ao*RL / (Rout + RL)$

$A = (1000 * 4)/(1 + 4) = 800$

$R_{if} = R_{in}(1 + \beta A)$

$R_{if} = 2000 \times (1 + 1/10 \times 800)$

$Ri_f = 162000\ \Omega = 1.62 \times 10^5$

$V_1 = I_1 R_{if} = (1.25 \times 10^{-6}) \times (1.62 \times 10^5)$

$V_1 = 0.202V$

(a) Describe the principles of operation of an electro-pneumatic controller. (8)
(b) Describe the principles of a fuel-air ratio controller. (8)

Sep 2022

(a) An electro-pneumatic controller is a control system that uses a pneumatic (air- based) actuator to control a process based on an electrical input signal. The system consists of three main components: a sensor, a controller, and an actuator.

The sensor is responsible for measuring the process variable, such as temperature, pressure, or flow rate. The sensor sends an electrical signal to the controller, which compares the measured value to the desired setpoint. If the measured value is different from the setpoint, the controller sends a signal to the actuator to adjust the process.

The actuator is responsible for converting the electrical signal from the controller into mechanical movement, which is used to adjust the process. In an electro- pneumatic controller, the actuator is typically a pneumatic cylinder or a pneumatic valve.

The controller uses a control algorithm to calculate the required output signal to the actuator based on the difference between the measured value and the setpoint. This output signal is sent to the actuator, which adjusts the process until the measured value is brought back to the setpoint.

Overall, the purpose of an electro- pneumatic controller is to maintain the process variable at a desired setpoint by adjusting the process using a pneumatic actuator based on an electrical input signal.

(b) A fuel-air ratio controller is a control system used to maintain the desired ratio of fuel to air in the combustion process of an engine or furnace. The controller monitors the output of a sensor that measures the fuel-air ratio and adjusts the fuel flow or air flow accordingly to maintain the desired ratio. The desired fuel-air ratio is typically set to optimize the efficiency and performance of the engine or furnace.

The principles of operation of a fuel-air ratio controller involve the use of a control loop. The control loop consists of the sensor, a control valve, and a controller. The sensor measures the fuel-air ratio and sends a signal to the controller, which compares the measured value to the desired setpoint. Based on this comparison, the controller sends a control signal to the control valve to adjust the fuel flow or air flow as necessary to maintain the desired fuel-air ratio.

The control valve is typically a motorized valve that can be opened or closed to adjust the fuel flow or air flow. The controller may use a proportional- integral-derivative (PID) control algorithm to calculate the appropriate control signal based on the deviation of the measured value from the setpoint. The controller may also use other algorithms or control strategies to optimize the control performance. Overall, the fuel-air ratio controller helps to ensure that the engine or furnace is operating at optimal efficiency and performance by maintaining the desired fuel-air ratio at all times.

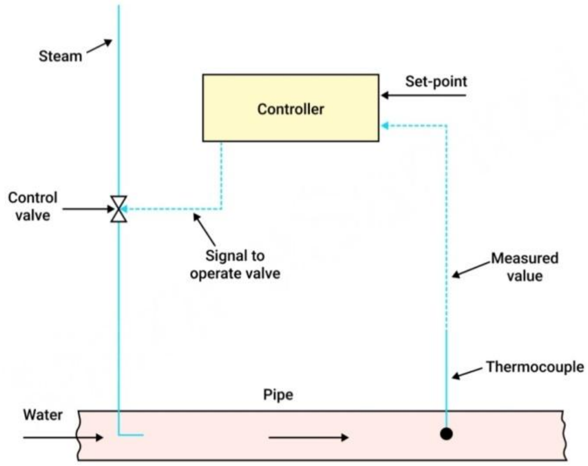
(a) Explain about the basics and tuning of PID controllers (4)
(b) Explain about automatic control system and its advantages (6)
(c) Explain about control loop transmitted (6)

Jul 2022

(a) A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable.
The basic tuning parameters of PID loop are:

- Gain: Also called proportional band or P-gain, the gain determines how much change the OP will make due to a change in error.
- Reset: Also called integral or I-gain, the reset determines how much to change the OP over time due to the error (regardless of the direction of movement of the error).
- Preact: Also called derivative or D- gain, the preact determines how much to change the OP due to a change in direction of the error or PV.

(b) The automatic control system is used for the regulation and quality control of processes as well as the environment. A control system is employed in many industrial processes (controlled equipment, plant, or system). It manages the process by converting the variable to a desired variable. Control systems can be either manual or automatic. If a human operator is necessary to provide input at any point during the process, it is considered as "manual" control. In an "automatic" control system, there is a controller that can take the position of a human operator, which is highly efficient and this automatic controller is programmed to precisely regulate the process.
The controlling of physical variables like temperature, voltage, frequency, flow rate, current, location, speed, etc., is done by a control system. These physical variables are named "controlled variables" in most cases.



Advantages of an automatic control system- It helps in boosting productivity.

- Quality can be improved.
- Efficiency in terms of energy and comfort.
- It is possible to use the remote control.
- Input can be controlled.

(c) A control loop transmitter is a device that measures a specific process variable (PV) and converts it into a standardized output signal, typically a 4–20 mA current loop. This output is then transmitted over a pair of wires to a control system, such as a Distributed Control System (DCS) or a Programmable Logic Controller (PLC).

- 4 mA represents the minimum value of the measured parameter.
- 20 mA represents the maximum value. This range allows for continuous monitoring and precise control of the process variable.

Working:

1. Sensing the Process Variable: The transmitter receives input from a sensor (e.g., thermocouple, RTD, pressure sensor) that detects the physical parameter.
2. Signal Conditioning: The raw signal from the sensor is often weak and noisy. The transmitter conditions this signal—amplifying, filtering, and converting it into a usable form.
3. Analog-to-Digital Conversion: The conditioned signal is then converted into a digital value that corresponds to the measured parameter.
4. Current Loop Output: The transmitter adjusts the output current within the 4–20 mA range based on the digital value, ensuring that the output signal accurately represents the process variable.
5. Transmission: The 4–20 mA current signal is transmitted over a pair of wires to the control system. This setup allows for long-distance signal transmission without significant loss or interference, making it ideal for industrial environments.

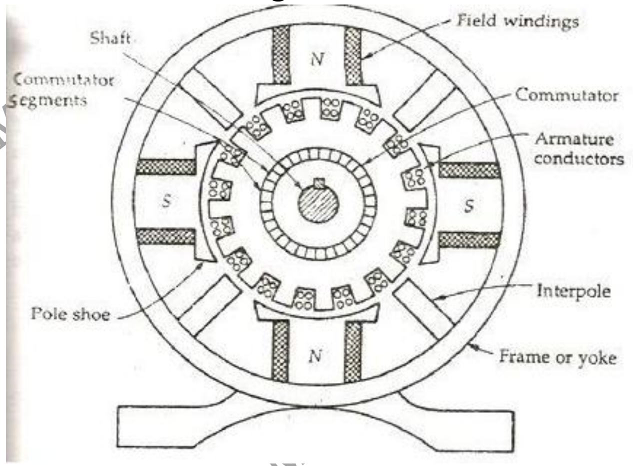
DC Generator

- **Notes:**

(a) Draw a 4-pole d.c generator construction diagram labelling its main parts. (8)
(b) Describe briefly its (8)
(i) Field system
(ii) Armature
(iii) Commutator
(iv) Brushes

Jan 2025

(a) A 4-pole d.c. generator construction diagram:



(b)

(i) Field System:
The field system consists of field poles that are placed in the stator. In the case of a 4-pole DC generator, there are four such poles arranged symmetrically in pairs (North and South). The poles are excited by a current supplied by a field winding or permanent magnets. The magnetic field produced by these poles induces electromotive force (emf) in the armature as it rotates, following Faraday's Law of Electromagnetic Induction. The field system determines the strength and direction of the magnetic field.

(ii) Armature:
The armature is the rotating part of the DC generator. It consists of a core, typically made from laminated iron to reduce eddy current losses, and coils of copper wire wound around the core. The armature rotates inside the magnetic field produced by the field system. As the armature moves, the conductors (winding) cut the magnetic lines of force, which induces a current in the armature according to Faraday's law. The armature is connected to the commutator to ensure unidirectional current.

(iii) Commutator:
The commutator is a cylindrical device attached to the armature shaft. It is made of copper segments separated by insulating material. The purpose of the commutator is to reverse the direction of the current in the armature windings as they rotate, ensuring that the output current is direct (DC). Without the commutator, the generator would produce alternating current (AC), as the direction of current would reverse every half-turn of the armature.

(iv) Brushes:
The brushes are made of carbon or graphite and are positioned against the commutator. Their primary function is to maintain electrical contact between the rotating armature and the external load circuit. The brushes allow the current generated in the armature windings to flow into the external circuit, making it possible to use the generated electricity. The friction

between the brushes and the commutator also causes wear, so they are typically replaced over time.

A 4-pole lap wound DC shunt generator has an open e.m.f of 250V when the flux per pole is 0.08 Wb and the speed is 10 rev/sec. The speed of the generator is reduced to 10 per cent and the flux per pole is increased by 5% when the generator supplies a load of 100A. Determine the terminal voltage, if the armature resistance is 0.06 ohm and the new total field circuit resistance is 200 Ω

Dec 2023

Given:

P=4

A=P(lap)

I_L=100A,

Ra=0.06Ω,

Rsh=200Ω

I_L=100A,

Ra=0.06Ω,

Rsh=200Ω

To find:

Terminalvoltage,V_T

ϕ=0.08wb

n=10rps, n=N/60

A=P

Eg = 250V

∴Eg= $\frac{\phi ZPn}{A}$

250= 0.08×10×Z

Numberofconductors,Z = $\frac{250}{0.08\times10}$ = 312

Now,speed is reduced to 10

n'= 0.1×10 = 1rps

Flux per pole is increased by 5

ϕ= 1.05×0.08 = 0.084wb

New induced emf,Eg=ϕZn

=0.084×312×1

=26.2V

Also, I_a=I_L+ I_{sh}

Ia= IL+ $\frac{VT}{Rsh}$ = (100+ $\frac{VT}{200}$) –①

But, Vt = Eg- IaRa ----②

Substuting ① in ②

Vt = 2.62- (100 +$\frac{Vt}{200}$) * 0.06

= 26.2- 6 -0.0003Vt

Vt + 0.0003 Vt= 20.2

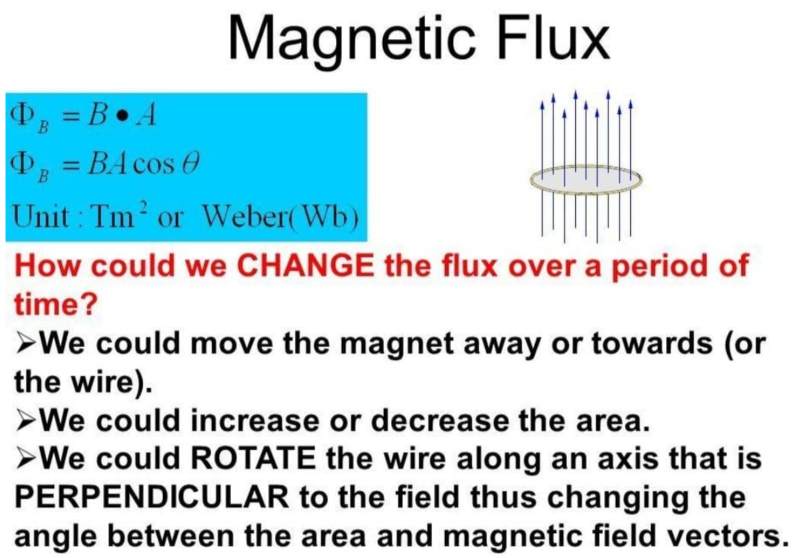
Vt = $\frac{20.2}{1.0003}$

Vt= 20.2 V

(a) Describe the means by which the magnetic flux associated with a conductor may be changed. (6)
(b) Find the generated e.m.f./conductor of a 6-pole D.C. generator having a magnetic flux/pole of 64m Wb and a speed of 1000 rev/min. If there are 468 conductors, connected in six parallel circuits, calculate the total generated e.m.f. of the machine. Find also the total power developed by the armature when the current in each conductor is 50A. (10)

Aug 2023

(a) The magnetic flux associated with a charged conductor refers to the total magnetic field passing through a surface, typically perpendicular to the direction of the magnetic field. When a current flows through a conductor, it creates a magnetic field around it according to Ampere's law. The magnetic flux is a measure of the total magnetic field lines passing through a given surface. For a charged conductor, the magnetic flux is influenced by the current flowing through it and the geometry of the conductor.



(b) Given
P = 6 = A
$\phi = 64 * 10^{-3}$ wb
N = 1000 rpm
Z = 468
To find,
EMF
Power developed when current in each conductor is 50A
We know that $E = \frac{P*\varphi*NZ}{60A}$
$E = \frac{6*64*10-3*1000*468}{60*6}$
E = 499.2V
Now
Current per conductor = 50A
Current in 6 parallel path
50 * 6 = 300A
So power developed = EMF X I
= 499.2 * 300
= 149.8 kW

Explain clearly why, in D.C. installation, a compound-wound electric generator is usually adopted for ship lighting purposes. Compare its performance with that of shunt and series wound machines. What attention does such a machine require when working and what care is necessary for its maintenance in a satisfactory condition? (16)

Jul 2023 | Oct 2024 | May 2024

DC installations on ships, a compound-wound electric generator is often preferred for lighting purposes due to its superior performance characteristics compared to shunt and series wound machines.

Compound-wound generators

- **Voltage Regulation:** Compound-wound generators combine the characteristics of both series and shunt wound generators. They have both series and shunt windings. The series winding helps to boost the voltage under heavy load conditions, while the shunt winding provides good voltage regulation under varying load conditions. This results in better overall voltage regulation, making compound-wound generators ideal for lighting systems where consistent voltage is crucial to avoid flickering and ensure steady light output.
- **Load Handling:** Ships' lighting systems experience varying loads. Compound-wound generators handle these variations better because the series winding compensates for the voltage drop caused by increased load. This adaptability to changing loads ensures that the lighting system remains stable and reliable.

Comparison with Shunt and Series Wound

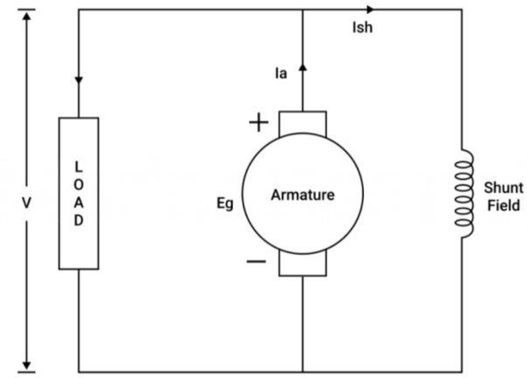
- **Shunt Wound Generators:** Performance: Shunt wound generators have good voltage regulation under steady load conditions. However, their voltage can drop significantly under heavy loads because the field current decreases as the load increases. Use Case: Suitable for applications with relatively constant loads but not ideal for varying loads like lighting systems on ships.
- **Series Wound Generators:** Performance: Series wound generators produce high voltage under no-load or light-load conditions and low voltage under heavy loads due to the nature of series winding where the field current depends on the load current. Use Case: Typically used for applications requiring a high starting torque but not suitable for stable voltage applications like lighting.
- **Compound Wound Generators:** Performance: Combine the benefits of both shunt and series wound generators. They maintain relatively stable voltage across a wide range of loads. Use Case: Ideal for ship lighting systems where load can vary significantly and stable voltage is necessary.

Attention and Maintenance

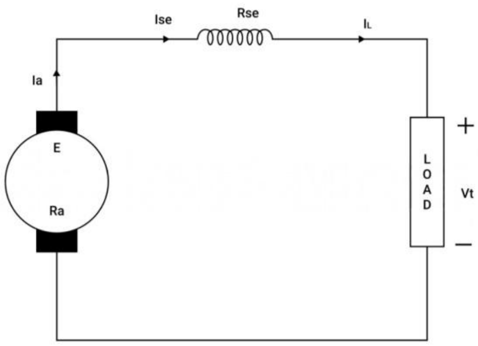
- **Regular Monitoring:** Continuously monitor voltage and current output to ensure the generator operates within specified parameters. Check for any abnormal noises or vibrations during operation.
- **Load Management:** Ensure that the load connected to the generator is within its rated capacity to prevent overloading, which can damage the windings and affect voltage regulation.
- **Inspection and Cleaning:** Regularly inspect and clean the generator to remove dust, dirt, and debris that could cause overheating or electrical faults. Pay special attention to the commutator and brushes, ensuring they are clean and in good condition.
- **Brush and Commutator Maintenance:** Check the brushes for wear and ensure they are making good contact with the commutator. Replace brushes that are worn out. Inspect the commutator for signs of wear or scoring and smooth it if necessary.

- **Lubrication:**Lubricate bearings as per the manufacturer's recommendations to ensure smooth operation and prevent mechanical wear.
- **Electrical Connections:**Tighten and inspect all electrical connections to prevent loose contacts that can lead to arcing and potential faults.
- **Testing:** Periodically test the generator under load conditions to ensure it performs as expected. Perform insulation resistance tests to check for any insulation degradation.

By selecting compound-wound generators for ship lighting, you achieve better voltage regulation and adaptability to varying loads, ensuring reliable and stable lighting. Proper attention and regular maintenance are essential to keep the generator in optimal working condition and prolong its service life.



Shunt Wound Generator



Series DC Generator

(a) Explain the effect of changing current and its associated magnetic flux on the induced e.m.f (6)
(b) A d.c. generator gave the following O.C.C. when driven at 1000 rev/min. Field Current (A) 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6
Armature Voltage (V) 32, 58, 78, 93, 104, 113, 120, 125
If the machine is run as a shunt generator at 1000 rev/min, the shunt-field resistance being 1000, find
(i) the O.C. voltage
(ii) the critical value of the shunt-field resistance,
(iii) the O.C. voltage if the speed was raised to 1100 rev/min, the field resistance being kept constant at 100 Ω.

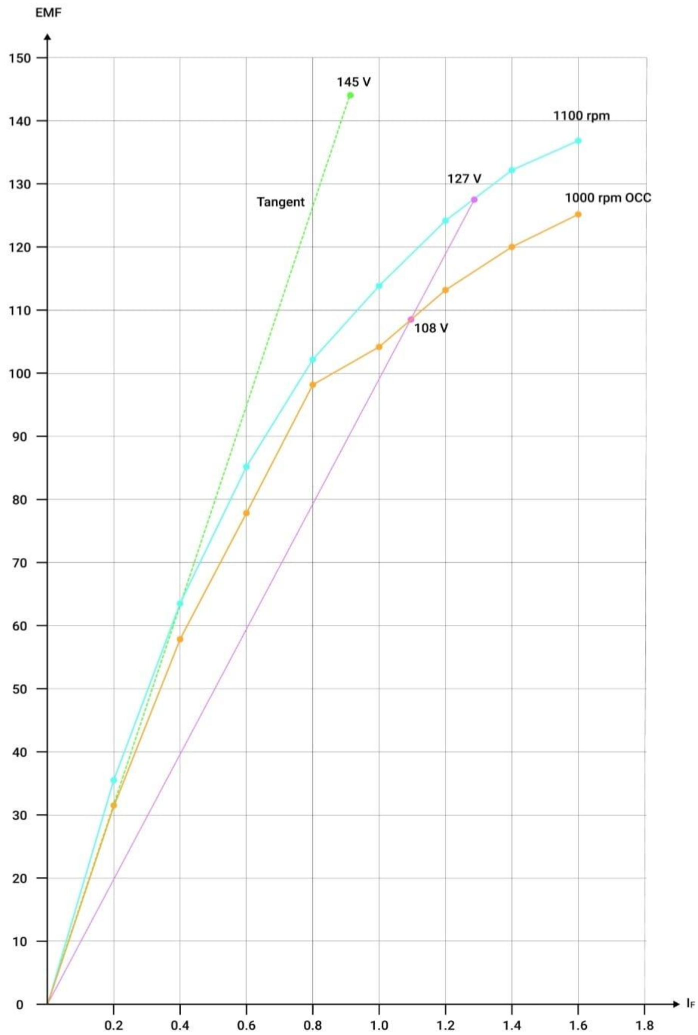
Dec 2022

(a) When the current through a conductor changes, it produces a magnetic field around it. This changing magnetic field induces an electromotive force (emf) in any nearby conductor, According to Faraday's law of induction. The emf produced is directly proportional to the rate of change of magnetic flux through the conductor, which is a measure of the strength and extent of the magnetic field lines passing through it.

Increasing the current through a conductor results in a stronger magnetic field, which leads to a larger magnetic flux and a higher induced emf. Conversely, decreasing the current weakens the magnetic field, reduces the magnetic flux, and lowers the induced emf.

Similarly, changing the magnetic flux around a conductor also induces an emf, according to Lenz's law. If the magnetic flux through a conductor increases, the induced emf opposes this increase, whereas a decrease in magnetic flux causes an emf that opposes this decrease.

(b)



(i) The O.C voltage

The 1000 rev/min OCC is plotted against field current armature voltage and cut by the 100 Ω field voltage drop line which is plotted by drawing a straight line through any deduced point and the origin. Thus considering a If value of 1 A, then field voltage line would be 1 × 100 = 100 V. Join this point to the origin. 100 V. The point intersection at 108 V is the answer required.

(ii) The tangent is drawn to the 1000 rev/min OCC. The critical resistance Reis determined by taking any voltage value on this tangent and dividing by the current.

Thus Ra = $\frac{145\text{ V}}{0.9A}$ = 161.1 Ω

The critical resistance for this speed is 161.1 Ω.

(iii) The 1100 rev/min OCC is obtained by multiplying the original 1000 rev/min values by 11/10 = 1.1

I_f	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
EMF 1000 rpm	32	58	78	93	104	113	120	125
EMF 1100 rpm	35.2	63.8	85.8	102.3	114.3	124.3	132	137.4

EMF 1100 rpm
This 1100 rev/min characteristic when plotted is cut by the 100 Ω field voltage drop line at 127 volts.

---

a) Describe the effect of running an induction motor on reduced voltage. (6)
(b) A 90V d.c. generator is used to charge a battery of 40 cells in series, each cell having an average e.m.f.of 1.9 V and an internal resistance of 0.00252. If the total resistance of the connecting cells is 12, calculate the value of the charging current. (10)

Aug 2022 | **Apr 2025-1** | **Aug 2024** | **May 2024-2**

(a) Running an induction motor on reduced voltage has several effects, including:

- When the voltage supplied to the motor is reduced, the current drawn by the motor increases to maintain the power requirement (P = VI). Higher current can lead to several issues.
- The increased current results in higher losses in the motor windings, leading to elevated temperatures.
- Overheating is a major concern as it can damage the insulation, winding, and other components of the motor.
- Lower voltage leads to reduced starting torque, affecting the motor's ability to accelerate and start rotating properly. This can result in difficulties in starting heavy loads or moving the motor from a standstill.
- The pullout torque, which is the maximum torque the motor can deliver without stalling, is significantly reduced under reduced voltage conditions.
- Operating the motor at reduced voltage results in lower efficiency. Motors are designed to operate optimally at their rated voltage, and deviating from this value can lead to inefficiencies in power consumption.
- The combination of increased current, overheating, and reduced performance can contribute to a shortened overall lifespan of the motor. Continuous operation at
- reduced voltage accelerates wear and tear on the motor components.
- Induction motors are sensitive to voltage sags or fluctuations. A significant drop in voltage, even for a short duration, can cause a motor to stall or operate erratically.

(b) Given:
Generator voltage = 90V
Number of cells in series 40
Average EMF of each cell = 1.9V
Internal resistance = 0.0025Ω
Total resistance = 1 Ω
To find
Charging current, I
EMF of the battery, E_b = 40 * 1.9 = 76V Internal resistance, R_i = 40 * 0.0025 = 0.1 Ω
Total resistance, R = 1 + 0.1 = 1.1 Ω
We know,

$V_{charging} = V_{gen} - E_b$

= 90 -76

= 14

Then, I = $\frac{V}{R}$

= $\frac{14}{1.1}$

= 12.72A

DC Motor

- **Notes:**

(a) What is meant by the term 'back e.m.f.' as applied to an electric motor?
(b) A 40kW, 220V shunt motor has a full-load efficiency of 90 per cent, an armature resistance of 0.075 ohms and a shunt-field resistance of 55ohms. When 'at starting', the starter handle is moved onto the first stud, it is desired to limit the current, through the armature to 1.5 times the value which it has when the motor is on full load. What must be the total value of the starting resistance? If, on overload, the speed falls to 90 per cent of its normal full-load value, what would be the armature current? Neglect the effect of armature reaction. (10)

Dec 2023 **Oct 2022**

(a) Back EMF, or counter-electromotive force, is the voltage that is generated in a motor by the rotation of the motor's shaft. It is caused by the magnetic field that is created by the current flowing through the motor's windings. The back EMF opposes the current that is flowing through the windings, which limits the amount of current that can flow and the amount of torque that can be produced.
The back EMF is proportional to the speed of the motor's rotation. As the motor's speed increases, the back EMF also increases. This causes the current that is flowing through the windings to decrease, which in turn causes the torque that is produced to decrease.

(b)
Output power = $40 * 10^3$
FL efficiency = 90
∴ input power = output × $\frac{100}{90}$
= $40 * 10^3 * \frac{100}{90}$ = 44 ,444W
Input current (I_L)=$\frac{\text{power}}{\text{voltage}}$ = $\frac{4444}{220}$ = 202.02A
Shunt field current, I_{sh} = V R_{sh} =$\frac{220}{55}$ =4 A
$I_L = I_a + I_{sh}$
∴ Armature current, $I_a = I_L - I_{sh}$ = 202.02 – 4
= 198.02A
Armature starting current = 1.5 × Ia = 1.5 ×198.02
= 297.03 A
Now, resistance of armature circuit =220/ 297.3= 0.74 Ω
Resistance to be added = 0.74 -0.075 = 0.665 Ω
Starting resistance = 0.0665 Ω (Ans)
on normal load, $E_b = V - I_aR_a$ = 220 - (198.2* 0.075)
E_b = 205.13 V
on 90 percent = 205.14* $\frac{90}{100}$ = 184.62

∴ Armature voltage drop = 220-184.62 = 35.3
Hence armature current = $\frac{35.38}{0.075}$ = 471.7 A (Ans)

A 105V, 3kW d.c. shunt motor has a full-load efficiency of 82 percent. The armature and field resistances are 0.25Ω and 900 respectively. The full-load speed of the motor is 1000 rev/min. Neglecting armature reaction and brush drop, calculate the speed at which the motor will run at no load if the line current at no load is 3.5A. Calculate the resistance to be added to the armature circuit, in order to reduce the speed to 800 rev/ min, the torque remaining constant at full-load value. (16)

Dec 2023

Given:
V = 105 V
On full load O/P = 3000W
η_{FL} = 82
R_a = 0.25 Ω
R_{sh} = 90 Ω
N_{FL} = 1000 rpm
I_{LNL} = 3.5 A
On no load:
$I_{sh} = \frac{V}{Rsh}$
$= \frac{105}{90}$ = 1.17A
$I_{aNL} = I_{LNL} - I_{sh}$
I_{aNL} = 3.5 -1.17 = 2.33 A
E_{bNL} = 105- (2.33*0.25)= 104.42V
On Full Load:
$\eta_{FL} = \frac{O/P}{I/P}$ = 3000 * 100/82
$\eta_{FL} = \frac{O/P}{I/P}$ = 3660W
$I_{LFL} = \frac{Input\ power}{V} = \frac{3660}{105}$ = 34.86A
$I_{aFL} = I_{LAL} - I_{SH}$
= 3660/105 = 34.86A
$I_{aFL} = I_{LAL} - I_{Sh}$
= 34.86 - 1.17 = 33.7A
$E_{bFL} = V - I_{aFL} * R_a$
E_{bFL} = 105-(33.7*0.25)
We know that, E ∝ N
$\frac{EbFL}{EbNL} = \frac{NFL}{NNL}$
$N_{NL} = \frac{1000*104.42}{96.57}$
N_{NL} =1080 Rev/min
Suppose 'R' is the added resistance to reduced speed, then
E_{bL} =105-33.7(R+0.25)
$\frac{EbL}{EbFL} = \frac{800}{1000}$
$E_{bL} = \frac{800}{1000}$ *96.57
E_{bL} =77.26V
77.26 = 105 - 33.7(R + 0.25)
R = 0.57Ω

(a) Explain what is meant by the back e.m.f. of a motor. (6)
(b) A d.c. motor takes an armature current of 110 A at 480 V. The resistance of the armature circuit is 0.2 Ω. The machine has 6 poles and the armature is lap connected with 864 conductors. The flux per pole is 0.05 wb. Calculate (10)
(a) speed,
(b) the gross torque developed by the armature

Apr 2023

(a) Back EMF is the electromotive force (EMF) that is generated in the armature of a motor by the rotation of the armature. It is proportional to the speed of the motor and the flux per pole. The back EMF opposes the applied voltage, which limits the current in the armature and the

torque that the motor can produce.
The back EMF can be calculated using the following formula:
$E_b = K_e \varphi N$
where:
E_b is the back EMF in volts
Ke is the motor's electromagnetic constant
φ is the flux per pole in webers (Wb)
N is the speed of the motor in revolutions per minute (rpm) .The back EMF is an important factor in the operation of a motor. It limits the current in the armature and the torque that the motor can produce. The back EMF also helps to regulate the speed of the motor.

(b) Given
A = P (for lap wound)
I_A = 110A
V = 480V
ϕ = 0.05wb
Z = 864
R_A= 0.2 Ω
N = ?
$E_B = V - I_a R_a$
458 = 480 - (110 * 0.2)
$458 = \frac{0.05*6*N*864}{60*6}$
∴ N = 636.1 rpm
$T_A = \frac{P\varphi IZ}{2\pi A} = \frac{6*0.05*110*854}{2\pi A}$ = 756.3 Nm
(Or)
$T_A = 9.55 * \frac{EB*IA}{N}$
= 9.55 * (458 *110)/636.1
=756.37 Nm

(a) Describe the normal criteria used for setting thermal protection relays and their advantage compared to magnetic types (6)
(b) A series motor runs at 600 r/min when taking 110A from a 230V supply. the resistance of the armature circuit is 0.120 and that of series winding is 0.032. the useful flux per pole is 110A is 0.024 wb and that for 50A is 0.0155wb. Calculate the speed when the current has fallen to 50A (10)

Mar 2023 **Sep 2022**

(a) Thermal protection relays are designed for sustained overcurrent protection, typically set between 105-120% of the full load current with a time delay. They are not intended for momentary overcurrents.
The overcurrent setting depends on the following:
- The electrical system's maximum continuous load capacity determines the relay settings to ensure the system operates without tripping under normal conditions.
- The relay settings are influenced by the insulation class and its capacity to withstand elevated temperatures.
- The amount of power consumption and heat generated during normal operation is evaluated to set the relay accurately.
- The relay takes into account the cooling mechanism in place to ensure that heat dissipation during operation is factored into the thermal protection settings.

Advantages of Thermal relays over Magnetic relays:

- Thermal relays provide a time delay, preventing tripping from momentary overcurrents that might not cause actual damage. Magnetic relays respond much faster.
- Thermal relays operate based on the heat generated by an overcurrent, offering a more accurate reflection of the actual thermal stress on the system. Magnetic relays respond to the magnitude of the current, irrespective of heat generation.
- Thermal relays are more economical because they use bimetals instead of more expensive magnetic solenoid coils.
- Thermal relays are effective for sustained overcurrents, providing protection that is independent of other factors like the system voltage or magnetic field fluctuations.

(b) Given,
Speed = 600rpm
Voltage = 230V
Current = 110A
Resistane,
Armature Ra = 0.12Ω
Series winding Rs = 0.03Ω
Flux per pole,
ϕ_{110} = 0.024wb
ϕ_{50} = 0.0155wb
To find speed at 50A
$E_{b110}= V_t - (I_A R_a + I_S R_S) = 230-110(0.12 +0.03) = 213.5V$
$E_{b50} = V_T - (I_A R_A + I_S R_S) = 230 - 50(0.12 +0.03) = 222.5V$
We know, E = ϕ PNZ/60A
So, $E_B \, \alpha \phi \, N$

$$\frac{Eb110}{E650} = \frac{\varphi 110\, N110}{\varphi 50\, N50}$$

$$\frac{213.5}{222.5} = \frac{0.024 \times 600}{0.0155 * N50}$$

N_{50} = 968rpm

(a) Explain about the various speed control methods of DC series motors. (6)
(b) The Armature circuit resistance of an 18.65KW 250V series motor is 0.12. The brush voltage drop is 3V and series field resistance is 0.05Ω. When the motor takes 80A speed is 600 r.p.m. Find the speed when the motor is 100 A.

Nov 2022

(a) The speed of the DC series motor can be controlled by following two methods. They are
Flux control method.
Variable Resistance in series with Motor
1. Flux control method: In this method, flux variation can be achieved in four different ways. They are,

- Field diverter method.
- Armature diverter method.
- Tapped field control method.
- Paralleling field coils method

Field diverter method:
In this method, variable resistance Rx is connected in parallel with the series field winding of the motor. Here, variable resistance is known as diverter. Field flux can be decreased by

reducing field current. Field current can be reduced by lowering the resistance value in the diverter. Hence the speed of the motor increased by decreasing field flux in the field winding. The circuit diagram of this method is shown in the image given below.

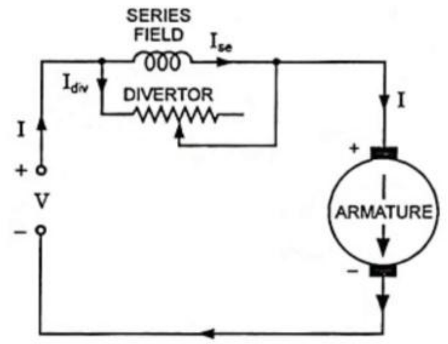
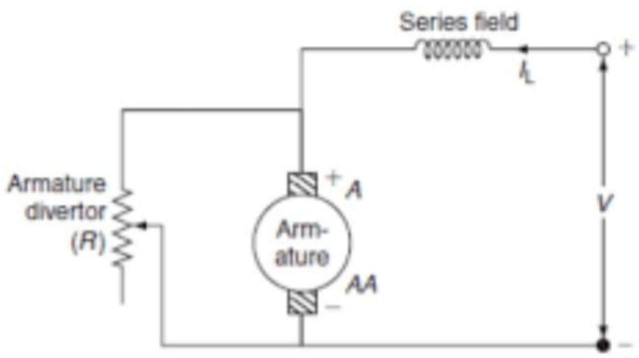


Fig. 1.72 *(a) Field Divertor Method of Speed Control For DC Series Motors*

Armature diverter method:

In this method, diverter Rx is connected across the armature winding of the motor. This method is used to control speeds below the rated value. If you decrease the resistance value in the diverter, the total parallel resistance of the diverter and armature decreases. So, the total current in the motor increases. This current is passing through the field winding of the motor. So, the field flux increases. Hence, the speed of the motor decreased. The circuit diagram of this method is shown in the image given below.



Tapped field control method:

In this method, field flux can be controlled by varying the number of turns in the field winding. Here field winding is provided with a number of taps. If you connect the whole field winding in the circuit, the motor runs at normal speed. The flux in the field winding decreases by changing the number of taps in the field winding. Thereby, the field flux decreases and hence, the speed of the motor increases. The circuit diagram of this method is shown in the image given below.

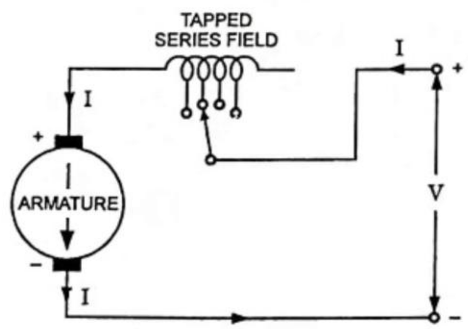


Fig. 1.72 *(b) Tapped Field Control For DC Series Motors*

(d) Paralleling field coils method:
In this method, the field coils are regrouped to achieve several speeds. This is mostly applied in the case of fan motors. In the circuit diagram shown below, we can see that three speeds can be easily achieved for a four-pole motor by using this method.
2. Variable Resistance in series with Motor:
By increasing the resistance in series with the armature will lead to a drop in the potential difference across the armature terminals. A voltage drop across the armature will decrease the speed of the motor. Also, it is to be noted that, due to the flow of full motor power through this resistance, there will be a considerable power loss.

(b) Given:

V= 250 V

brush drop = 3V = V_b

R_a= 0.1 Ω

R_f = 0.05 Ω

N_1 = 600 rpm

R = Ra + Rf

When motor takes 80 A, back EMF

$E_{b1} = V-I_a (R_a+R_f) - V_b$

= 250 - 80(0.1+0.05)

E_{b1} = 235 V

When motor takes 100 A, back EMF

$E_{b2} = V-I_a (R_a+R_f) - V_1 = 250 – 100(0.1 + 0.05)-3$

E_{b1} = 232 V

Now, ϕ ∝ Iα

also, $\frac{N2}{N_1} = \frac{Eb2}{Eb1} * \frac{\varphi 1}{\varphi 2} = \frac{Eb2}{Eb1} * \frac{Ia1}{Ia2}$

$\frac{N2}{600} = \frac{232}{235} * \frac{80}{N2}$

N_2 = 474 rpm

Speed at 100 rpm = 474 rpm

(a) Explain the Speed-Current Characteristics of D.C motor. (6)
(b)A 4-pole, 32 conductor, lap-wound d.c. shunt generator with terminal voltage of 200 volts delivering 12A to the load has Ra 2 and field circuit resistance of 200 ohms. It is driven at 1000 rpm. Calculate the flux per pole in the machine. If the machine has to be run as a motor with the same terminal voltage and drawing 5A from mains, maintaining the same magnetic field, find the speed of the machine. (10)

Nov 2022

(a) SPEED - CURRENT CHARACTERISTICS.
Since the speed of the DC motor is given by:

N= k(E/Φ) , where k= proportionality constant.

N = k{(V - IR)/Φ}

The resistance of the armature is minimal so voltage drop (IR) can be neglected and supply voltage is constant. So speed is inversely proportional to flux.

Now, in the DC series motor, the flux is produced by the armature current flowing in the field winding. So, the flux produced is directly proportional to the armature current. Hence, the speed of the series motor becomes inversely proportional to the armature current.

The curve between them is a rectangular hyperbola.

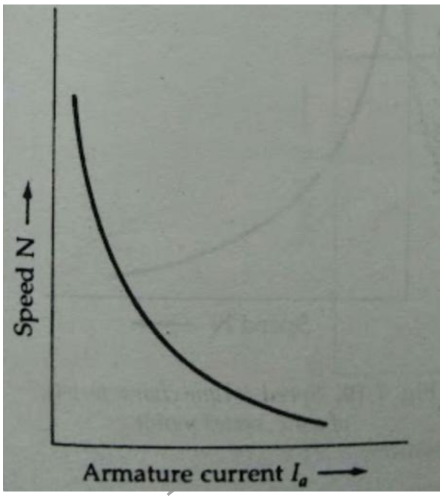


Fig. Speed - current characteristics

Thus, when the armature current is low the speed will be very large. Therefore, at no load or light load, there is a possibility of dangerously high speed, which may damage the rotor. Hence, the DC series motor should never be run at no load.

(b) Given:

P = 4

A = P (lap)

Z = 32

V = 200V

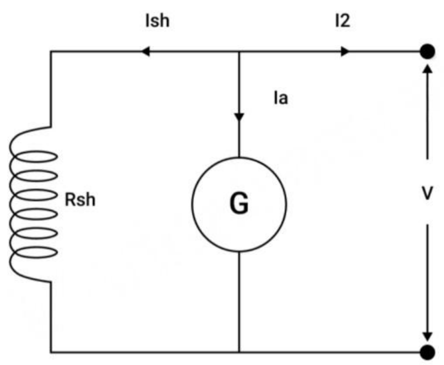
I_L = 12A

R_a = 2Ω

Rsh = 200 Ω

N =1000 rpm

When running as a generator, shunt current



Ish = $\frac{V}{Rsh} = \frac{200}{200}$ = 1 A

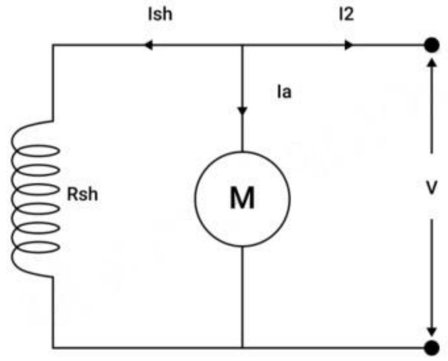
Armature current, Ia = $I_L + I_{sh}$ = 12+1 = 13A

EMF induced, E_b = V+Ia Ra = 200+ (13 × 2) = 226V

$E_b = \frac{\phi ZNP}{60A}$

$\varphi = \frac{226\times60}{32\times1000}$ = 0.423 wb

When running as a motor, Armature current



$I_a = I_L - I_{sh}$ = 5-1 = 4 A

EMF induced, $E_1 = V - I_aR_a$ = 200 - (4×2)

E = 192 V

∴ Speed N = $\frac{Eb * 60}{\phi Z}$

$= \frac{60 * 192}{0.423 * 32}$ = 850 rpm

(a) Explain and describe why and how space heaters are fitted to motors. (6)
(b) Give a clear explanation of the following effects in a three phase induction motor,
(i) the production of rotating field,
(ii) the presence of an induced rotor current,
(iii) the development of torque.
A 4-pole, 250V motor has its armature removed in order to test the continuity of the field windings which are connected in series and consist of 2000 turns each. What is the average e.m.f. induced when the current is switched off, if the flux falls from 0.026Wb to 0.001 Wb in 0.2s? (10)

Oct 2022

(a) Space heaters are fitted to motors in order to prevent moisture from condensing inside the motor when it is not in use. This can be a problem in environments where the humidity is high, as the moisture can short out the motor's winding and cause it to fail. Space heaters work by providing a low-level heat source that is sufficient to keep the temperature inside the motor above the dew point, thereby preventing moisture from condensing on the windings.
Space heaters are typically fitted to the exterior of the motor, either on the housing or on the end bells. They may be in the form of heating elements, such as resistance wire or cartridge heaters, or they may be heated air blowers. The heaters are controlled by thermostats or temperature sensors that turn them on and off as needed to maintain a consistent temperature inside the motor.

(b) (i) The production of rotating field: In a three phase induction motor, the stator winding is supplied with a three phase AC voltage. This causes a rotating magnetic field to be produced in the stator. The direction and speed of the rotating field is determined by the phase sequence and frequency of the AC voltage.

(ii) The presence of an induced rotor current: When the rotating field of the stator cuts the conductors of the rotor, an induced current is generated in the rotor. This induced current creates a magnetic field in the rotor, which interacts with the magnetic field of the stator.

(iii) The development of torque: The interaction between the magnetic field of the stator and the magnetic field of the rotor causes a torque to be developed in the rotor. The magnitude of the torque is determined by the strength of the magnetic fields, the speed of the rotor, and the angle between the magnetic fields. The direction of the torque is determined by the direction of the magnetic fields and the direction of rotation of the rotor.

From Faraday's law, E_{av}

$E_{av} = \frac{N(\Phi1-\Phi2)}{t}$

$E_{av} = \frac{2000\times4\times(0.026-0.001)}{0.2}$

Induced EMF = 1000V = 1kV

A 4-pole lap wound D.C shunt generator has an open e.m.f of 250V when the flux per pole is 0.08 Wb and the speed is 10 rev/sec/ The speed of the generator is reduced to 10% and the flux per pole is increased by 5% when the generator supplies a load of 100A. Determine the terminal voltage, if the armature resistance is 0.060 and the new total field circuit resistance is 2002. (16)

Aug 2022

Given:

P = 4

A = P(lap)

I_L = 100A

R_a = 0.06Ω

R_{sh} =200ϕ

To find

(i) Terminal voltage, V_T

ϕ = 0.08wb

n = 10rps

A = P

E_a = 250V

$E_b = \frac{\phi ZNP}{A} = \phi Zn$

250 =.08*10*Z

Number of conductors, $Z = \frac{250}{(0.08*10)} = 312$

Now, speed is reduced to 10 n =0.1 × 10 = 1 rps

Flux per pole is increased by 5

ϕ = 1.05 * 0.08 = 0.084wb

New induced emf, E_g = ϕ*Zn

= 0.084 * 312 * 1

= 26.2V

Also, $I_a = I_L + I_{sh}$

$I_a = I_L + \frac{VT}{Rsh} = 100 + \frac{VT}{200}$ ---①

But, $V_T = E_g - I_a*R_a$ ----②

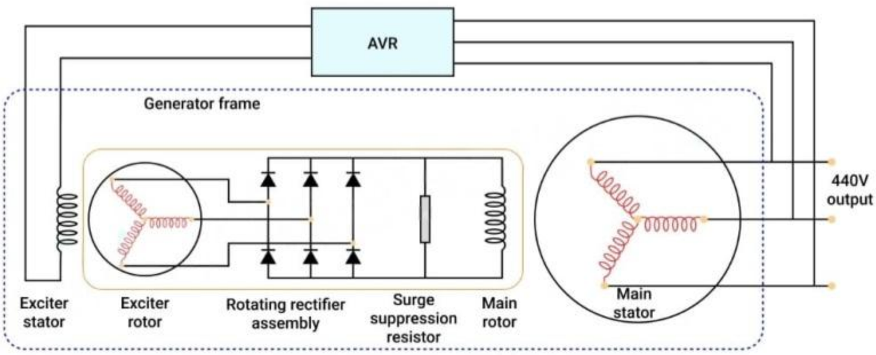
Substuting in ① in ②

$V_T = 26.2 - (100 + V_T/200) * 0.06$
$= 26.2 - 6 - V_t/3000$
$V_T = 20.2/1.0003$
(Since Vr/30000 is very small, neglect the value)
$V_T = 20.2V$

(a) Describe the basic principles a self-excited generator. (6)
(b) The armature resistance of a 200 V, Shunt motor is 0.4 ohms and the no-load armature current is 2A. When fully loaded and taking an armature current of 50 A, the speed is 1200 rev/min. Find the no-load speed and state the assumption made in the calculation.

Apr 2025-1 | Aug 2022 | Aug 2024 | May 2024-2

(a) The basic principles of a self-excited generator:
When the generator is first started, there is a small amount of residual magnetism in the rotor winding. This residual magnetism is due to the fact that the rotor winding is made of ferromagnetic material, which retains a small amount of magnetism even when there is no current flowing through it. The prime mover (usually a diesel engine or a turbine) rotates the rotor of the generator. As the rotor rotates, the residual magnetism in the rotor winding induces an electromotive force (EMF) in the stator winding. The EMF induced in the stator winding is proportional to the speed of rotation of the rotor and the strength of the residual magnetism.
The EMF induced in the stator winding is fed to the automatic voltage regulator (AVR). The AVR rectifies the AC voltage from the stator winding and uses it to excite the rotor winding. The DC current from the AVR flows through the rotor winding, creating a magnetic field. This magnetic field interacts with the residual magnetism in the rotor winding, creating a stronger magnetic field. The stronger magnetic field induces a higher EMF in the stator winding
The process of self-excitation continues until the generator reaches its rated voltage. At this point, the AVR reduces the excitation current to maintain the generator voltage at the desired level.



(b) Given:
Armature resistance: $R_a = 0.4\Omega$
Voltage: V = 200V
No-load armature current: $I_{ao} = 2A$
Full load current: $I_a = 50A$
Full load speed : N = 1200rpm
To find:
No-load speed : No
On No-load: $E_oV- I_{ao} R_a = 200- (2*0.4) = 199.2V$

On full-load: $E_a = V - I_a R_{ao} = 200 - (50*0.4) = 180V$

We know, $E = \frac{\phi * PNZ}{60}$

So, $N = \frac{60E}{\phi PZ}$

Then, $N_o = \frac{60Eo}{\phi PZ}$

For the Shunt motor, the field is unaffected by the loading of the armature.

So, $\phi = \phi o$

$\frac{No}{N} = \frac{Eo}{E}$

$N = N \times \frac{Eo}{E}$

$= 1200 \times \frac{199.2}{180} = 1328rpm$

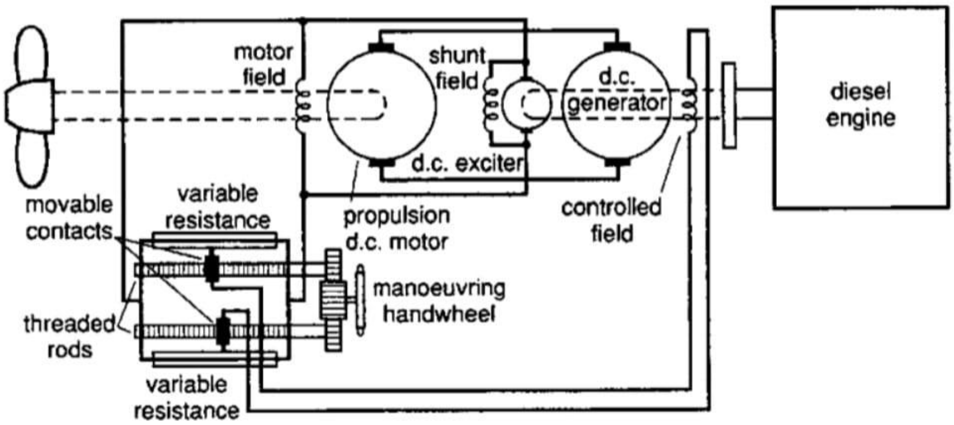
Electric Propulsion

- **Notes:**

(a) Sketch a diesel electric propulsion arrangement for a ship (8)
(b) Describe the operation of the propulsion arrangement sketched in (a), including in your description how reversal of the propulsion motor is achieved (8)

Apr 2025-1 | **May 2024 - 2** | **Aug 2024**

(a) This system has an a.c. Conduction motor driving its direct current generator. Field current for both generator and motor is delivered through a 3-phase rectifier from the a.c. Supply. This arrangement is a D.C. scheme with a diesel engine as the prime mover driving the single D.C. Generator at a constant speed. An exciter mounted on an extension of the generator shaft provides field current both for the generator and for the direct current propulsion motor. The exciter is itself a d.c. Shunt generator.



Simple Ward-Leonard system for diesel-electric propulsion

At the start-up, the armature windings of the exciter have current generated in them when they pass through the field, emanating from the residual magnetism of the exciter poles. The small current generated initially circulates through the windings of the exciter poles, strengthening their magnetic fields until full output is reached.
The current generated in the d.c. Exciter is delivered unchanged to its own field poles and to the field poles of the d.c. Propulsion motor. It is available to the field poles of the generator but only through the regulating resistances of the manoeuvring control.
If the contacts control are at the mid positions of the resistances, then no current flows to the main generator poles, and there is no output from it to the propulsion motor.
Rotation of the manoeuvring handwheel and gears turns the threaded bars to move the contacts along the resistances in opposite directions. As the contacts travel towards extremities and resistance lessens, current from the exciter flow to the generator field poles. The direction of current flow and the level are used to control the output of the generator and, in turn, the propulsion motor. Propeller speed is proportional to the actual voltage produced in the generator and fed to the propulsion motor.

Advantages

- The large amount of electric power available for main propulsion can be diverted for cargo or dredge pump operation as well as for bow or stern tube thrusters or fire pumps of the emergency and support vessel (ESV).
- Reduction in size of propulsion machinery spaces.
- Electric propulsion separates the shaft and parallel system from the direct effect of a diesel prime mover and from transmitted terminal vibrations.
- Flexible and absence of physical constraints on machinery layout.
- Very smooth speed control system over a very wide range.
- Speed can be controlled in both directions of rotation of the motor.

Disadvantages

- Higher installation cost and lower efficiency compared with a diesel propulsion system.

(b) The conventional propulsion system of the ship is efficient but requires high operating costs and increases marine pollution. Among all the prospective alternative power sources, the electrical propulsion system is one of the best-tried-out alternatives in today's
The electric propulsion system consists of a prime mover, which may be of two types:

- Diesel driven
- Turbine or steam-driven.

Operation:

- The propeller shaft of the ship is connected to large motors, which can be D.C or A.C driven and are known as propulsion motors. Power for the propulsion motor is supplied by the ship's generator and prime mover assembly.
- The generator can be direct or alternating current type with diesel or steam-driven prime mover, depending upon the requirement or demand of the owner/ship.
- In the electrical propulsion system, the direction of the rotation of the propeller is governed by either the electrical control of the motor itself or by changing the electrical supply.
- Normally, a variable-speed electrical motor is used for a fixed-pitch propeller system, and constant or variable can be used for a variable-pitch propeller or CPP.

Electric motors

- **Notes:**

(a) What is single phasing of a 3 ph induction motor? (6)
(b) What are the causes of single phasing? (6)
(c) Explain any method of protection against single phasing (4)

May 2023

(a) Single phasing of a three-phase induction motor refers to a condition where one of the three phases supplying power to the motor becomes interrupted or disconnected. As a result, the motor loses the supply voltage in one of its phases, causing various issues in its operation.
A single phase condition subjects the motor to an excessive vibration, imbalance, drawing high currents in the other healthy phases and motor heating.

(b) The causes of single phasing in a three-phase induction motor:

- **Faulty Power Supply:** Problems in the power supply system, such as an open circuit, blown fuse, or tripped circuit breaker, can lead to single phasing.
- **Loose Connections:** Loose electrical connections in the motor's wiring or the supply lines can result in the loss of one phase.
- **Faulty Contactor or Motor Starter:** A defective contactor or motor starter can fail to adequately switch or maintain the supply to one of the phases
- **Faulty Motor Windings:** Internal faults within the motor windings, such as short circuits or open circuits, can lead to the loss of one phase and cause single phasing.

(c) One method of protection against single phasing is the use of a phase failure relay. A phase failure relay is a protective device that monitors the supply voltages of the motor and detects any loss or imbalance in the phases. When single device that monitors the supply voltages of the motor and detects any loss or imbalance in the phases. When single phasing occurs, the phase failure relay detects the absence or imbalance of one phase and quickly activates a protective action.
The protective action can be in the form of tripping a circuit breaker or contactor, thereby disconnecting the motor from the power supply and preventing further operation. This helps to safeguard the motor against potential damage due to single phasing and ensures that the motor remains protected until the supply voltage is restored.

(a) With reference to single phasing applied to a.c. motors: (8)
(i) Explain the meaning of single phasing;
(ii) Describe its effect;
(iii) State the most common cause of single phasing.
(b) Sketch a simple diagram of a direct on line starter, showing in detail the overload and single phase protection trip (8)

Apr 2023 **Jul 2024** **Feb 2024** **Dec 2022**

(a) (i) Single Phasing of AC motor: Single phasing is a condition in which one of the phases of a three-phase alternating current (AC) motor is disconnected or interrupted, resulting in the loss of one phase of power. This can occur due to a fault in the power supply, a loose connection, or a problem with the motor itself.

(ii) Effects of single phasing:

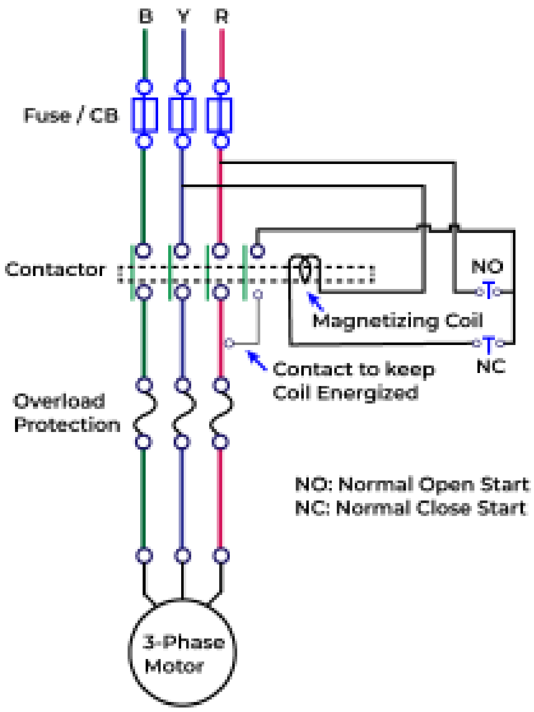
- The loss of one phase causes an imbalance in the current flow, resulting in an increase in current in the remaining two phases. This can lead to overheating and damage to the motor windings.

- The motor's torque, which is the force that causes it to rotate, is significantly reduced when single phasing occurs. This can cause the motor to slow down or even stall.
- The unbalanced current flow and reduced torque can cause the motor to vibrate excessively, leading to noise and mechanical stress on the motor and its components.
- The increased current and vibration can cause the motor to overheat, which can damage the insulation and lead to a motor failure.

(iii) Causes of single phasing:

- One or more out of three fuses blow.
- If one of the contactor is open- circuited.
- If a protection device has improper settings.
- If the relay contact for the motor is damaged.
- Contactor are coated due to oxidation & hence not conducting.
- If circuit wires are damaged or short- circuited.

(b)



Electrical circuits & components

- **Notes:**

(a) Sketch and describe a power (watt) meter for an a.c. switchboard. (8)
(b) State why type of load governs power factor and give examples of power factor for a resistance load and for normal marine operation. (8)

Oct 2024

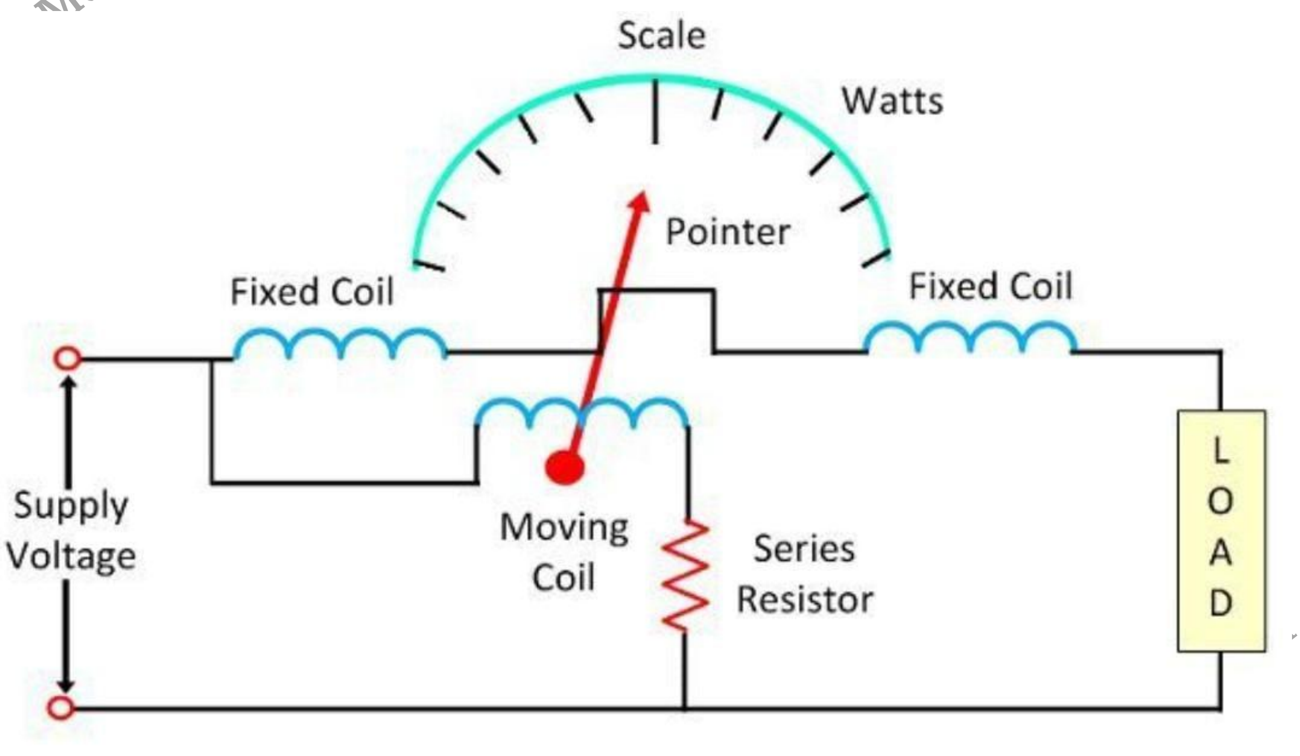
(a) A power measuring meter, called a **wattmeter,** can be connected into a circuit to measure power instead of making two measurements (current and voltage) and then calculating the power. The power dissipated can be read directly from the scale of the wattmeter.

Working Principle: A wattmeter consists of two stationary coils connected in series, and one moving coil. The stationary coils, wound with many turns of thick wire, have a low resistance. The moving coil wound with many turns of fine wire, has high resistance. For power measurements, the moving coil is connected across the source voltage with a series resistance of high value which determines the current through the coil in phase and proportional to voltage. The fixed coil is connected in series with the load, which can carry the load current.

The interaction of the two magnetic fields, produced by the fixed and moving coils, will cause the moving coil and its pointer to rotate in proportion to the voltage (across the load) and current (through the load).

(b) Power factor (PF) is governed by the type of load because different loads have varying proportions of resistive, inductive, and capacitive components. These components affect how current and voltage interact, influencing PF.

Load Types and Power Factor:
1. Resistive Loads (e.g., lighting, heating): PF = 1 (unity)
2. Inductive Loads (e.g., motors, transformers): PF < 1 (lagging)
3. Capacitive Loads (e.g., capacitors, power factor correction devices): PF > 1 (leading)



Electrodynameter Wattmeter

(a) Describe the principle of operation of EACH of the following detecting elements: (8)
(i) Bi-metal strips
(ii) Thermisters
(b) Explain, with the aid of sketches, typical applications where the devices described in (a) may be employed in high voltage electrical systems. (8)

Jan 2025

(a) (i) A bimetallic strip works on the principle of thermal expansion, which is defined as the change in the volume of metal with the change in temperature. The bimetallic strip works on two basic fundamentals of metals.

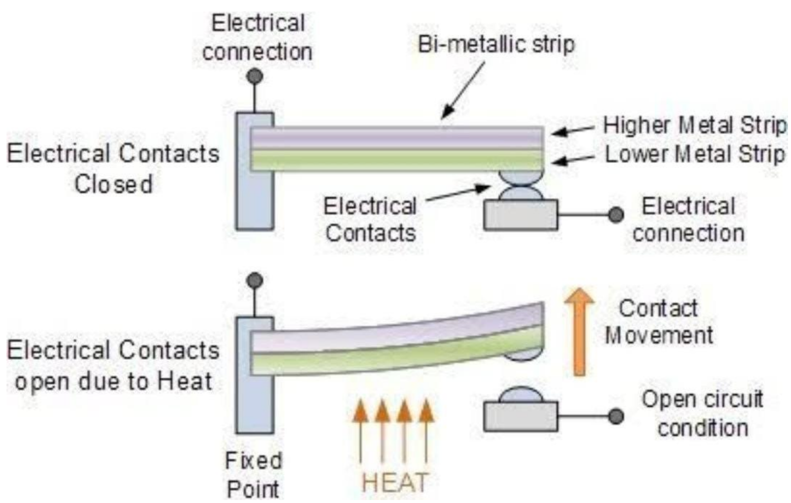
- The first fundamental is thermal expansion, which states that the metals expand or contract based on variations in temperature
- The second fundamental is the temperature coefficient, where each metal (having its own temperature coefficient) expands or contracts differently at a constant temperature.

(ii) The name "thermistor" is created by combining the words "thermal" and "resistor". As a passive component with temperature-sensitive properties, it is primarily employed as a temperature sensor.

A thermistor is a type of resistor that undergoes a significant change in resistance in response to variations in temperature.

Every type of resistor exhibits a certain level of temperature dependency, a characteristic encapsulated by their temperature coefficient. Thermistors, specifically, can achieve a high current coefficient. In thermistors, resistance decreases as temperature rises, leading to what is commonly known as a negative temperature coefficient (NTC). Conversely, thermistors with a positive temperature coefficient are referred to as positive temperature coefficient thermistors (PTC).

(b) Bi-metallic strip used in Fire detectors:



Thermistor used for overload protection of motor:
Thermistors are thermally sensitive resistors made of small pellets of semiconductor materials. They are embedded into the insulation of the three-phase windings of the stator windings at the manufacturing stage.

They operate with a negative temperature coefficient of resistance. They are temperature sensors, which are used to monitor the winding temperature.

The resistance is calibrated in terms of temperature in the meters which are pointer operated according to the current through the resistor placed in a bridge. They are connected so that if the winding temperature gets too high, the starter contactor will be tripped and stop the motor.

They are also mounted in the gaps created in the stator core to measure the temperature of the stator iron core be more than the core temperature when the machine is loaded. The thermistors in the core is used to give an alarm if the core temperature exceeds a set value.

(a) Sketch, the circuit diagram of an instrument used for measuring electrical insulation resistance. (8)
(b) Describe the circuit diagram sketched in (a), explaining how it operates when measuring electrical insulation resistance. (8)

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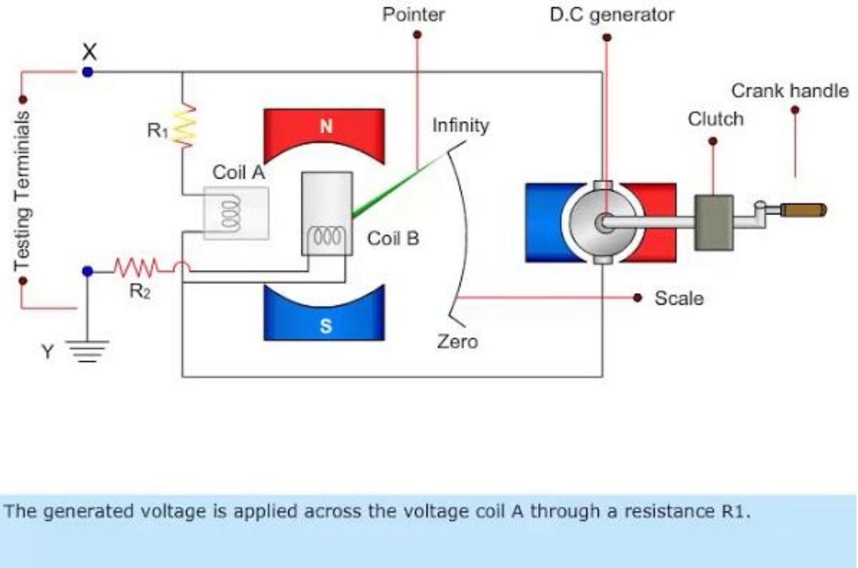
(a)



(b) Working Principle of megger
Megger works on the principle of electromagnetic attraction. The centrifugal clutch on the generator is the mechanism that provides the constant for the insulation test. The insulation with low resistance is tested using a steady voltage.

1. The armature of the generator is rotated by the hand-driven crank lever. The clutch mechanism is designed to slip at a predetermined speed, which facilitates the generator to maintain a constant speed and hence the constant voltage while testing.
2. The two coils A and B constitute a moving coil voltmeter and an ammeter, both are combined to form one instrument.
3. The 'hot' terminal of the equipment whose Insulation resistance has to be measured is connected to the testing terminal X terminal Y is connected to the body of the equipment which is generally grounded.
4. When the crank handle is rotated the voltage is generated in the generator, the generated voltage is applied across the voltage-coil A through resistance R1.
5. When terminals X and Y are free initially, no current flows through coil B. The torque produced by coil A rotates the moving element to show infinity.
6. While testing the terminals X and Y are connected across the terminal and body of the machine for measurement. Now the current passes through the deflecting coil B.
7. The deflecting torque produced by coil B interacts with the torque of coil A and rotates the moving element to indicate the resistance value.

8. The voltage generated by this instrument is 500 V. Megger meters are available to generate 1000 V, 2,500 V, and 5000 V also.
9. High-voltage meggers are either motor-operated or power operated.

With the aid of a circuit diagram, explain how a Galvanometer can be used as an Ammeter. (16)

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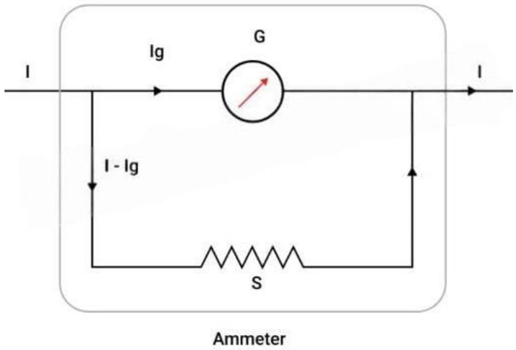
Conversion of Galvanometer to Ammeter:
A Galvanometer is converted into an ammeter by connecting it in parallel with a low resistance called shunt resistance. Suitable shunt resistance is chosen depending on the range of the ammeter.



Ammeter

In the given circuit,

Rg - Resistance of the galvanometer
G - Galvanometer coil
I - Total current passing through the circuit
lg - Total current passing through the galvanometer, which corresponds to full-scale reading
Rs - Value of shunt resistance

When current lg passes through the galvanometer, the current through the shunt

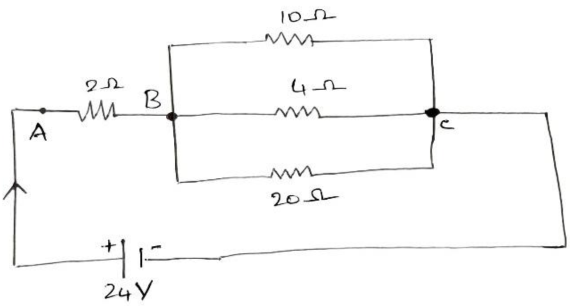
resistance is given by Is = I - lg. The voltages across the galvanometer and shunt resistance are equal due to the parallel nature of their connection.

Therefore, **Rg*lg = (I-lg)*Rs**

The value of s can be obtained using the above equation.

Find the p.d. Between A-B and B-C shown in the figure below.

Oct 2023



parallel resistance R_p) using the formula:

$$\frac{1}{R_p} = \frac{1}{10} + \frac{1}{4} + \frac{1}{20}$$

$$R_p = 2.5\Omega$$

The series resistor (2Ω) is added to the equivalent parallel resistance to find the total resistance R_{total}):

$$R_{total} = 2 + 2.5 = 4.5\Omega$$

The current in the circuit I) is calculated using Ohm's Law: $I = \frac{V}{R}$, where V is the voltage (24V).

$$I = \frac{24}{4.5} = 5.333 \text{ A.}$$

Drop in AB: The voltage drop across the 2Ω resistor V_{AB}) is calculated using Ohm's Law:

$$V_{AB} = I \times R = 5.333 \times 2 = 10.666 \text{ V.}$$

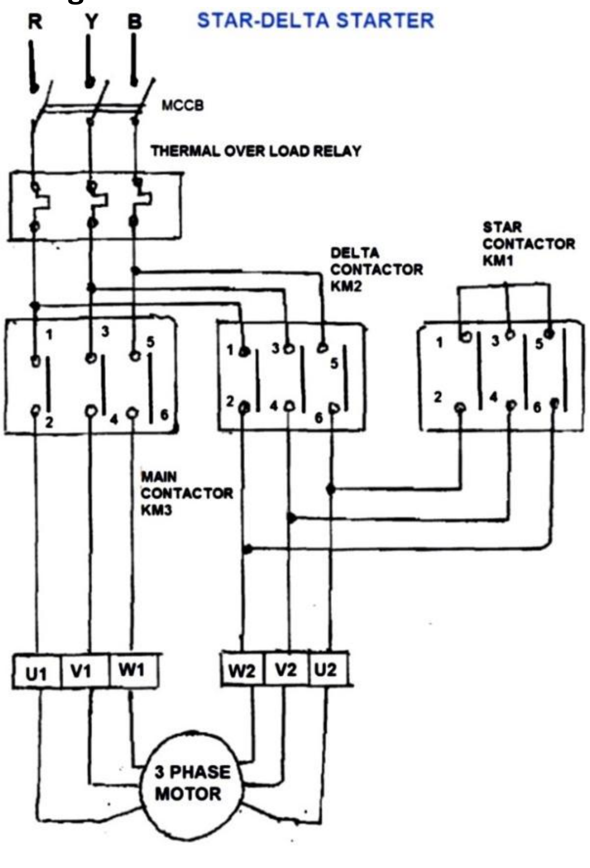
Drop in BC: The voltage drop across the parallel resistors V_{BC}) is calculated using Ohm's Law:

$$V_{BC} = I \times R_p = 5.333 \times 2.5 = 13.333 \text{ V.}$$

(a) Sketch and describe a Star-Delta starter for starting an induction motor (10)
(b) Three similar coils, each having a resistance of 10 ohms and an inductance of 0.02 H are connected in
(i) Star
(ii) Delta to a 3-phase, 50-Hz supply with 500V.
Calculate the total power absorbed and the line current in each case. (6)

Dec 2023

(a) Star-delta starter for starting induction motor:



Star delta starter is used to start the squirrel cage induction motor. This starter reduces both starting torque and starting current during starting period.
Both end connections of the three windings of induction motor are usually brought out to facilitate the star-delta starting scheme.

Suitable change over provision from star to delta connection is available in the starter assembly.
These change over contacts enable the six ends to be started connected for starting and then, to be reconnected in delta after the rotor comes up to speed. It also has a timer for setting the time in star position.
In star connection, phase voltage is equals to 1/√3 line voltage and in delta connection, phase voltage equals to line voltage.
This will cause overheating of the motor and consequent failure. Further, the voltage across the windings is reduced resulting in reduced flux in the iron. This will reduce the torque of the motor

(b) solution
Given
R=10Ω
L=0.02, Xl = 2πfL = 2 x π x 50 x 0.02 = 6.283 Ω
Vl = 500 V
F = 50 Hz

To find
Total power in Star, Delta
Phase current in Star, Delta

Solution
Case 1 Star
Phase Impedance = $\sqrt{R^2 + (Xl^2)} = \sqrt{(10^2 + 6.283^2)} = 11.80\ \Omega$
Phase Voltage = $\frac{v_L}{\sqrt{3}}$
Phase Voltage = $\frac{500}{\sqrt{3}}$= 288.67 V

$I_{ph} = \frac{v_L}{\sqrt{3}} = \frac{500}{\sqrt{3} * 11.80}$ = 24.46 Amps

I_{ph} = I line in Star Connection.

Cos $\phi = \frac{R}{Z} = \frac{10}{11.80} = 0.84$

Power
P = 3 x V_{ph} x I_{ph} cos ϕ
P = 3 x 288.6 x 24.45 x 0.84
P = 17929.982 Watt
P = 17.92 kW

Case 2 Delta

$V_{ph} = V_L$ = 500V

Z_{ph} = 11.80 Ω

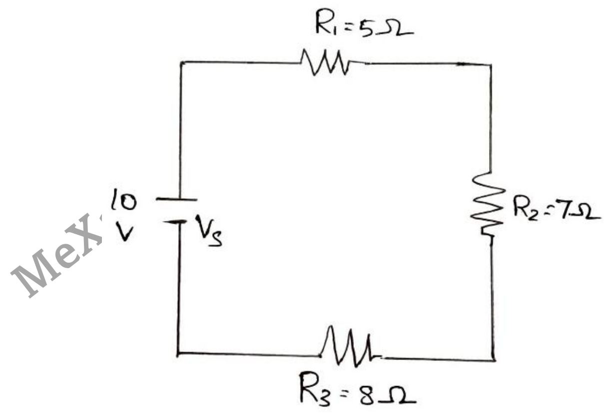
$I_{ph} = = \frac{Vph}{Z} = \frac{500}{11.80}$ = 42.37 Amp

I_L = √3 x I_{ph} = √3x 42.37 = 73.38 Amp

Power = 3 x V_{ph} x I_{ph} x cos ϕ
= 3 x 500 x 42.37 x 0.86
= 53.38 kW

The resistors 5Ω, 7Ω and 8Ω are connected in series across a voltage source of 10 V. Find the voltage drop across each resistor and also the total power consumed by the circuit. (16)

Oct 2023



Since the resistors are connected in series, the current through each resistor are equal.

Applying Kirchhoff's voltage law:

$$V_s - IR_1 - IR_2 - IR_3 = 0$$

Substituting the known values in the above equation, we have $10 - 5I - 7I - 8I = 0$

$$20I = 10$$

$I = \frac{10}{20} = 0.5A$

We can apply Ohm's law to find the voltage drop across each resistor.

$V_{R1} = R_1 \times I = 5\Omega \times 0.5A = 2.5V$

$V_{R2} = R_2 \times I = 7\Omega \times 0.5A = 3.5V$

$V_{R3} = R_3 \times I = 8\Omega \times 0.5A = 4V$

Let's find the power consumed by each resistor using the formula $P = R \times I^2$**.**

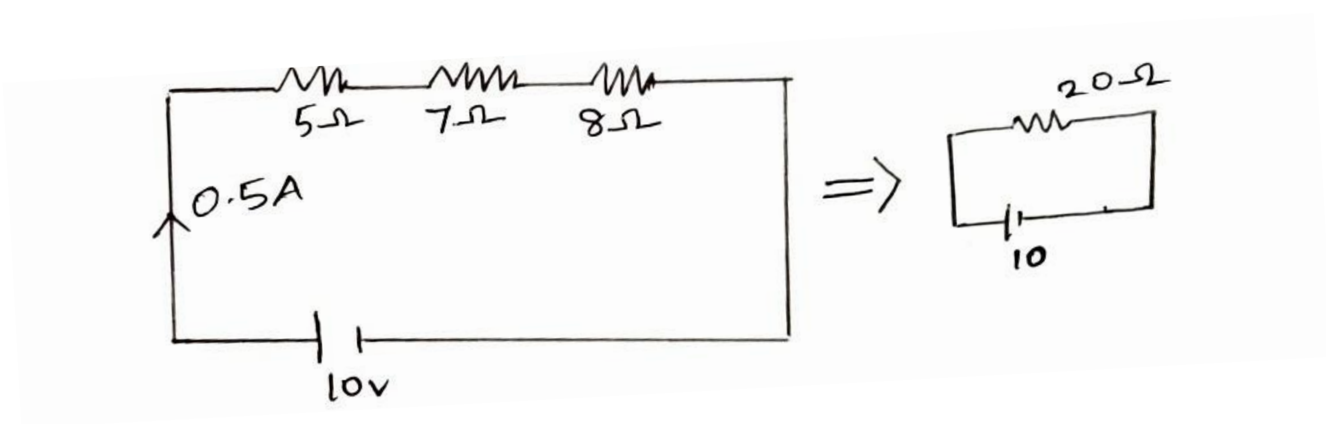
$P_{R1} = 5\Omega \times (0.5A)^2 = 1.25W$

$P_{R2} = 7\Omega \times (0.5A)^2 = 1.75W$

$P_{R3} = 8\Omega \times (0.5A)^2 = 2W$

Total power consumed by the circuit $= P_{R1} + P_{R2} + P_{R3} = 1.25W + 1.75W + 2W = 5W$

Given: $R_1 = 5\Omega$**,** $R_2 = 7\Omega$**,** $R_3 = 8\Omega$ **P.D = 10V**



The resistors are connected in series. $R_{eq} = R_1 + R_2 + R_3 = 5 + 7 + 8 = 20\Omega$

The current through the circuit is: $I = \frac{V}{R} = \frac{10}{20} = 0.5A$

Voltage drop across each resistor: $V_1 = I \times R_1 = 0.5 \times 5 = 2.5V$ $V_2 = I \times R_2 = 0.5 \times 7 = 3.5V$

$$V_3 = I \times R_3 = 0.5 \times 8 = 4V$$

Power consumed by the circuit: $P = VI = 10 \times 0.5 = 5W$ $P = I^2R = (0.5)^2 \times 20 = 5W$

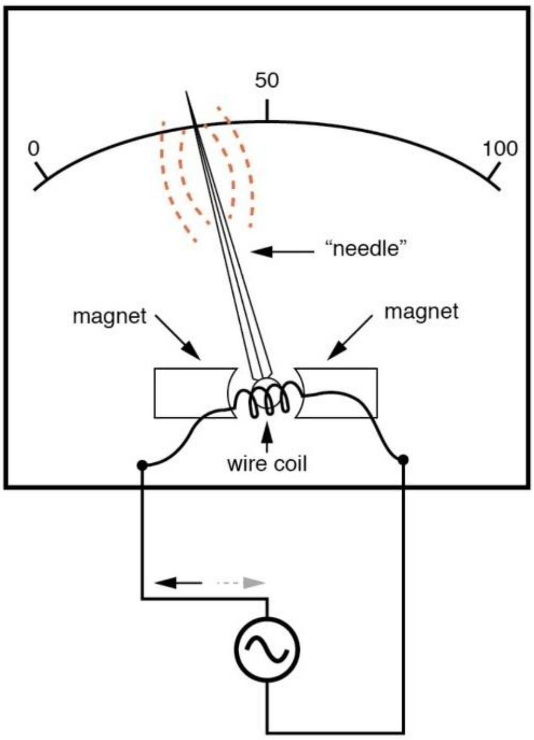
Write short notes on any two of the following:
(a) Voltmeter
(b) Multi meter
(c) Megger

Oct 2023

(a) Voltmeter:
A voltmeter, also known as a voltage meter, is an instrument that measures the voltage or potential difference between two points of an electronic or electrical circuit. Usually, the voltmeter is used for AC and DC circuits. It's operates on the basis of Ohm's law.

Voltmeters are made in a wide range of styles, some separately powered (e.g. by battery), and others powered by the measured voltage source itself. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a multimeter are standard test instruments used in electrical and electronics work.

(b) Multimeter



A multimeter is a versatile electronic measuring instrument that combines multiple functions into a single device. It can measure various electrical properties, including:
Voltage: Measures the electrical potential difference between two points.
Current: Measures the flow of electrical charge.
Resistance: Measures the opposition to the flow of electrical current.

Types of Multimeters:
Analog Multimeter: Uses a moving needle to indicate the measured value.
Digital Multimeter: Displays the measured value on a digital display.

voltmeter is connected in parallel with a circuit to measure the voltage drop across it. It must be constructed to drain very little electricity from the circuit so that it does not significantly alter the circuit under test. A big resistor is linked in series with the galvanometer to accomplish this. Its value is designed so that when the design voltage is applied across the meter, it deflects to its full-scale reading.

(c) Megger
Megger is used to measure insulation resistance and it is powered by a inbuilt DC generator or battery of a higher voltage range, it is called Megohmmeter. Megger works on the principle of electromagnetic attraction. When a primary coil that is carrying current is placed under the vicinity of a magnetic field it experiences a force. This kind of force generates a torque that is made to deflect the pointer of the device which gives some reading.

(a) Name the factors the resistance of a conductor depends on? (4)
(b) Describe three types of Resistive strain gauge. (6)
(c) Explain the working of a strain gauge used for pressure measurement. (6)

Oct 2023

(a) The resistance of a conductor depends on the following factors:
Length of the conductor: The longer the conductor, the greater the resistance.
Cross-sectional area of the conductor: The thicker the conductor, the lower the resistance.
Resistivity of the material: The higher the resistivity of the material, the greater the resistance.
Temperature: The higher the temperature, the greater the resistance.

(b) Three types of resistive strain gauge are:
Bonded strain gauge:
This is the most common type of strain gauge. It consists of a thin grid of metal foil bonded to a flexible backing material. The grid is bonded to the surface of the object to be measured, and the change in resistance of the grid is measured as the object is strained.
Unbonded strain gauge:
This type of strain gauge is not bonded to the surface of the object to be measured. It is instead placed in contact with the object, and the change in resistance of the gauge is measured as the object is strained.
Semiconductor strain gauge:
This type of strain gauge is made from a semiconductor material. The resistance of the gauge changes as the semiconductor is strained.

(c) A strain gauge used for pressure measurement works by measuring the change in resistance of a thin metal foil as it is strained. The foil is bonded to a diaphragm, which is a thin, flexible membrane. When pressure is applied to the diaphragm, it deflects, causing the foil to strain. The change in resistance of the foil is measured using a Wheatstone bridge. The Wheatstone bridge is a circuit that consists of four resistors. When the bridge is balanced, the voltage across the bridge is zero. When the resistance of the strain gauge changes, the bridge becomes unbalanced, and a voltage is produced across the bridge. The magnitude of the voltage is proportional to the change in resistance of the strain gauge. The output voltage from the Wheatstone bridge is amplified and then converted to a digital signal. The digital signal is then processed by a microprocessor, which calculates the pressure applied to the diaphragm.

(a) Sketch and describe moving iron and moving coil instruments for measuring current. (10)
(b) How the moving iron instrument can be used to measure voltage? (6)

Oct 2023

(a) Moving iron instrument:
The moving iron instrument depends on the induced magnetism operation. The magnetic attraction or the repulsion between two iron vanes, one fixed and the other movable, defects a pointer.

Moving iron instruments are classified as: Attraction type Repulsion type

- **Attraction type:**The moving iron instrument is used for either D.C. or A.C. measurements. This instrument consists of control weight, balance weight, coil winding, moving iron, pointer and air chamber.
- **Coil winding:** It is flat and has a narrow slot-like opening.
- **Moving iron:** It is eccentrically mounted over the spindle and has a thin disc of soft iron.
- **Pointer:** It is connected moving iron and used to show the readings directly.
- **Spring:** It is used to provide a controlling torque.
- **Air chamber:** It is used to provide a damping torque. This chamber is closed at one end and has a lightweight aluminium piston. This aluminium piston is connected to the moving system.
- **Operating principle:** When current is passing through the winding, a magnetic field is created around them. So, the moving iron is attracted from a weaker field (outside the coil) to a strong field (inside the coil). Due to this movement of moving iron, the pointer moves along the measuring scale and shows the reading directly.

Repulsion type:

- This instrument has two main parts. They are fixed vane and movable vane.
- Operating principle: When current is passing through the coil, both the vanes are magnetised with similar polarities on the same side. Due to the similar polarities of the vanes, a repulsion force is created in between them. This repulsion force is used to move the moving vane. While the movement of moving vane, the pointer also moves and shows the reading directly. Repulsion-type moving iron instruments are classified into two types. They are a)radial vane type and b) co-axial vane type

repulsive type

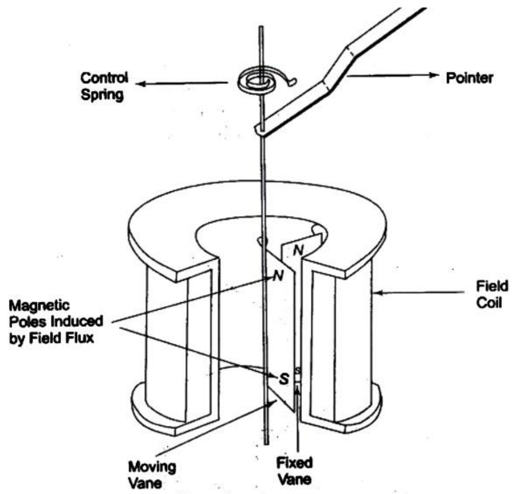


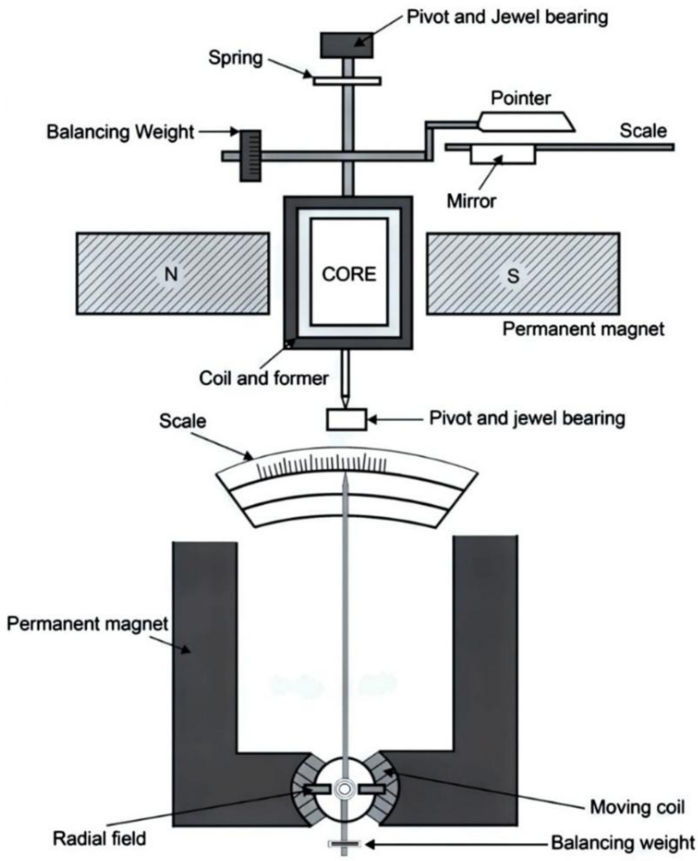
Fig. 2.8 Repulsion Type AC Meter (Radial Vane Type)

Moving Coil Instrument Principle: The moving coil (MC) instrument operates on the principle that a current-carrying conductor placed within a magnetic field experiences a mechanical force.

Types of moving coil instrument:

- **Permanent Magnet Moving Coil (PMMC):** Uses a permanent magnet to create the magnetic field.
- **Dynamometer Type:** Uses an electromagnet to create the magnetic field, suitable for both AC and DC measurements.

- **Construction:**
- **Permanent Magnet:** Provides a stable magnetic field.
- **Coil:** A lightweight coil wound on an aluminum frame, free to rotate within the magnetic field.



(b) A moving coil instrument, specifically a Permanent Magnet Moving Coil (PMMC) type, can be adapted to measure voltage by incorporating a high-value resistor in series with the moving coil. This arrangement is known as a voltmeter.

The PMMC instrument measures current, so to measure voltage, the voltage to be measured is converted to a proportional current through a known resistance. The current then passes through the moving coil, causing the pointer to deflect, and this deflection is calibrated to indicate the voltage.

Components:

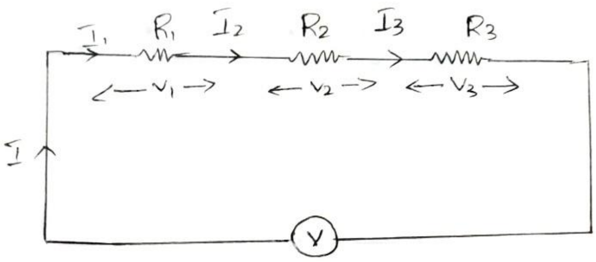
- **Moving Coil Galvanometer:** The basic instrument that measures current.
- **Series Resistor:** A high-value resistor connected in series with the moving coil.

- Series Resistor Selection Voltage Division Current Flow Calibration
- **Series Resistor Selection:** The resistor value is chosen such that the combination of the resistor and the moving coil allows the desired voltage range to be measured.
- **Voltage Division:** When a voltage (V) is applied across the series combination of the resistor (R) and the moving coil, the voltage drop across the resistor (VR) and the voltage drop across the coil (VC) add up to the applied voltage (V).
- **Current Flow:** The current (I) through the series circuit is given by Ohm's Law: (I = (V)/(R + RC), where (R) is the series resistor and (RC) is the resistance of the moving coil.
- **Calibration:** The scale of the PMMC instrument is calibrated in volts instead of amperes. The pointer deflection corresponds to the voltage applied across the series combination.

Derive the formula for Total resistance of a circuit containing 3 resistors in
(a)Series (8)
(b) Parallel (8)

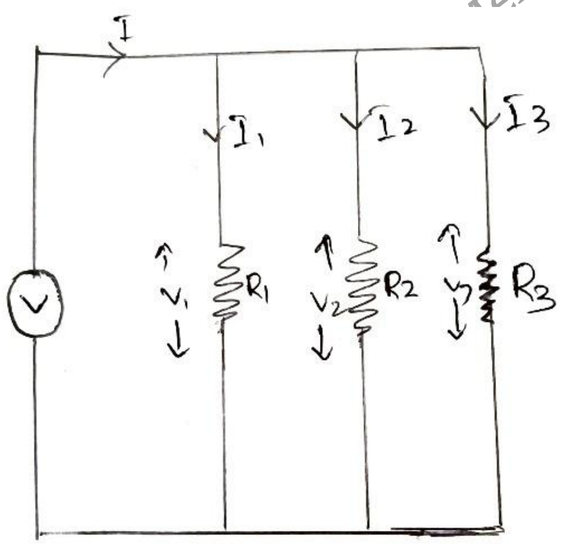
Jun 2023

a) Resistance in Series
Resistance are said to be connected in series if the current through each resistance is the same.



- $I = I_1 = I_2 = I_3$
- $V = V_1 + V_2 + V_3$
- $IR_{eq} = IR_1 + IR_2 + IR_3$
- $R_{eq} = R_1 + R_2 + R_3$ (Total Resistance)

b) Resistance in Parallel
Resistance are said to be connected in parallel if the potential across each resistance is the same.



- $V = V_1 = V_2 = V_3$

- $I = I_1 + I_2 + I_3$
- $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

(a) What is difference between EMF and PD of a battery. (6)
(b) Calculate the value of I1 in the following circuit. (10)

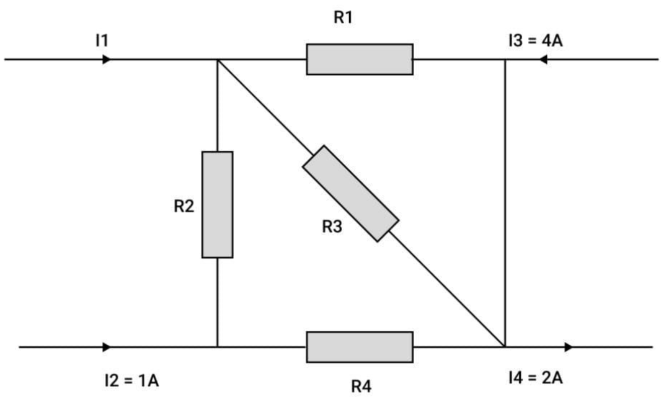
May 2023

(a) The electromotive force (EMF) of a battery is the maximum potential difference that can be produced by the battery. The potential difference (PD) of a battery is the actual potential difference that is measured across the battery terminals. The PD of a battery is always less than or equal to the EMF of the battery.

The EMF of a battery is determined by the chemical reactions that take place inside the battery. The PD of a battery is determined by the resistance of the battery and the current that is flowing through the battery.

The EMF of a battery is a constant, while the PD of a battery can vary depending on the load that is connected to the battery.

(b)



By Kirchoff's law:
$I_1 + I_2 + I_3 - I_4 = 0$
$I_1 + 1 + 4 - 2 = 0$
$I_1 = -3A$
Current flow in opposite to that indicated by arrow

(a) Describe the principle of variable-capacitance transducer.
(b) A coil of resistance 10 Ω and inductance 100mH is connected in series with two parallel capacitors each of value 100 μF across a 250 V, 50Hz supply. Determine (10)
(i) The circuit current
(ii) The total power factor
(iii) The power taken from the supply

Aug 2023

(a) Transducers based on the principle of changes in the capacitance are generally termed as capacitive transducers. These kinds of transducers are most common in linear displacement based applications. Other than displacement, many of the industrial variables such as pressure, level, moisture, etc. can be translated into an electrical signal by means of change in the capacitance.

PRINCIPLE OF A CAPACITIVE TRANSDUCER

The capacitive transducer is functioning similar to the working of a parallel plate capacitor. The capacitance is calculated as a function of area between two parallel plates, the distance between the plates and the dielectric medium in between the plates. It is expressed as:

C = $(A/\mathrm{d})\varepsilon o \varepsilon r$

Where,

A is the area of parallel plates

d is the distance between the plates

εo is the absolute permittivity of free space.

εr is the relative permittivity of free space.

The working principle of the capacitive transducer is based on the change in capacitance due to any of the change in area of the parallel plates, the distance between the plates or the permittivity of free space. Since the capacitance is a function of A, d and ε, i.e., C = f(A, d, ε), any variable which changes any one of the quantities, the capacitance of the parallel plate capacitor gets changed. Further, this change in capacitance can be further converted into the required electrical form.

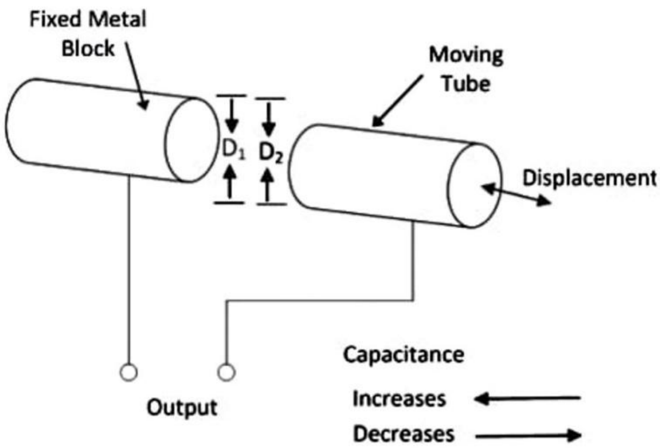
The capacitance is connected to voltage and charge by the expression:

Q = CV

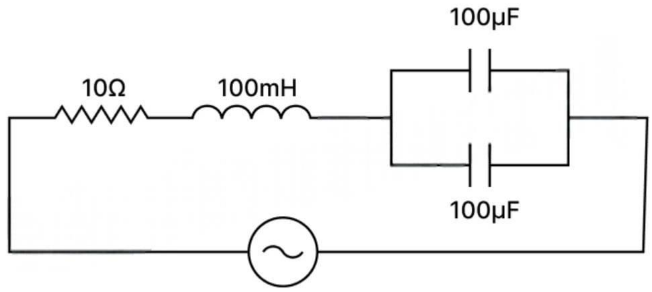
Where,

- Q is the charge in coulomb.
- C is the capacitance in farad.
- V is the voltage in Volts.

If the capacitance is affected by any of the above parameters, the output is transduced into an electrical form proportionally. In most of the cases, the changes are caused by means of physical variables such as pressure, displacement, force, thickness, etc. If there is change in dielectric medium between the parallel plates, there will be change in capacitance, and hence it can be used for the measurement of fluid level. Similarly, the change in dielectric medium due to change in the composition causes the change in absorption on moisture.



(b)



Given values

- **Resistance,** $R = 10\,\Omega$
- **Inductance,** $L = 100\text{ mH}$
- **Capacitance,** $C = 100\,\mu\text{F}$ **(with two in parallel, total** $C = 200\,\mu\text{F}$**)**
- **Voltage,** $V = 250\text{ V}$
- **Frequency,** $f = 50\text{ Hz}$

Capacitive Reactance X_C**):**

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 200 \times 10^{-6}} = 15.91\,\Omega$$

$$X_L = 2\pi f L = 2\pi \times 50 \times 100 \times 10^{-3} = 31.41\,\Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{10^2 + (31.41 - 15.91)^2} = \sqrt{100 + 240.28} = \sqrt{340.28} = 18.445\,\Omega$$

$$I = \frac{V}{Z} = \frac{250}{18.445} = 13.55\text{ A}$$

$$PF = \frac{R}{Z} = \frac{10}{18.445} = 0.542\text{ (lagging)}$$

Lagging because $X_l > X_c$

Power= I^2R

13.55^2 X 10= 1836.025W

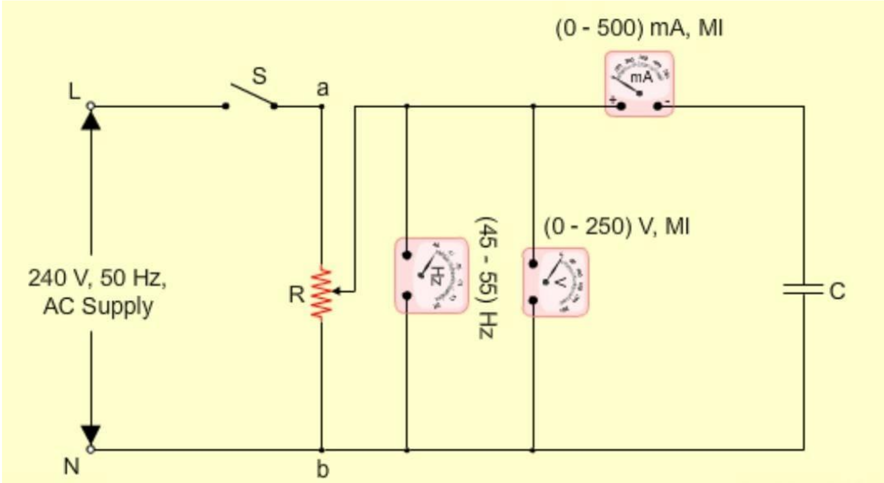
(a) Describe in detail the method used to measure the capacitance of a capacitor. (6)
(b) A circuit has a resistance of 3R and an inductance of 0.01 H. The voltage across its ends is 60V and the frequency is 50Hz. Calculate (10)
(i) The impedance
(ii) The power factor
(iii) The power absorbed

Mar 2025 **Dec 2024 - 1**

(a) Procedure

8. Connect the components as shown in the above image.
9. Switch ON the supply by closing the switch S and set the potential divider such that 50 V is applied across the capacitor.
10. Note down the readings of voltmeter and ammeter.
11. Calculate the impedance of the circuit using the formula Z= V/I. In this circuit, since there is no resistance connected, the impedance is equal to the capacitance. That is, Z=Xc
12. After calculating the capacitance Xc, record the result.
13. Calculate the capacitance Xc again using the formula Xc = 1/2pi fC and verify the results. (Use frequency meter to measure the frequency values)

14. Find the capacitance value for different values of capacitors by repeating steps 1 to 5.



(b) Given:

$R = 3\Omega, L = 0.01H, V = 60V, f = 50Hz, X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 0.01 = 3.14\Omega$

(i) $Z = \sqrt{R^2 + X_L^2} = \sqrt{3^2 + 3.14^2} = 4.34\Omega$

(ii) We know that $Cos\phi = \frac{R}{Z} = \frac{3}{4.34} = 0.69$

(iii) P = I^2R

I = $\frac{v}{z} = \frac{60}{4.34}$ =13.82A

$\therefore P = 13.82^2 \times 3$

$P = 572.9W$

---

a) State Ohm's Law. (3)

(b) State the limitations of Ohm's Law (3)

(c) 3 resisters of value 2 Ω, 4 Ω and 8 Ω are connected in series across a supply of 42 V. Find the current taken from supply and voltage drop across each resistor (10)

Jun 2023

(a) Ohm's law states that the current through a conductor is directly proportional to the voltage across it, and inversely proportional to the resistance of the conductor.

Mathematically, Ohm's law can be expressed as:

$$\mathbf{I = \frac{V}{R}}$$

where:

- is the current (in amperes)
- V- is the voltage (in volts)
- R- is the resistance (in ohms)

(b) The limitations of Ohm's law are:

- Ohm's law is only valid for a linear conductor. A linear conductor is a conductor whose resistance is constant.
- Ohm's law is only valid for a constant temperature. The resistance of a conductor changes with temperature.
- Ohm's law is only valid for a small range of voltages and currents. The resistance of a conductor can change significantly at high voltages and currents.

(c) Given:

$R_1 = 2\Omega$, $R_2 = 4\Omega$, $R_3 = 8\Omega$ $V = 42V$ $R_{eq} = R_1 + R_2 + R_3 = 2 + 4 + 8$ $R_{eq} = 14\Omega$

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

$I = \frac{42}{14}$

$I = 3A$

(ii) $V_1 = I \times R_1 = 3 \times 2 = 6V$

$V_2 = I \times R_2 = 3 \times 4 = 12V$

$V_3 = I \times R_3 = 3 \times 8 = 24V$

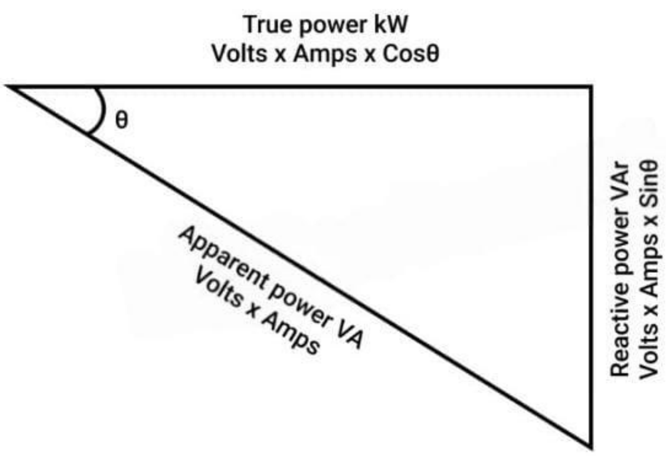
So, the voltage drop across the 2-ohm resistor is 6 volts, across the 4-ohm resistor is 12 volts, and across the 8-ohm resistor is 24 volts.

---

a) Explain power factor with a.c. Sine wave and phasor diagram. (6)
(b) A circuit has a resistance value of 25 Ω and an inductunce value of 0.3 H. If it is connected to a 230. 50Hz supply, find the circuit current, the power factor and the power dissipation. (10)

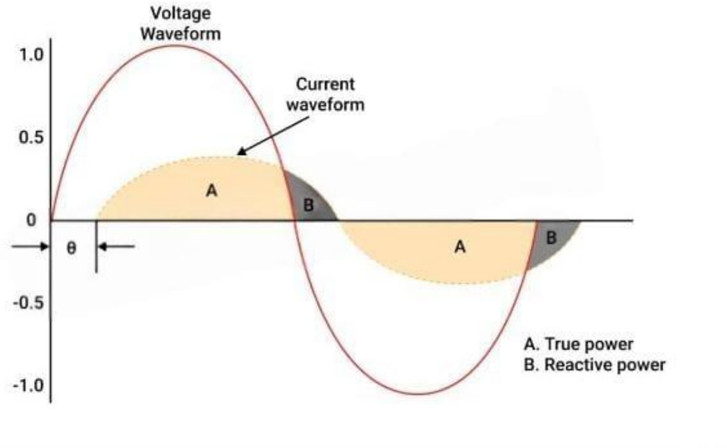
Sep 2024 - 1 | Mar 2024

(a) Power factor is a measure of the efficiency of an electrical system and is defined as the ratio of true power (real power) to apparent power. Mathematically, it is expressed as Power **Factor = True Power / Apparent Power**. The power factor is a dimensionless quantity and is often represented as a value between 0 and 1 or as a percentage. A typical power factor for ship systems is 0.8 lagging, indicating that the current waveform lags the voltage waveform by a certain angle (θ).



A low power factor on electrical systems results in increased reactive power, causing higher I2R heating, reduced overall system efficiency, and elevated energy costs. The inefficient use of apparent power due to a low power factor leads to higher currents, increased resistive heating in components, and diminished capacity for useful work, ultimately impacting the system's performance and contributing to higher operational expenses.

From the graph you can see that it is only the part of the current waveform that is in phase with the voltage that is actually able to do any work, however this current is causing I^2R heating and costing fuel to generate.



(b)

$X_L = \pi fL$

$= 2 * 3.14 * 50 * 0.3 = 94.2\,\Omega$

$Z = \sqrt{25^2 + 94.2^2} = 97.5\Omega$

$I = \frac{230}{97.5} = 2.36A$

Powerfactor $= \cos\phi = \frac{R}{Z} = \frac{25}{97.5} = 0.256$ (lagging)

$P = VI\cos\phi = 230 \times 2.36 \times 0.256 = 139W$

or

$P = I^2R = 2.36^2 \times 25 = 139W$

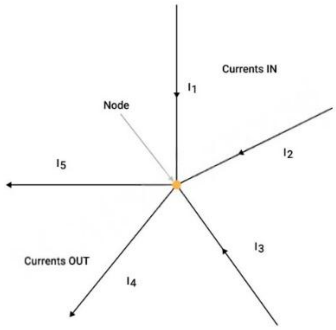
(a) What is Kirchoff's current Law. (6)
(b) Calculate the value of I2 in the circuit, when I1 = -6A (10)

May 2023 - 2

(a) 1. Kirchhoff's First Law or Kirchhoff's Current Law
According to Kirchhoff's Current Law,
The total current entering a junction or a node is equal to the charge leaving the node as no charge is lost.

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

The algebraic sum of every current entering and leaving the node has to be null. This property of Kirchhoff law is commonly called conservation of charge, wherein I(exit) + I(enter) = 0.



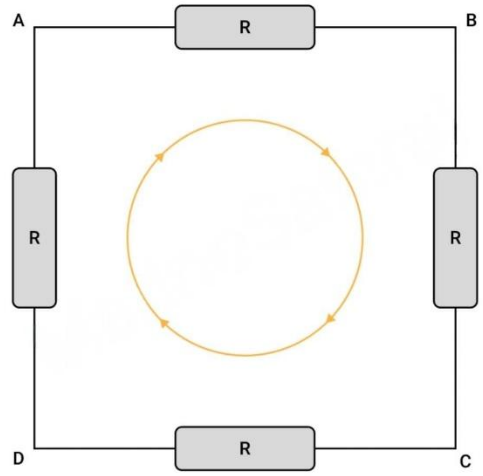
2. Kirchhoff's Second Law or Kirchhoff's Voltage Law

According to Kirchhoff's Voltage Law,

The voltage around a loop equals the sum of every voltage drop in the same loop for any closed network and equals zero.

$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$

The algebraic sum of every voltage in the loop has to be equal to zero and this property of Kirchhoff's law is called conservation of energy.



(b) Diagram for question

BY KIRCHOFF'S LAW

$I_1 + I_2 + I_3 = I_4$

$-6 + I_2 + 4 = 2$

$I_2 = 2 + 6 - 4$

$I_2 = 4A$

(a) How does a moving coil ammeter measure large current? (6)
(b) A moving coil instrument with a coil resistance of 1.98 Ω, produces full scale deflection from a current of 10 mA. Determine the value of shunt required to extend the range upto 10 A. (10)

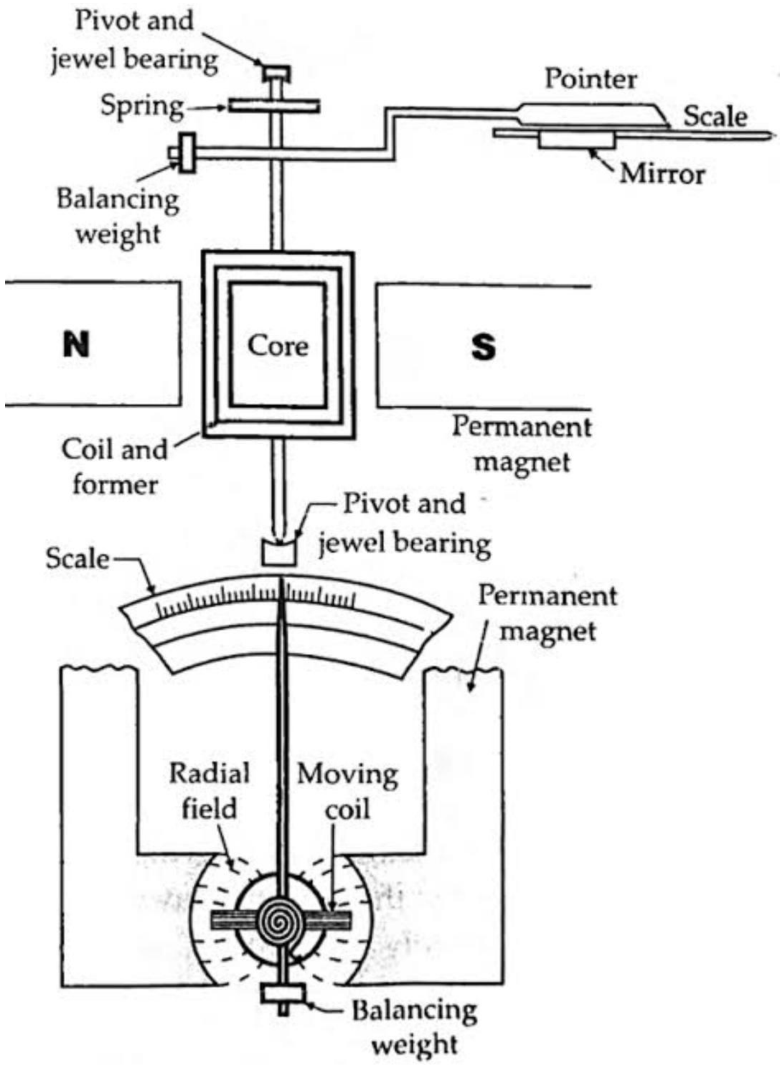
Sep 2024 - 1 | **Mar 2024**

(a) A moving coil ammeter measures large currents through the use of a shunt resistor.

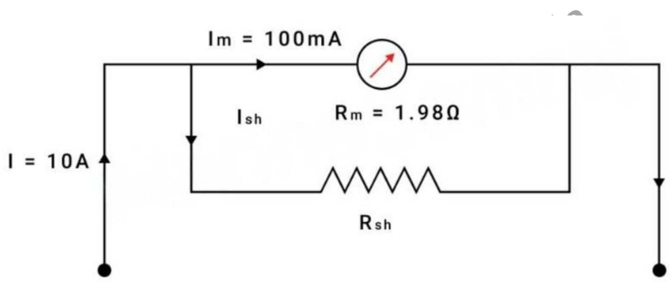
Basic Principle: A moving coil ammeter operates on the principle of a coil placed in a magnetic field. When current flows through the coil, it experiences a torque that causes it to move, deflecting a needle to indicate the current.

Shunt Resistor: To measure large currents, a shunt resistor, which is a low-resistance resistor, is connected in parallel with the moving coil. The shunt resistor allows the majority of the current to bypass the delicate moving coil.

Current Division: The current is divided between the shunt and the coil based on their resistances. Since the shunt resistor has a much lower resistance compared to the moving coil, most of the current flows through the shunt. As current flows through the circuit, the moving coil detects a small, proportional fraction of the total current (due to the shunt resistor). The needle deflection is proportional to this small current, but the scale is marked to show the total current, providing an accurate measurement.



(b)



Given:

I_m = 100mA = 0.1A, R_{sh} = 1.98 Ω,I = 10A

To find shunt resistance, R_s

$$R_s = \frac{I_m R_m}{I - I_m}$$

$$R_s = \frac{0.1 \times 1.98}{10 - 0.1}$$

$$R_s = \frac{0.198}{9.9}$$

$$R_s = 0.02\Omega$$

The shunt resistance, R_s, required is 0.02Ω.

(a) Name at least three types of temperature sensing devices for remote indication. (4)
(b) Explain the working of a Thermocouple type temperature sensor. (8)
(c) What are various materials used in a thermocouple? (4)

Sep 2024 - 1 | **Mar 2024**

(a) Three types of temperature sensing devices for remote indication are:

- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Infrared (IR) Sensors
- Bimetallic thermometer
- Fiber optic temperature sensor

(b) The working of a Thermocouple type temperature sensor:
A thermocouple consists of two different metal wires joined together at one end to form a measuring junction. When there is a temperature gradient between the measuring junction and the other end of the thermocouple (reference junction), it creates a voltage known as the Seebeck voltage or thermoelectric voltage.

The principle behind a thermocouple is based on the Seebeck effect. Different metals have different characteristics, and when two dissimilar metals are joined, they exhibit a voltage difference when subjected to a temperature gradient. This voltage difference is measured and used to determine the temperature.

The Seebeck voltage generated at the measuring junction is a function of the temperature difference between the measuring junction and the reference junction. By knowing the characteristics of the thermocouple and measuring the generated voltage, the temperature at the measuring junction can be determined using calibration tables or mathematical equations specific to the type of thermocouple being used.

1. In a thermocouple, two different metals are joined together at junctions with different temperatures.
2. A thermocouple causes an electric current to flow in the shown circuit when it is subjected to a change in temperature.
3. The amount of current produced depends on the temperature difference between the measuring and reference junctions.
4. Heating the measuring junction of the thermocouple produces a voltage greater than the voltage across the reference junction.
5. The difference between the two voltages is proportional to the temperature difference and can be measured with a voltmeter.

(c) Various materials used in a thermocouple:
Different combinations of metal alloys are used as the materials for thermocouples. The choice of materials depends on the temperature range and the specific application requirements. Some common types of thermocouple materials include:

Type K: Chromel (Nickel-Chromium) and Alumel (Nickel-Aluminum)
Type J: Iron and Constantan (Copper-Nickel)
Type T: Copper and Constantan

Type E: Chromel and Constantan
Type N: Nicrosil (Nickel-Chromium-Silicon) and Nisil (Nickel-Silicon)
Type R and Type S: Platinum alloys, such as Platinum-Rhodium and Platinum

---

(a) What are non-linear resistors? (4)
(b) Give three examples of Non-linear resistors with their characteristics. (8)
(c) Give examples of application of non-linear resistors. (4)

May 2023 - 2

(a) Non-linear resistors, also known as variable resistors or nonlinear elements, are electronic components whose resistance varies with changes in voltage, current, temperature, or other external factors. Unlike linear resistors, their resistance values are not constant but exhibit non-linear behavior.

(b) Three examples of non-linear resistors with their characteristics are:
Thermistors: Thermistors are temperature-sensitive resistors. Their resistance decreases exponentially as the temperature increases. They are available in two types: Negative Temperature Coefficient (NTC) thermistors, where resistance decreases with increasing temperature, and Positive Temperature Coefficient (PTC) thermistors, where resistance increases with increasing temperature.

Varistors: Varistors, also known as Voltage Dependent Resistors (VDRs), are used to protect electronic circuits from transient voltage surges. Their resistance decreases significantly when the applied voltage exceeds a certain threshold. They have a high resistance under normal operating conditions but exhibit a low resistance during voltage spikes.

Light-dependent resistors (LDRs): LDRs are photoconductive devices whose resistance changes with the intensity of light falling on them. They have high resistance in the dark and low resistance in the presence of light. LDRs are used in light sensors and automatic lighting control systems.

(c) Examples of applications of non-linear resistors:
Voltage regulators: Voltage regulators use non-linear resistors to maintain a constant output voltage, even when the input voltage or load current changes.

Current limiters: Current limiters use non-linear resistors to limit the current flowing through a circuit, even when the voltage or resistance of the load changes.

Oscillators: Oscillators use non-linear resistors to create a periodic output signal

---

(a) Name the various types of Capacitors. (6)
(b) A 500W, 100V bulb is to be connected across 250V, 50Hz mains. Find the value of the capacitor required to be connected in series. (10)

May 2023

(a) Various types of capacitor:
Ceramic Capacitors: Small and inexpensive capacitors made of ceramic materials. They have a wide range of capacitance values and are commonly used in various applications.

Electrolytic Capacitors: These capacitors use an electrolyte as one of their plates. They have high capacitance values and are used in applications requiring higher voltage and capacitance.

Film Capacitors: Constructed using a thin plastic film as the dielectric. They have good stability, high insulation resistance, and are used in AC and DC applications.

Tantalum Capacitors: Capacitors that use tantalum metal as the electrode. They have high capacitance per volume, excellent stability, and are commonly used in electronic devices.

Aluminum Capacitors: Also known as electrolytic capacitors, they use aluminum as the electrode. They have a high capacitance range and are commonly used in power supply applications.

Supercapacitors: Capacitors with extremely high capacitance values, capable of storing and releasing energy quickly. They are used in applications requiring rapid energy discharge.

Variable Capacitors: Capacitors with adjustable capacitance, used in tuning circuits for radios and other devices.

(b)

current taken by bulb = $\frac{500}{100} = 5A$

Impedance of lamp = $\frac{100}{5} = 20\Omega$

On 250V, impedance of the circuit is = $\frac{250}{5} = 50\Omega$

Impedance^2 = R^2 + X_C^2

Thus $X_c = \sqrt{50^2 - 20^2}$

$X_c = 45.8\Omega$

Again $X_c = \frac{1}{2\pi f C}$

$\therefore 45.8 = \frac{1}{2 \times 3.14 \times 50 \times C}$

$C = \frac{1}{2 \times 3.14 \times 50 \times 45.8}$

$C = 69.5\mu F$

(a) What are the routine maintenance carried out on lead acid batteries? (6)
(b) When a 10Ω resistor is connected across a battery, the current is measured to be 0.18A.
If similarly tested with a 25Ω resistor, the current is measured to be 0.08A. Find the e.m.f. of the battery and its internal resistance. Neglect the resistance of the ammeter used to measure the current. (10)

May 2023

a) Routine maintenance carried out on lead acid batteries:
Regular Inspection: Perform visual inspections of the battery to check for any signs of damage, corrosion, leaks, or loose connections. Look for bulging or swelling of the battery case, which could indicate internal issues.

Cleaning: Keep the battery and its terminals clean and free from dirt, debris, and corrosion. Ensure that the terminals are tight and secure.

Electrolyte Levels: For flooded lead-acid batteries, check the electrolyte levels regularly. If the battery is not maintenance-free, you may need to remove the cell caps and check the fluid levels. Add distilled water if necessary, but be careful not to overfill.

Charging: Lead-acid batteries should be kept fully charged to maintain their capacity and prolong their lifespan. Regularly charge the battery using a suitable charger that matches the battery's voltage and capacity. Avoid overcharging, as it can cause damage.

Equalization (for flooded batteries): Periodically perform an equalization charge to balance the individual cell voltages and ensure even charging. This process helps prevent stratification, where acid concentration varies within the battery.

Testing: Use a battery tester or a multimeter to check the battery's voltage and overall health. This can help identify any potential issues or determine if the battery needs replacement.

b)
Let E = EMF of battery
Let R_i = its internal resistance
Then $E = 0.18(10 + R_i)$ ----- ①
and $E = 0.08(25 + R_i)$ ----- ②
Equating ① and ②
$0.18(10 + R_i) = 0.08(25 + R_i)$
or
$1.8 + 0.18R_i = 2 + 0.08R_i$
$\therefore 2 - 1.8 = (0.18 - 0.08)R_i$
or
$0.2 = 0.1R_i$
or
$R_i = 2\Omega$
Substituting in E
$E = 0.18(10 + 2) = 0.18 \times 12 = 2.16V$

(a) What is self induction? (6)
(b) A coil of 800 turns is wound on a wooden former and a current of 5A is passed through it to produce a magnetic flux of 200 micro-webers. Calculate the average value of e.m.f. induced in the coil when the current is (i) switched off in 0.08 seconds (ii) reversed in 0.2 seconds.

May 2023

(a) Self-induction, or self-inductance, is a phenomenon in which a changing current in a coil of wire induces an electromotive force (EMF) in the same coil. This induced EMF opposes the change in current, creating a back electromotive force. It occurs due to the interaction between the magnetic field generated by the current and the coil itself. Self-inductance is quantified by the property called self-inductance, measured in henry (H). The effect of self-induction is most notable during sudden changes in current, causing a delay in the rise or fall of current in the coil. Self-induction is utilized in inductors and transformers, enabling energy storage, signal manipulation, and voltage/current transformation.

(b) (i)

$E_{av} = \frac{N\phi}{t}$

$= \frac{800 \times 200 \times 10^{-6}}{0.08}$

$= \frac{16 \times 10^{4} \times 10^{-6}}{8 \times 10^{-2}}$

$E_{av} = 2$ volts

(ii) $E_{av} = \frac{N(\phi_1 - \phi_2)}{t}$

Here, $\phi_2 = -\phi_1$,

but is in the reverse direction. Thus flux change is from ϕ_1 to zero and then up again to ϕ_1 or a total change of $(\phi_1 + \phi_2) = 2\phi_1$ webers.

Thus $E_{av} = \frac{800[200\times10^{-6}]-[-200\times10^{-6}}{0.2} = \frac{800 \times 400 \times 10^{-6}}{2\times10^{-1}}$

$= \frac{32 \times 10^{4} \times 10^{-6}}{2\times10^{-1}}$

= 1.6 volts

(a) Explain what is meant by phase difference between voltage and current values. (6)
(b) An inductance coil has a resistance of 19.5 Ω and when connected to a 220V, 50Hz supply, the current passing is 10A. Find the inductance of the coil. (10)

Jan 2025 - 1 | Jul 2024 | Feb 2024

(a) In an AC circuit, the phase difference between voltage and current refers to the angle between their vectors. This angle signifies whether the current is lagging or leading the voltage. The phasor diagram visually represents this phase difference, indicating whether one alternating quantity is ahead (leading) or behind (lagging) another. A leading quantity reaches its maximum or zero values earlier than another, while a lagging quantity reaches them later. The phasor representation helps visualize electrical parameters and understand the timing relationship between voltage and current waveforms in the circuit.

(b)

Impedance $Z = \frac{V}{I} = \frac{220}{10} = 22\Omega$

The resistance R is 19.5Ω

Therefore reactance $X = \sqrt{Z^2 - R^2}$

$= \sqrt{22^2 - 19.5^2} = 10.15\Omega$

Also $X = 2\pi f L$

$\therefore L = \frac{10.15}{2 \times 3.14 \times 50} = \frac{0.1015}{3.14}$

$= 0.032H$

(a) Describe the measures to be taken and the effect on various outputs when running a 60Hz system on a 50Hz supply (6)
(b) A series circuit consists of a capacitor of 50μF and a coil of inductance 1.5H and resistance of 300 ohms. Find the total impedance when working on a 50Hz supply. Find whether the current leads or lags the voltage (10)

Sep 2022

(a) The basic, RPM is in direct proportion to Hz. If you decrease the power supply frequency, the motor will slow down. On the contrary, if you increase the frequency, the motor will speed up. The RPM change is proportional to the Hz change. 60Hz motor will run 20% slower on 50Hz power supply This also results in 20% less power.

Basically, running the electric machine slower usually means it will be demanding less power. That's good, as the motor also decrease 20% of its power, and the cooling fan is slow down too. But the critical factor here is the V/Hz ratio. It goes up 20%! Not good. This means that during parts of every power line cycle the magnetic structure of the motor will probably be overloaded.

The only recourse here is to correct the V/Hz with the variable value that is easy to change – V the voltage. Lower the voltage with a transformer to correct the V/Hz ratio.

(b) Given,
L=1.5H
so, X_L=2πfL =2π×50×1.5= 471Ω

C = 50μF

So, $x_C = \frac{1}{2\pi fL} = \frac{1}{2\pi\times50\times50\times10^{-6}}$ =63.70 Ω

Total reactance, $X = X_L - X_c$ = 471 - 63.70 = 407.30 Ω

Impedance, $Z = \sqrt{R^2 + X^2}$ = $\sqrt{300^2 + 407.3^2}$ = 506 Ω

Since the inductive reactance is more, the circuit is inductive, so the current lags with the voltage.

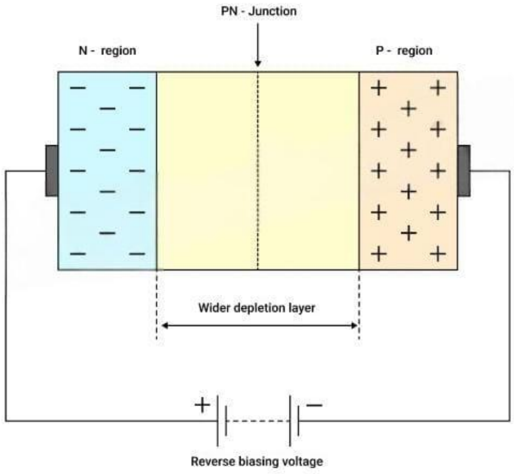
Draw and explain the shape of the characteristic curve of a p-n junction diode in forward and reverse bias modes (16)

Mar 2025 | **Dec 2024 - 1** | **Sep 2022** | **Aug 2022**

Reverse Biased PN Junction Diode
When a diode is connected in a Reverse Bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

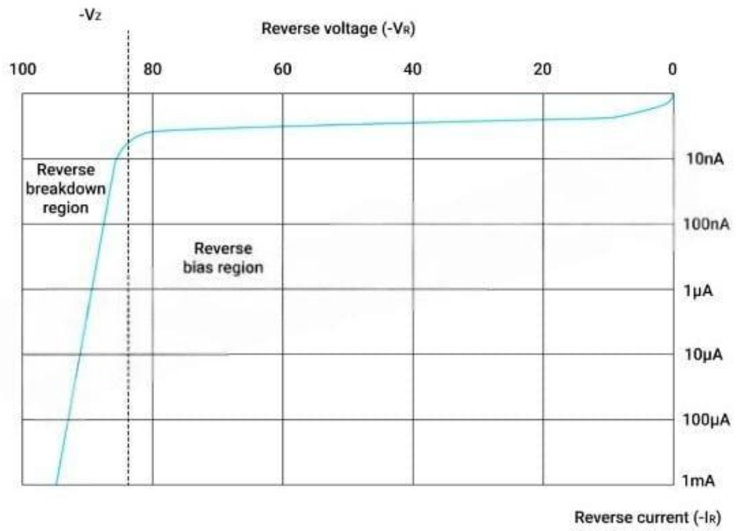
The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator and a high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material. The below sketch shows increase in the Depletion Layer due to Reverse Bias



This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small reverse leakage current does flow through the junction which can normally be measured in micro-amperes, (μA).

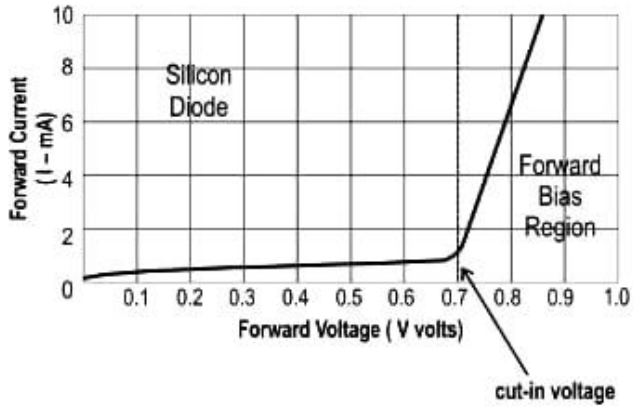
One final point, if the reverse bias voltage Vr applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.



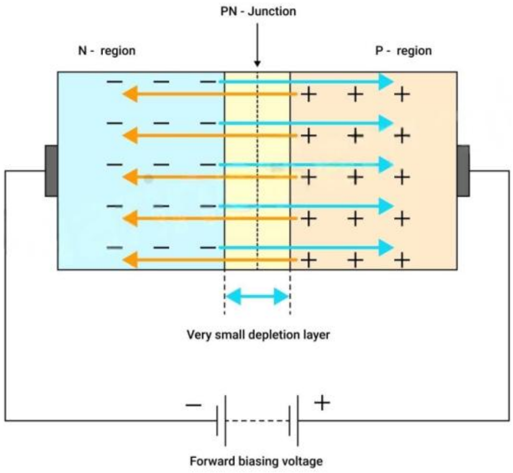
Forward Biased PN Junction Diode

When a diode is connected in a Forward Bias condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the "knee" on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.



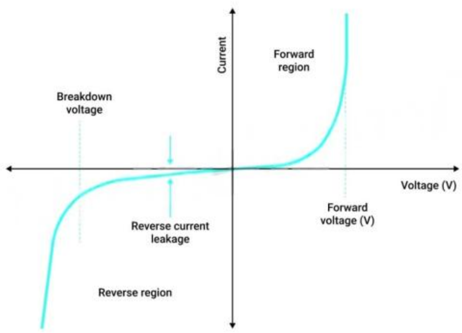
The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point.



This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes.

Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

Characteristic curve:



(a) Show graphically the effect of a.c. Current due to pure inductive load. (6)
(b) A 220V, 50Hz supply is applied to a choke-coil of negligible resistance and the circuit current is measured to be 2.5A. Find the inductance of the coil and the power dissipated. (10)

Feb 2023

(a)

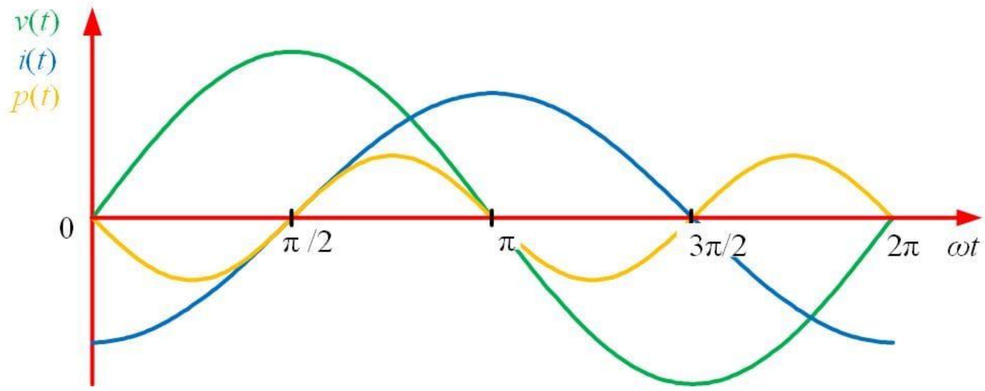


Figure 3: Current, voltage and power waveforms.

(b) Since $Z = \frac{V}{I}$

Then, $Z = \frac{220}{2.5} = 88\Omega$

Now $R = 0$

$\therefore X_L = Z$ or $X_L = 88\Omega$

So, $L = \frac{X_L}{2\pi F} = \frac{88}{2\times3.14\times50} = \frac{0.88}{3\cdot14}$

Or $L = 0.28H$

Also as $R = 0$, $\cos\phi = \frac{0}{88} = 0$ $\therefore = 220 \times 2.5 \times 0 = 0$

Alternatively since $P = I^2R$ then $P = 2.5^2 \times 0 = 0$ The circuit has choke-coil. So, the Circuit is purely Inductive. Hence Power is Zero.

(a) Explain mutual induction with the help of two insulated coils (6)
(b) A coil of 800 turns is wound on a wooden former and a current of 5A is passed through it to produce a magnetic flux of 200 micro-webers. A secondary coil of 2000 turns is wound on it. Find the emf induced in the secondary coil when the current is switched off in 0.08sec.

Jan 2023

(a) Mutual inductance is a fundamental principle of electromagnetism. When two coils are placed near each other, the magnetic field generated by a current in the first coil can induce a voltage in the second coil. This effect occurs due to the changing magnetic flux that links the two coils, in accordance with Faraday's law of electromagnetic induction.

Mutual inductance M is a measure of how effectively a change in current in one coil induces a voltage in another coil, and it is given by:

$V_2 = M\frac{dl_1}{dt}$

- V_2 is the **induced voltage in the secondary coil** (in volts),
- M is the **mutual inductance** between the two coils (in henries),
- $\frac{dl_1}{dt}$ is the **rate of change of current** in the primary coil (in amperes per second).

The mutual inductance depends on factors like the number of turns in each coil, their proximity, the core material, and how well the magnetic flux is linked between them. This principle is widely used in transformers, wireless charging systems, and many electrical devices.

(b) The induced EMF in the secondary coil is given by $E_{av} = -N\frac{\phi_2 - \phi_1}{t}$.

$$E_{av} = -2000\,\frac{0 - 200 \times 10^{-6}}{0.08}$$

$$E_{av} = -2000\,\frac{-200 \times 10^{-6}}{0.08}$$

$$E_{av} = \frac{2000 \times 200 \times 10^{-6}}{0.08}$$

$$E_{av} = \frac{0.4}{0.08}$$

$$E_{av} = 5$$

The induced voltage in the secondary coil is 5 V.

(a) Explain about non-linear resistors with some examples and illustration on how they differ from linear resistor. (6)
(b) A Diode half-wave rectifier supplies a resistive load of 100Ω from a 100V AC R.M.S. voltage source. The diode is a resistance of 5Ω during conduction state. (10)
Calculate
(i) The DC output voltage
(ii) DC average load current.

Nov 2022

(a)
An electrical circuit having a linear component, such as a linear resistor (or inductor, capacitor), as its component is called a linear circuit. A linear circuit is an electric circuit in which the output voltage and current of a linear circuit are linear functions of its input voltage and current.
Non-linear circuits having non-linear resistors, connected individually or in series or parallel combinations, change with time or with the level of voltage or current in the circuit
Linear circuits obey superposition theorem. They are governed by linear differential equations. They can be analyzed with Fourier Analysis and Laplace Transform and with scientific calculators.
Non-linear circuits do not normally have closed form solutions. Non-linear circuits can be analyzed using approximate numerical methods.
The behavior of resistors in linear circuit can be specified by a single number or a straight line on a graph.

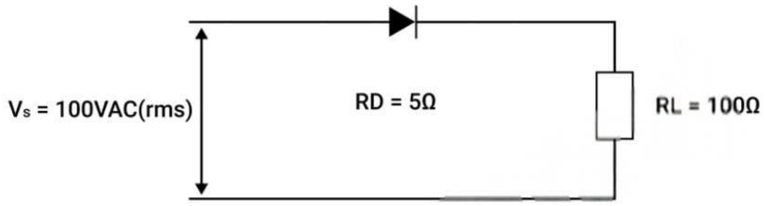
The behavior of non-linear resistors is specified by its detailed transfer function, given by a curved line on a graph.
Linear resistors obey Ohm's Law. The current through the linear resistor is inversely proportional to its resistance value, provided the temperature is constant. Its V-I curves are straight lines.
There are some elements which do not obey Ohm‟s Law. Their V- I curves are not straight lines i.e., the V-I curves are non-linear. Such resistors are called nonlinear elements.
Filaments of incandescent lamps are typical examples of non-linear elements. Diodes, thermistors and varistors also have non-linear V-I curves.

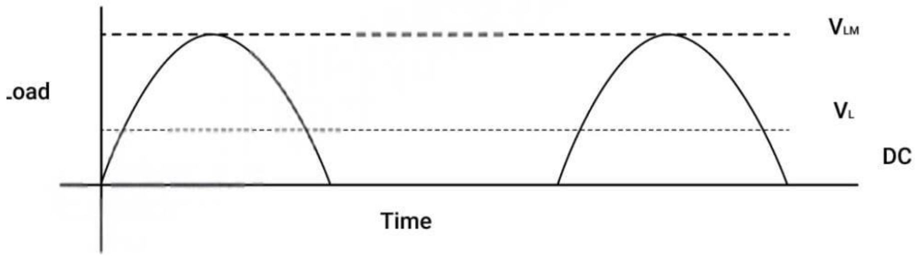
(b) Given,

V_{RMS} = 100V AC

$R_D = 5\Omega$

$R_l = 1000\Omega$





(i) The DC output voltage:

$V_{rms} = \frac{V_m}{\sqrt{2}}$

$V_m = V_{RMS} \times \sqrt{2} = 100 \times 1.4142 = 141.4V$

$$V_{DC} = \frac{V_m}{\pi(R_L + R_D)} \times R_L = \frac{141.4 \times 100}{\pi(100+5)} \; V_{DC} = 42.87V$$

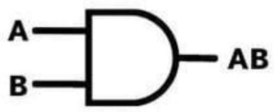
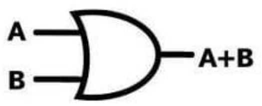
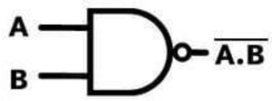
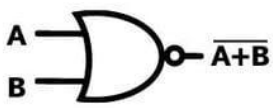
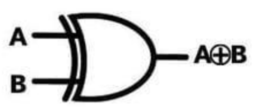
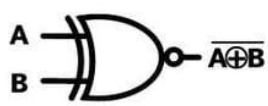
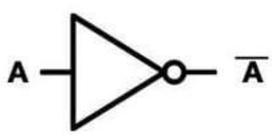
(ii) DC average load current:

$$I_{AV} = \frac{V_{DC}}{R_L} = \frac{42.87}{100} \; I_{AV} = 0.428amp$$

(a) Explain about the working of basic logic gates - AND, OR, NOT, NAND, NOR, XOR and XNOR (10)
(b) List out some applications of logic gates to the automated use of machinery onboard ships (6)

Nov 2022

(a) Logic Gate (AND, OR, XOR, NOT, NAND, NOR & XNOR)

Logic Gate	Symbol	Description	Boolean
AND		Output is at logic 1 when, and only when all its inputs are at logic 1, otherwise the output is at logic 0.	X = A-B
OR		Output is at logic 1 when one or more are at logic 1. If all inputs are at logic 0, output is at logic 0.	X = A+B
NAND		Output is at logic 0 when, and only when all its inputs are at logic 1, otherwise the output is at logic 1	X = $\overline{A.B}$
NOR		Output is at logic 0 when one or more of its inputs are at logic 1. If all the inputs are at logic 0, the output is at logic 1.	X = $\overline{A+B}$
XOR		Output is at logic 1 when one and Only one of its inputs is at logic 1. Otherwise is it logic 0.	X = A⊕B
XNOR		Output is at logic 0 when one and only one of its inputs is at logic 1. Otherwise it is logic 1. Similar to XOR but inverted.	X = $\overline{A \oplus B}$
NOT		Output is at logic 0 when its only input is at logic 1, and at logic 1 when its only input is at logic 0. That's why it is called and INVERTER	X = $\bar{A}$

(b)

OR Gate Applications: OR gates detect the occurrence of one or more events, making them useful in safety systems to trigger actions when parameters exceed safe limits.

AND Gate Functions: AND gates can act as Enable gates to allow data passage or Inhibit gates to block data, useful in frequency measurement.

Parity Generation: Ex-OR and Ex-NOR gates are used in parity generation and checking, crucial for error detection in data.

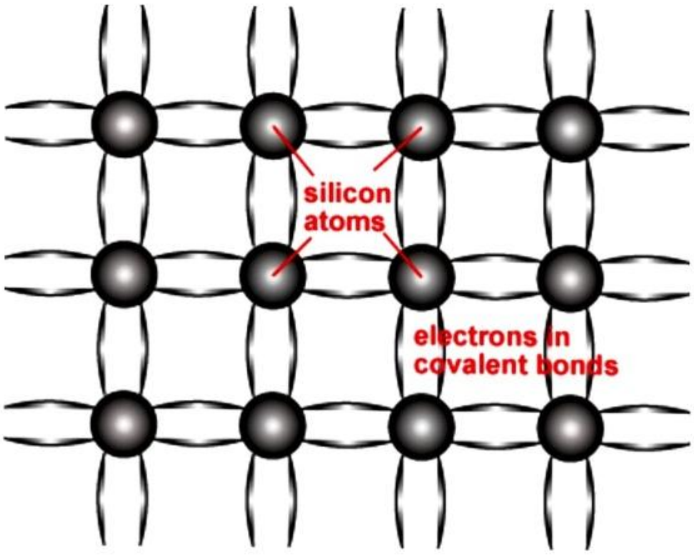
Inverter Uses: NOT gates, or inverters, are used to create square wave oscillators for generating clock signals due to their low power consumption and easy interfacing.

Explain the following:
(i) Atomic Structure of Semiconductors (4)
(ii) Covalent bonding in semiconductors (4)
(iii) PN Junction diode (4)
(iv) Diode Equation (4)

Nov 2022

(i) Semiconductors, such as Silicon (Si) are made up of individual atoms bonded together in a regular, periodic structure to form an arrangement whereby each atom is surrounded by 8 electrons. An individual atom consists of a nucleus made up of a core of protons (positively charged particles) and neutrons (particles having no charge) surrounded by electrons.

(ii) The electrons surrounding each atom in a semiconductor are part of a covalent bond. A covalent bond consists of two atoms "sharing" a pair of electrons. Each atom forms 4 covalent bonds with the 4 surrounding atoms. Therefore, between each atom and its 4 surrounding atoms, 8 electrons are being shared.

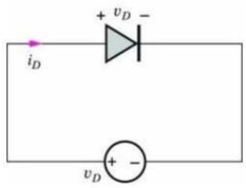


(iii) The PN junction diode consists of a p-region and n-region separated by a depletion region where charge is stored. The effect described in the previous tutorial is achieved without any external voltage being applied to the actual PN junction resulting in the junction being in a state of equilibrium.
However, if we were to make electrical connections at the ends of both the N-type and the P-type materials and then connect them to a battery source, an additional energy source now exists to overcome the potential barrier.

The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, better known as the PN Junction Diode.

(iv) Diode current equation

$$i_D = I_S\left[\exp\left(\frac{qv_D}{nkT}\right)-1\right] = I_S\left[\exp\left(\frac{v_D}{nV_T}\right)-1\right]$$



where
I_S = reverse saturation current (A)
v_D = voltage applied to diode (V)
q = electronic charge (1.60 x 10-19 C)
k = Boltzmann's constant (1.38 x 10^{-23} J/K)
T = absolute temperature
n = nonideality factor (dimensionless)
V_T = kT/q = thermal voltage (V) (25 mV at room temp.)

I_S is typically between 10^{-18} and 10^{-9} A, and is strongly temperature dependent due to its dependence on n_i^2. The nonideality factor is typically close to 1, but approaches 2 for devices with high current densities. It is assumed to be 1 if the value of "n"

Discuss the suitability and limitations of the following insulating materials for use on board ships and state suitable application in each case. Particular reference should be made to the influence of environment, and its effect, on deterioration in service:
(a) Pure rubber (3)
(b) Paper (3)
(c) Mica (3)
(d) Asbestos (3)
(e) Porcelain (2)
(f) Ebonite (2)

Oct 2022

(a) Pure rubber: Pure rubber is a good insulator, but it is not very resistant to heat or chemicals. It is also not very strong, so it is not suitable for use in applications where it will be exposed to a lot of stress. Pure rubber is suitable for use in applications where it will be exposed to a moderate amount of heat and chemicals, such as in electrical insulation.

(b) Paper: Paper is a good insulator, but it is not very resistant to heat or moisture. It is also not very strong, so it is not suitable for use in applications where it will be exposed to a lot of stress. Paper is suitable for use in applications where it will be exposed to a moderate amount of heat and moisture, such as in electrical insulation.

(c) Mica is a good insulating material for use on board ships because it has excellent electrical insulation properties and is resistant to temperature fluctuations. However, it is brittle and can be prone to cracking or breaking when subjected to mechanical stress. It is best suited for applications where it is not subjected to mechanical stress, or where it can be protected from such stress. eg: Fireproof cables for emergency lightings.

(d) Asbestos is a good insulating material for use on board ships because it has excellent electrical insulation properties and is resistant to temperature fluctuations. However, it is a known carcinogen and should not be used in any application where it may be inhaled or ingested. eg: In olden days used in steam pipe laggings for heat-insulation.

(e) Porcelain is a good insulating material for use on board ships because it has excellent electrical insulation properties and is resistant to temperature fluctuations. However, it is brittle and can be prone to cracking or breaking when subjected to mechanical stress. It is best suited for applications where it is not subjected to mechanical stress, or where it can be protected from such stress. eg: Used in HV electrical cable insulations.

(f) Ebonite is a good insulating material for use on board ships because it has excellent electrical insulation properties and is resistant to temperature fluctuations. It is also resistant to moisture and chemical attack, making it suitable for use in marine environments. However, it is relatively brittle and can be prone to cracking or breaking when subjected to mechanical stress. It is best suited for applications where it is not subjected to mechanical stress, or where it can be protected from such stress. eg: Used for insulation coating inside pipelines.

With the aid of clearly drawn and labeled sketches, describe the construction and the principle of operation, of a galvanometer of permanent-magnet moving-coil type. Is such an instrument suitable for use in A.C. circuits? Give reasons for your answer. (16)

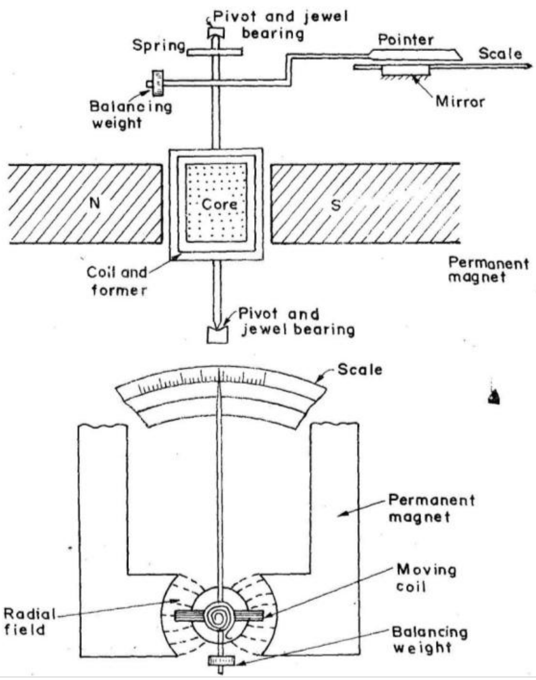
Sep 2022

A galvanometer is a type of ammeter. It is an instrument for detecting and measuring small electric current. Moving coil galvanometer: In a circuit, the current can be measured using a device called moving coil galvanometer. The principle using which the moving coil galvanometer works is that "a torque is experienced by a current carrying coil placed in a magnetic field".

Construction It has a rectangular coil of thin insulated copper wire. This coil has a large number of turns which is wound over a light frame made of metal. A strip made of fine phosphor bronze from a movable torsion head is used to suspend the coil between the pieces of poles of horse shoe magnet. The hair spring of the phosphor bronze (HS) with few turns connects the lower end of the coil. A binding screw is connected at the other end of the spring. Inside the coil, a soft iron cylinder is placed symmetrically. A radial magnetic field is produced by the hemispherical magnetic poles. Here, the magnetic field and the coil‟s plane are parallel to each other in all positions.

In order to measure the coil‟s deflection, suspension wire with a small plane mirror (m) is used together with a lamp and scale arrangement.

NO, galvanometer can‟t be used for AC circuits



Electrical Distribution

- **Notes:**

With reference to a three phase shipboard electrical distribution system:
(a) Enumerate the advantages of an insulated neutral system (4)
(b) Enumerate the disadvantages of an insulated neutral system (4)
(c) State why an Earthed neutral system may be earthed through a resistor (4)
(d) Compare the use of an insulated neutral system as opposed to the use of an Earthed neutral system with regard to the risk of electric shock from either system (4)

Apr 2024 | Jan 2025

(a) An insulated neutral system is one where the neutral is not directly connected to the earth (ground) or the ship's hull. The advantages of such a system are:

- It allows the system to continue operating even if one phase experiences a ground fault, ensuring operational continuity.
- In the event of a fault, insulation monitoring devices can detect the issue without causing an immediate shutdown of the system.
- Since the neutral is not earthed, there is less risk of creating short circuits through unintended earth faults.
- The system avoids sparking in hazardous areas because grounding faults do not immediately lead to dangerous short-circuit conditions.

(b) Despite its advantages, an insulated neutral system has certain disadvantages:

- While a single earth fault does not stop the system, a second fault on a different phase may lead to a severe short circuit.
- Continuous operation with a ground fault increases the voltage stress on the insulation of the system, leading to potential equipment damage.
- Monitoring and maintaining insulation integrity can be more complex and require specialised equipment.
- Since the system is not earthed, detecting fault current levels accurately can be challenging, making it harder to locate the fault.

(c) An earthed neutral system can be connected to the earth via a resistor to limit the fault current in the event of an earth fault. Reasons for this include:

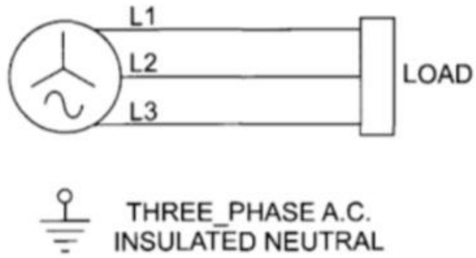
- The resistor limits the magnitude of the fault current, preventing damage to equipment by ensuring it does not rise to dangerous levels.
- By limiting fault currents it enables easier detection and clearing of faults without causing major disruptions to the system.
- Limiting fault current reduces the possibility of dangerous arc flashes, improving safety for personnel working on or near electrical systems.
- The resistor helps protect equipment by preventing excessive fault current, which could cause thermal damage or mechanical stress.

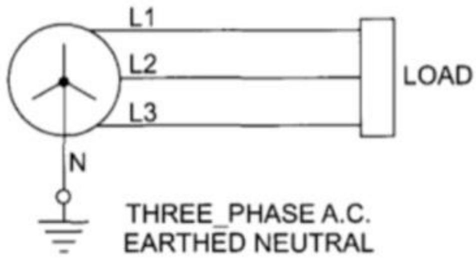
(d) Use of an insulated neutral system as opposed to the use of an Earthed neutral system concerning the risk of electric shock

Insulated Neutral System:

- In an insulated neutral system, there is typically less immediate risk of electric shock from a single fault as the system continues to operate without creating a path to earth. However, because the fault is undetected, subsequent faults could present severe risks, including high voltage exposure.
- Earthed Neutral System:
- In an earthed neutral system, a fault between a live conductor and the earth creates a low-resistance path, which allows a high current to flow. While this may trip protective devices, reducing shock risk, the fault is easily detectable. However, the risk of electric

shock is higher if a person is in contact with live parts, as the circuit will quickly complete through the earth.





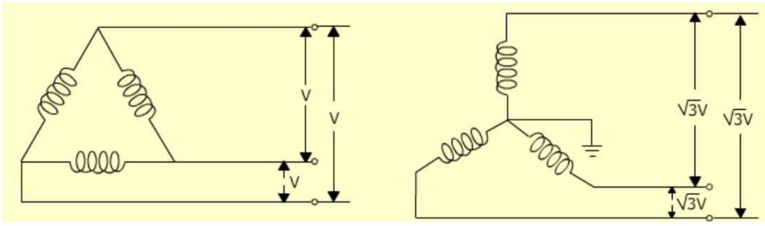
(a) What are the benefits of 3 Ph supply over a single phase supply system? (6)
(b) Explain 3-wire and 4-wire 3 Phase a.c. Distribution systems. (10)

Nov 2023

(a) Benefits of 3-phase supply over single phase

- **Power delivery:** Three-phase power is given by expression P=√3VIcos¢, therefore it can be seen 3 phase supplies √3 times more power than the single phase.
- **Distribution:** Star or delta connected 3 phase supply is easier to distribute requiring 3 wires without need of neutral, whereas 1 phase supply requires a neutral wire.
- **RMF Generation:** 3 phase supply naturally generates an RMF when connected to the stator of the motor, 1 phase requires additional components such as capacitors to achieve the same.
- **Generation:** A star-connected alternator needs to induce only V÷√3 emf in phase winding, this makes the windings require less copper.
- **Load Balance:** In 3 phase balanced supply the Negative sequence and zero sequence components are zero this reduces losses and improves machinery performance and transmission efficiency.
- **Flexibility:** 3 3-phase 4 4-wire system will allow us to run loads of different voltages without the need for a transformer.

(b) Three-phase, 3-wire distribution system: AC power distribution mainly uses a phases, 3-wire distribution system. The connection of the three phases may be either delta or star with a grounded star point. For a delta connection, V (voltage across a phase winding) is the voltage between two lines or phases. V3V is the voltage between two phases for a star connection. Three-phase, 4-wire distribution system: The star-connected phase windings are used in this system. The star point is the place from where the neutral wire or the fourth wire is taken. If V is denoted as the voltage of each winding, v3V is the line voltage or line-to-line voltage and V is the phase voltage or line-to-neutral voltage, India and many other countries follow this type of distribution system. The standard phase voltage in these countries is 230 volts. So, the line-to-line voltage or line voltage is /3 x 230 - 400 volts, The connection of single-phase motors and single-phase domestic or residential loads is made between neutral and any one of the phases. But in the case of three-phase loads (three-phase induction motor), the connection is made between the neutral and all three phases.



(a) How busbar inspection and maintenance is carried out. (10)
(b) What are safety precautions taken while doing maintenance on the busbar? (6)

Feb 2023 | **Mar 2025** | **Dec 2024-1**

(a) Any maintenance on bus bars should only be performed when the ship in Dry dock or Black out condition:

1. Open the door for main and emergency switchboards where inspection is to be performed
2. Carryout visual inspection of copper plate and nut bolts. Mark any missing or burn out areas
3. By hand or using a metal or plastic stick (where access for hand is not possible), tap the bus plates gently so as to make out for any loose connection. Ensure to wear electrical gloves even when bus bar is not live
4. The bus bars are mechanical supported inside the switchboard by means of insulators, which may be of rubber or ceramic materials (bad conductors). Check for any damages in the insulator part
5. By using only dedicate size spanner or pre adjusted torque wrench, tighten the nuts in the bus bar connection for main and emergency switch boards
6. Check the tightness of the wire connections, which is connected to the circuit breakers
7. Clean the bus bar and switchboard area with the help of vacuum cleaner
8. If you find any loose connection or spark, black-out the particular and adjacent bus bar before tightening the nut
9. If you find any metal piece or nut bolts missing or inside the panel, ensure to remove it as the same can cause short circuit or fire

The ship's electrical officer is required to inspect the bus bar periodically for record keeping and also as stated by the preventive maintenance system. This is done to avoid any type of accident from electrical faults on ships. When doing such inspection the following highest safety measures are to be taken with all required PPEs as the Bus bar is "LIVE":

1. Check the load in the running generator by means of KW meter provided in the main switchboard.
2. Open the bus bar access door provided at the backside of MSB or ESB.
3. Do the visual inspection and by the help of infrared temperature gun, measure the temperature of copper plates and bus bar connection. It should not be more than given limits depending upon the generator load. Example if the generator load is 50%, the room temperature is 28 deg c, the bus bar temperature must be within 50 deg c, if the temperature is too high then something is abnormal.

Once the inspection and maintenance is completed:

1. Close the bus bar access doors
2. Remove the lock out tag

3. Restore the main power supply by the generators
4. Inform the Chief Engineer and the in- charge of that particular machinery regarding the same
5. Reset the main power and check if there is any abnormal sound in main switch board and emergency switch board
6. Monitor the temperature of the bus bar area with laser temperature gun
7. Keep the emergency switchboard in the auto mode.

(b) Safety before doing bus bar maintenance:

1. Put the “lockout” tag on all generators and the emergency generator
2. Keep all the generator systems including the load-dependent start-stop system in manual mode
3. Ensure to wear rubber gloves even when the board is not in “Live” condition
4. Wear all required personal protective equipment (PPEs) when working on switchboard
5. If the ship is in a complete blackout situation, ensure that before cleaning the main and emergency switchboard, the area is well-lit by sufficient lights. In the dry dock same can be arranged from the shore workshop.

With the aid of a simple circuit diagram, explain the electrical distribution system for essential loads on board a cargo ship (16)

Feb 2022 | **Jan 2025-1** | **Jul 2024** | **Feb 2024**

- Main generators produce electricity for the ship during normal operation.
- Emergency generator produces electricity for the ship in the event of an emergency.
- The main bus bar is a central electrical distribution point that connects the main generators, emergency generators, and emergency switchboards. The main bus bar supplies 440V directly, 220V via transformers and 24V DC via transformers and rectifiers
- Emergency switchboard distributes electricity to the ship's emergency systems, such as navigation lights, communication equipment, and life support systems. The emergency generator is also connected to the emergency switchboard.
- Bus tiebreaker is a switch that can connect the main bus bar to the emergency switchboard. This allows the emergency generator to power the ship's emergency systems in the event of a failure of the main generators. It is the devices that prevent two electrical sources from being connected to the same circuit at the same time. This helps to prevent electrical accidents.

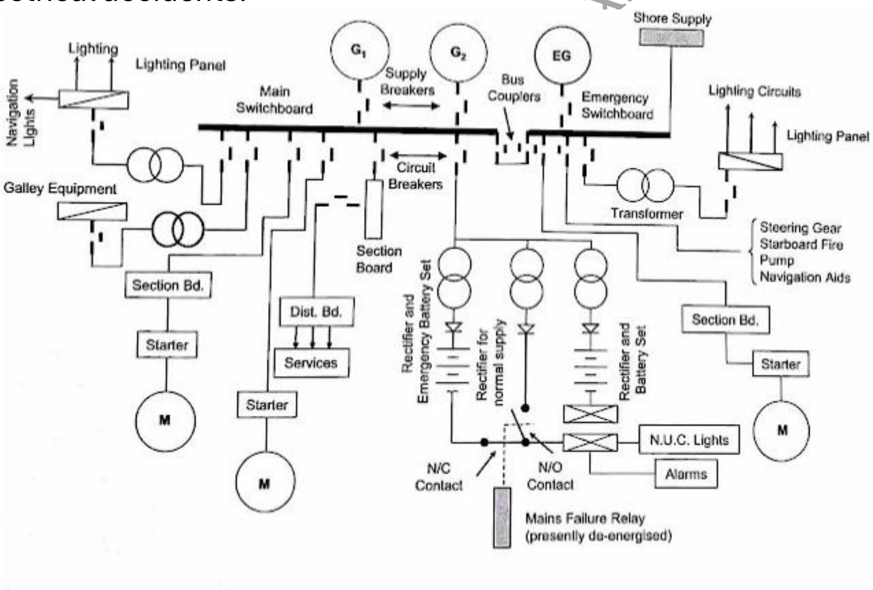


Figure 4.9 – A Ship's Typical Electrical Distribution System

- Shore supply is a connection that allows the ship to receive electricity from a shore-based power source. This is often used when the ship is docked. The general scheme of a ship’s electrical power system is common to nearly all ships. The below figure shows a typical electrical distribution system of a vessel.
- In normal operation, the main generators are connected to the main bus bar and the main bus bar is connected to the emergency switchboard. This allows the main generators to power the ship's entire electrical system.
- If there is a failure of the main generators, the bus tie breaker will automatically open, disconnecting the main bus bar from the emergency switchboard. The emergency generator will then start automatically and begin powering the ship's emergency systems.
- The bus tiebreaker interlock prevents the main generators and the emergency generator from being connected to the emergency switchboard at the same time. This helps to prevent electrical accidents.
- A shore supply can be used to power the ship's electrical system when the ship is docked. To do this, the shore supply is connected to the main bus bar. The main generators are then turned off and the bus tiebreaker is opened. This disconnects the main generators from the ship's electrical system.
- The ship's electrical power system is designed to provide a secure and reliable supply of electricity to the ship and its crew.

Electrical safety

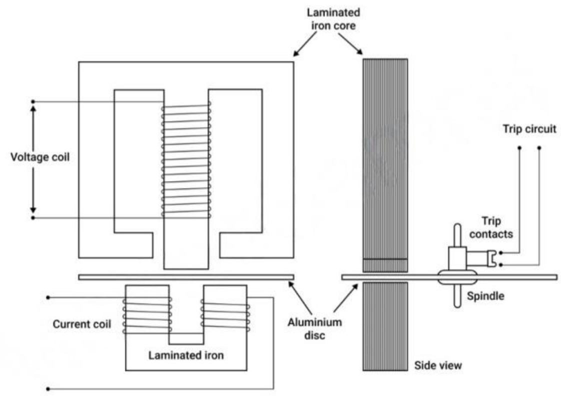
- **Notes:**

(a) What is the purpose of reverse power relay? (6)
(b) Explain with the aid of a simple sketch the working of a reverse power relay. (10)

Jan 2023

(a) The reverse power relay is a directional protective relay that prevents power from flowing in the reverse direction. The relay is used in installations where a generator runs in parallel with the utility or another generator so as to prevent power from the bus bar or another generator from flowing back to the active generator when its output fails.
The relay monitors the power from the generator and in case the generator output falls below a preset value, it quickly disconnects the generator coil to avoid power from flowing into the stator coil.
The generator output can fail due to problems with the prime mover, – turbine or engine that drives the generator, issues with speed controller, or different frequencies during synchronization.
When the prime mover fails, the generator stops producing power and may instead start drawing power from the other parallel sources and start motoring. The reverse power relay senses any reverse direction of power flow and disconnects the generator to avoid any possible damage.

(b)



The relay is made of a lightweight non-magnetic aluminum disc between two soft laminated iron core electromagnets, and fixed on a spindle running on low friction bearings. The upper electromagnet is wound with a voltage coil which is then supplied from one phase and an artificial neutral of the generator output. The other magnet has a current coil from supplied from a current transformer connected to the same phase as the voltage in the upper electromagnet.
The voltage coil has a high inductance, designed in a way that the current lags the voltage in the coil by about 90 degrees. This lag ensures that the magnetic field generated from the current in the upper coil lags the magnetic field produced by the current in the lower electromagnet. The two magnetic fields which are out of phase, produces eddy current in the aluminium disc, and this creates a torque that tries to rotate the disc.
Under normal condition when power is flowing as expected, the trip contacts of the relay are open, and the disc is against a stop. If a reverse power starts to flow, the disc rotates in the opposite direction, moves away from the stop and towards the trip contacts that activates the trip circuit.
Most of the reverse power relays have adjustable settings to allow the customer do the settings according to the installed equipment. The trip point is usually adjustable to between 2 and 20 percent of the input current while the time delay is adjustable from 0 to 20 seconds.

A 5 second time delay is often used to avoid tripping the circuit during synchronization. In most practical applications, the reverse power settings are between 8 to 15 percent for diesel engines and between 2 and 6 percent for turbine power movers.

a) Describe the normal criteria used for setting thermal protection relays and their advantage compared to magnetic types.
(b) Calculate the r.m.s. value, the form factor and peak factor of a periodic voltage having the following values for equal time intervals changing suddenly from one value to next: 0, 5, 10, 20, 50, 60, 50, 20, 10, 5, 0, -5, -10, V etc. What would be the r.m.s. value of a sine wave having the same peak value?

Dec 2022

(a) Thermal protection relays are designed for sustained overcurrent protection, typically set between 105-120% of the full load current with a time delay. They are not intended for momentary overcurrents.

The overcurrent setting depends on the following:

- The electrical system's maximum continuous load capacity determines the relay settings to ensure the system operates without tripping under normal conditions.
- The relay settings are influenced by the insulation class and its capacity to withstand elevated temperatures.
- The amount of power consumption and heat generated during normal operation is evaluated to set the relay accurately.
- The relay takes into account the cooling mechanism in place to ensure that heat dissipation during operation is factored into the thermal protection settings.

Advantages of Thermal relays over Magnetic relays:

- Thermal relays provide a time delay, preventing tripping from momentary overcurrents that might not cause actual damage. Magnetic relays respond much faster.
- Thermal relays operate based on the heat generated by an overcurrent, offering a more accurate reflection of the actual thermal stress on the system. Magnetic relays respond to the magnitude of the current, irrespective of heat generation.
- Thermal relays are more economical because they use bimetals instead of more expensive magnetic solenoid coils.
- Thermal relays are effective for sustained overcurrents, providing protection that is independent of other factors like the system voltage or magnetic field fluctuations.

(b)

RMS = Root Mean Square Hence, mean value of V^2:

$$V^2 = \frac{0^2 + 5^2 + 10^2 + 20^2 + 50^2 + 60^2 + 50^2 + 20^2 + 10^2 + 5^2}{10}$$

$$V^2 = \frac{0 + 25 + 100 + 400 + 2500 + 3600 + 2500 + 400 + 100 + 25}{10} \quad V^2 = \frac{9650}{10} = 965$$

$$\therefore RMS \text{ value} = \sqrt{965} = 31 \text{ V}$$

Average Value: $$\text{Average value} = \frac{0 + 5 + 10 + 20 + 50 + 60 + 50 + 20 + 10 + 5}{10}$$

$$\text{Average value} = \frac{230}{10} = 23 \text{ V}$$

Form Factor: $$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{31}{23} = 1.35$$

Peak Factor: $$\text{Peak factor} = \frac{\text{Maximum value}}{\text{RMS value}} = \frac{60}{31} = 1.94 \approx 2$$

RMS value of a sine wave with the same peak value:

$$RMS_{sine} = \frac{\text{Max value}}{\sqrt{2}} = \frac{60}{\sqrt{2}} = 42.42\ V \approx 42.2\ V$$

Explain why EACH of the following protective devices are fitted to a main electrical switchboard:
(a) Reverse power (4)
(b) Under voltage (4)
(c) Main circuit breaker overcurrent (4)
(d) Preferential trips (4

Nov 2022 **Jul 2022**

(a) Reverse power: This protective device is needed when alternators are connected for parallel operation. When the output power of the alternator to be protected decreases below a level, which is not sufficient to meet its own losses like friction, windage etc., the alternator will start drawing power from the other alternator and would start running as motor. Such running will affect the pistons of the engine and will cause damage. Sufficient protection is hence needed to prevent such running of the alternator using reverse power.

(b) Under voltage: An under voltage trip is fitted to the circuit breaker and is designed to prevent the breaker being engaged if the generator is not producing full voltage to prevent it being synchronised and causing a current surge. It also disengages the breaker if the voltage fails due to AVR failure or a voltage dip caused by a short circuit.

(c) Main circuit breaker overcurrent : An overcurrent protection relay is a protection device that safeguards the power system from a sudden rise in current that leads to detrimental faults. This relay can apply inverse-time characteristics so that the tripping time can be determined, based on the level of fault current, to protect the electrical elements from abnormal operating conditions. Thus the relay will be able to provide a shorter tripping time for currents of high magnitude when compared to the currents of the low magnitude.

(d) Preferential trip: a marine electrical distribution system is designed to disconnect non-essential circuits (e.g. breakers controlling air conditioning, galley power, blowers, refrigeration etc.) in the event of partial overload or partial failure of the supply, with the aim of preventing operation of the main breaker trip and loss of power on essential services.

(a) Describe how you would overhaul an electric motor that has been flooded with sea water (5)
(b) Explain how to check the insulation resistance of the motor, stating the minimum acceptable value (6)
(c) Principle of rotation of rotor and how to reverse the direction of a three-phase induction motor (5)

Jul 2022

(a)

- Put off the breaker
- Remove fuses
- Put tag 'Men at work'
- Remove terminal box cables and wind them in insulating tapes
- Dismantle the motor
- Clean all parts with FreshWater. Make sure all salts have been removed.

- If oil is present then use an oil degreaaser to clean
- Dry the with the help of a powerful lamp around 100w - 500w or low power heater.
- Keep proper ventilation to remove all moisture.
- Apply air during insulation varnish to the winding and leave it for some time to dry
- Check the bearings
- Check insulation resistance
- Assemble back the motor
- Run it idle for some time and then take it on load slowly
- Check noise/ vibration/ temperature/ smell and any other abnormality.

(b) Insulation resistance is carried out with the aid of an appropriately rated IR Tester (Megger). Before carrying out the job, appropriate safety paperwork such as Risk Assessment and Permit to Work is completed; this will ensure that the motor is isolated and it is safe for the test to be carried out. To prove the basic operation of the tester, short the two probes together and press the 'test' button. The display should read 0Ω. For an IR test on a three-phase machine, measure and log the phase-to-phase insulation resistance values. Three readings should be measured as U-V, V-W, and W-U. Measure and log the phase-to-earth insulation resistance values. Three readings should be measured as U-E, V-E and W-E.
The minimum acceptable IR value should be above 1 mega-ohm at 60°C

(c) The principle of rotation in a motor involves the interaction between magnetic fields generated by the stator (stationary part) and the rotor (rotating part). When electric current flows through the stator windings, it creates a magnetic field that interacts with the magnetic field of the rotor, causing it to rotate. To reverse the direction of rotation in a motor, you can do one of the following:

- Switching the polarity of the power supply: By reversing the connections to the stator windings, you can change the direction of the magnetic field, thus reversing the rotation direction of the motor.
- Using a reversible motor: Some motors are designed to be reversible, allowing you to change the direction of rotation by simply changing the direction of the current flow through the windings.
- Using external control devices: In some cases, external control devices such as motor controllers or inverters can be used to reverse the direction of rotation by changing the phase sequence or controlling the speed of the motor.
- Each method may be more suitable depending on the specific motor and application requirements.

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a) Explain about Single Phasing Protection for poly phase motor (6)
(b) A 440V, 10Kw, 0.8 p.f, 3phase load is supplied as shown. Calculate short circuit fault current at the load and at the main switch board (10)

Jul 2022

(a) Effects of Single Phasing on 3 phase Induction Motors

- Single phasing is a particular case of unbalance.
- Single phase is often the cause of damage to the motor and its effects are far more
- Serious than those of practical values of unbalanced supply voltages

Single phasing is the operation of a poly phase induction motor, when one of the supply lines to the motor is severed or dead. Single phasing is also referred as „Open Phasing‟ or „Phase Failure‟ and a peculiar case of unbalanced supply voltage.

Single phasing may be caused by the blowing off of a fuse somewhere in the system through an earth fault. Loose contacts or burning out of a contact in control equipment will also result in phase failure

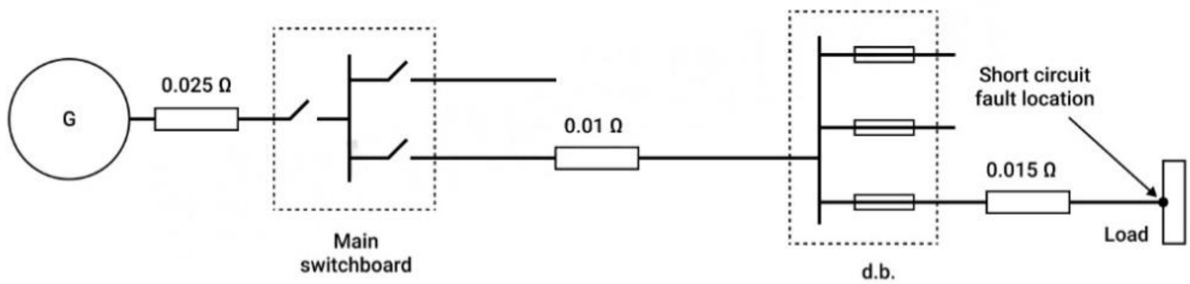
The usual cause of blow-outs in induction motors is single- phasing.

- A stationary motor will not start with one line broken.
- In fact, due to heavy standstill current, it is likely to burn-out quickly unless it is immediately disconnected.

Protection of poly phase from single phasing:

- Fuse
- Overcurrent relay
- Thermistor
- Current transformer

(b)



Suppose now a short-circuit fault occurs at the load terminals.

The total impedance is:

Z_F=0.025+0.01+0.015=0.05Ω

and the prospective short-circuit fault current is

IF=V/Z_F = 440V/0.05Ω

=8800A

For a short-circuit at the main switchboard 440V, the fault level is

440V/0.025Ω=17,600A

So, the prospective fault current level at MSB is 17600A

Electrical safety & Maintenance

- **Notes:**

With respect to personnel carrying out inspection and maintenance involving entry to boilers and other confined spaces:
(a) State the precautions needed for the operations of portable electrical tools and lighting, with respect to safety; (10)
(b) Outline the routine checks carried out on the equipments. (6)

Dec 2024

(a) When using portable electrical tools and lighting in confined spaces like boilers, you should follow the below safety precautions:

- Use insulated tools instead of non-insulated tools.
- Use intrinsically safe or explosion-proof tools and hand lamps.
- Wear safety glasses, face shields, hearing protection, and the correct type of safety gloves.
- Keep cords and hoses away from heat, oil, and sharp edges.
- Follow Safe working practices as per company SMS
- Have emergency procedures in place and rescuers who are ready, trained, and fit to perform their task.
- Conduct pre-work risk assessments.
- Ensure there is suitable ventilation.
- Provide training on the safe use of tools to all personnel.
- Use flame-proof lights if there is a likelihood of flammable gas, fume, or dust in the space.

(b)Routine Checks on Electrical Equipment Before Use
1. Visual Inspection: Check for physical damage to cables, plugs, and tool housing.Look for cracks, exposed wires, or signs of burning.
2. Check for Proper Insulation: Ensure there's no damage to the insulation on cables or wires.
3. Functionality Test: Briefly power up the tool outside the confined space to confirm it's working correctly.
4. Test Safety Devices: Test RCDs or GFCIs using the test button to confirm quick disconnection.
5. Check Labels and Certification: Ensure equipment is certified for use in confined spaces and labeled with relevant safety standards (e.g., IP ratings, EX ratings).
6.Earthing and Polarity Check: For earthed tools, confirm the earth connection is continuous and check for correct polarity in plugs.

(a) State FIVE essential electrical services that should be operable under fire conditions. (8)
(c) Explain how electric cables for the essential services in part (a) pass through bulkheads whilst maintaining gas tight and watertight integrity. (4)
(c) State the requirements for the cables which supply electrically driven emergency fire pumps. (4)

Mar 2024 **Sep 2024-1**

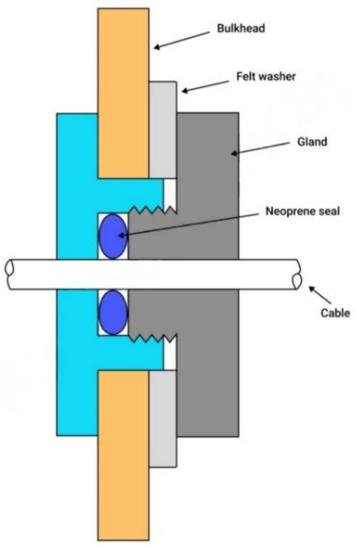
(a) Electrical services required to be operable under fire conditions are as follows:

- Control and power systems to power-operated fire doors and status indication for all fire doors
- Control and power systems to power-operated watertight doors and their status indication
- Emergency fire pump
- Emergency lighting

- Fire and general alarms
- Fire detection systems
- Fire-extinguishing systems and fire-extinguishing media release alarms
- Low location lighting
- Public address systems
- Remote emergency stop/shutdown arrangements for systems that may support the propagation of fire and/or explosion

(b) Scew Type gland packing

- The male and female halves of the gland packing are screwed together to form a watertight seal along the bulkhead.
- Neoprene seal and felt washer are compressed to make a good seal.
- This arrangement provides a passage for cables uninterrupted and without compromising the integrity of the bulkhead.



(c) Requirements for the cables that supply electrically driven emergency fire pumps:

- Ideally, the fire pump should be supplied by a dedicated circuit to ensure reliable power.
- The cables should not pass through the machinery spaces that contain the main fire pumps and their power sources.
- Cables should be made from materials specifically designed to resist fire.
- The cables should be routed clear of areas that are high temperatures, like galleys, laundries, and machinery spaces.
- Conductors must be sized to carry at least 125% of the full load current of the fire pump motor.
- Wiring should be installed within rigid metal conduit, intermediate metal conduit, or other approved conduit systems and meet appropriate fire-resistant standard.

(a) What is the function of insulation in an electric conductor? (3)
(b) What are the various classes of insulation? (8)
(c) What are the desired properties of insulating material? (5)

Jan 2024 | **Feb 2025** | **Nov 2024** | **June 2023**

(a) Primary function of insulators to prevents flow of electricity between conductors other objects and protect against electric shocks. Electrical insulators are used to hold conductors in position, separating them from one another and from surrounding structures. They form a barrier for energized parts of an electric circuit and confine the flow of current to wires or other conducting paths as desired.

(b)
1. Class Y Insulating Materials - 90°C: Cotton, silk, paper, and similar organic materials.
2. Class A Insulating Materials – 105°C: Impregnated paper, silk, cotton, polyimide and resins.
3. Class E Insulating Materials – 120°C: Enameled wire insulations on the base of molded polyvinyl epoxy resins and powder plastics.
4. Class B Insulating Materials – 130°C: Inorganic material (Mica, Fibre, Glass, Asbestos) impregnated with varnish and other compounds.
5. Class F Insulating Materials – 155°C: Mica, polyester epoxide varnished, and other varnish and in the high heat resistance.
6. Class H Insulating Materials – 180°C: Composite materials on mica, fiberglass, and other asbestos bases, impregnated in the silicon rubber except for other rubber compounds.
7. Class C Insulating Materials – 180°C: Mica, Ceramics, Glass, Teflon, and Quartz.

(c) The insulating material should have the following properties:
- High insulation resistance i.e. high resistivity.
- High dielectric strength
- Low permittivity
- High mechanical strength
- Non-hygroscopic i.e., it should not absorb moisture from air or soil
- Non-inflammable
- Unaffected by acids and alkalis
- The electrical and chemical properties of the material should not be affected by the temperature.

Explain the possible consequences if the following electrical current faults are not rectified (16)
(a) Earth current leakage
(b) Currents induced into the shafting of rotating machinery
(c) Overload currents
(d) Arcing at contact terminals
(e) Short circuit currents

Aug 2023

(a) Electrical currents can have serious consequences like fire due to electrical sparks caused by the leak and can ignite flammable materials. Damage to the equipment. Damage to the equipment leading to malfunctions and power outages, a shock to people if they come in contact with a leaking current, also it can accelerates the corrosion rate of electrical equipment and piping and can interfere with navigation and communication equipment, which can be critical for safety
(b) If the induced static current into the shafting of rotating machinery is not rectified or earthened, then it could damage the bearings due to electrical pitting on bearing races, accelerating wear and potentially leading to bearing failure. It can cause fire due to excessive heating, and the presence of an electric current can accelerate the corrosion rate of the shaft and other metallic components
(c) If the overload current is not rectified, it can cause a power outage due to tripping of the circuit or blow fuses which cuts the power to the affected circuit. It also can damage equipment and shorten their lifespan and can also cause fire due to overload

(d) Electrical arcing at contact terminals can have serious consequences, if not rectified promptly, it can cause fire hazards, damage to equipment and electrical overload.

Generator & circuit protection

- **Notes:**

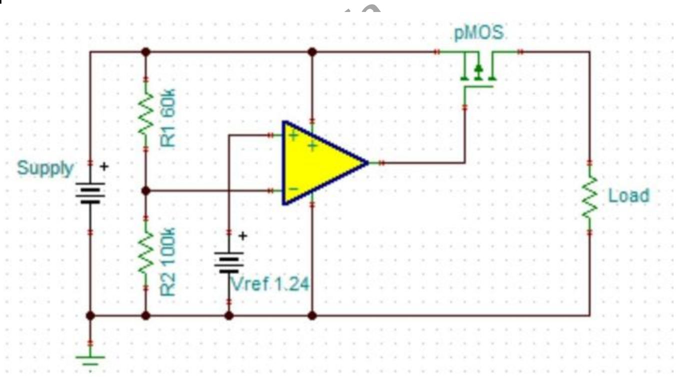
Describe with the aid of a diagram the operation of the following components of electrical equipment and explain the purpose of each: (16)
(a) Under voltage protection;
(b) Miniature circuit breaker
(c) Reverse power tripping

Dec 2024

(a) Under Voltage Protection Purpose:
Under voltage protection safeguards electrical equipment and systems by disconnecting the power supply when the voltage drops below a pre-set limit.
This prevents equipment malfunction, overheating, or damage caused by insufficient voltage.

Operation:

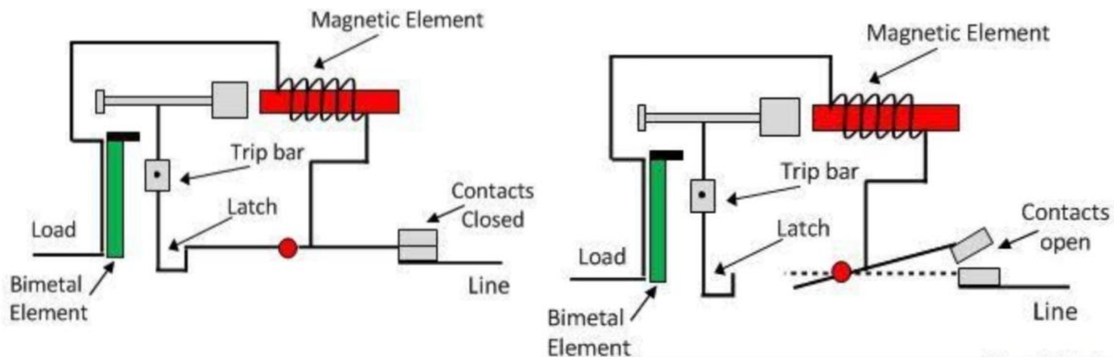
- A relay continuously monitors the voltage level in the system.
- When the voltage falls below the set threshold, the relay activates.
- The relay disconnects the load by opening a circuit breaker, preventing further operation under low voltage conditions.
- Once the voltage normalizes, the system requires manual or automatic resetting to resume operation



(b) Miniature Circuit Breaker (MCB)
An MCB protects electrical circuits from overcurrent and short circuits. It automatically interrupts the current flow to prevent overheating, fire, or damage to the connected equipment.

Operation:

- Overload Condition: A bimetallic strip inside the MCB heats up due to excessive current, bending and triggering the trip mechanism.
- Short Circuit Condition: A magnetic coil generates a strong magnetic field during a fault, instantly tripping the breaker.
- The circuit remains disconnected until the MCB is manually reset.



(c) Reverse Power Tripping

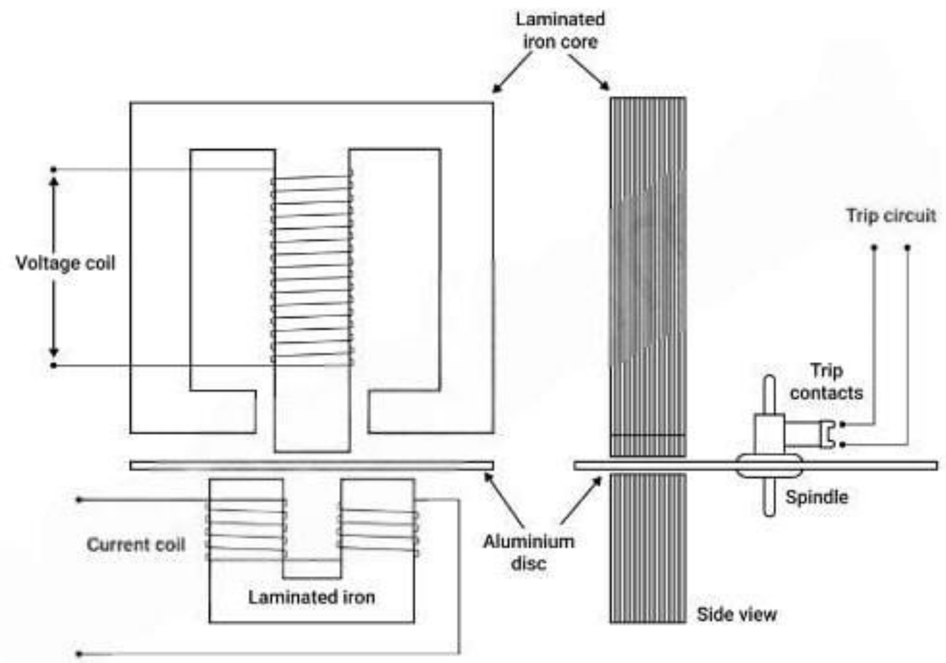
Reverse power tripping protects generators in parallel operation by disconnecting a generator that starts to consume power instead of supplying it. This condition can occur due to engine failure or load imbalance.

Operation:

- A reverse power relay monitors the direction of power flow.
- When power flow reverses (generator becomes a motor), the relay senses this condition.
- The relay sends a signal to the circuit breaker to trip, disconnecting the affected generator.
- This prevents damage to the generator and associated systems.

Working:

- Voltage coil and current coil both induce eddy currents in the aluminium disc, which produces torque, and the disc rotates
- Under normal forward power, the torque rotates the disc in one direction and this rotation is restricted by a stopper.
- If reverse power occurs, the direction of torque reverses, rotating the disc in the opposite direction, and moves away from the stopper, activating the trip.



(a) Describe with the aid of a simple sketch the arrangement of the three phase winding of an alternator showing the neutral point. (6)
(b) Explain why for most ships the neutral point is insulated. (5)
(c) Explain why in some installation the neutral point is Earthed. (5)

Oct 2022

(a) An alternator's three-phase winding consists of three sets of coils located in slots in the stator, surrounding the rotor's magnetic poles. Each phase winding is spaced 120° apart electrically, resulting in three alternating EMFs that are 120° out of phase with each other.
To form a star connection, one end of each phase winding is joined together to create a neutral point. The other ends of the windings are connected to outgoing conductors leading

to the bus bar. This neutral point can either be insulated or connected to a neutral line, depending on the system design.

(b) Why neutral point is insulation on most ships:
On ships, the neutral point is usually insulated to prevent the system from tripping in the event of a single earth fault. This is critical for maintaining power continuity to essential equipment like the steering gear, navigation systems, and emergency lighting.

By insulating the neutral, the system can tolerate one earth fault without immediate interruption, allowing time to locate and rectify the fault while ensuring continuous power supply. Only if a second earth fault occurs, creating a short circuit, will the protection system trip. This arrangement allows the ship to maintain essential operations.

(c) Why neutral point is earthed in some installations:
In systems where the neutral point is earthed, any earth fault in the system will immediately create a fault current, causing the circuit protection (e.g., breakers or fuses) to trip. This configuration is common in high-voltage systems to ensure that faults are quickly isolated, preventing damage to equipment and reducing the risk of electric shock or fire.

Earthed neutral systems also simplify fault detection and protection mechanisms, making them suitable for vessels with high-voltage installations where rapid fault isolation is a priority.

(a) State the necessary conditions required prior to the synchronizing of electrical alternators. (6)
(b) Describe the type of cumulative damage that may be caused when alternators are incorrectly Synchronized. (6)
(c) Explain how the damage referred to in (b) can be avoided/reduced. (4)

Jan 2025

(a) Necessary Conditions Required Before Synchronizing Alternators:
- **Voltage:** Voltage should be equal to or slightly higher than the busbar voltage. This is checked using a voltmeter.
- **Frequency:** The frequency should be equal to or slightly higher than the busbar frequency. In practice, the frequency of the incoming alternator is kept slightly higher so that when load is applied, it matches the busbar frequency. The synchroscope should move clockwise at a slow speed.
- **Phase Angle:** There should be no phase angle between the incoming and running generator. The synchroscope pointer should be at 12 o'clock, indicating a zero or acceptable phase angle difference between the incoming alternator and the busbar.

(b) Cumulative Damage from Incorrect Synchronization:
- **Mechanical Surge Torque:** A significant surge of torque is exerted on the rotor. This can cause damage to the rotor shaft (twisting, keyway damage), coupling (breakage), and stator windings (deformation). The stator core might also shift relative to its frame.
- **Electrical Surge:** A surge of current and power circulates through the system. This greatly strains the entire system, potentially leading to overheating and component failure. The sudden inrush of current could lead to circuit breakers tripping to protect the system

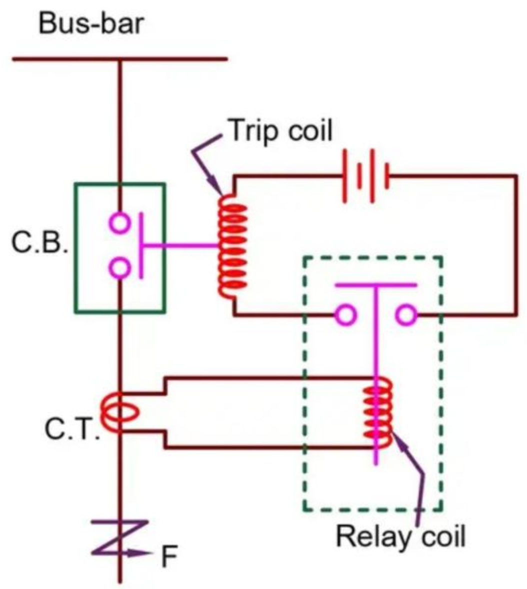
(c) Avoiding/Reducing Damage from Incorrect Synchronization:

Automatic Synchronization: Systems with automatic synchronization pre-program the correct voltage, frequency, and phase angle, greatly reducing the chances of errors.
Manual Synchronization with Synchroscope: With manual synchronisation, a synchroscope carefully compares the incoming alternator's frequency and phase angle to the busbar's. Adjust the incoming alternator's voltage to match the busbar. When the synchroscope pointer moves slowly clockwise and approaches the 12 o'clock position, close the alternator breaker to ensure proper synchronisation.

Overcurrent protection relays are built into main alternator breakers to safeguard the individual alternators and the distribution system against certain faults.
(a) Sketch a typical relay. (8)
(b) Describe the operation of the relay sketched in (a) (8)

Oct 2024

(a) Instantaneous Overcurrent relay Instantaneous Overcurrent relay



(b) The above-given picture is a representation of the working of an instantaneous overcurrent relay. As the name suggests, an instantaneous overcurrent relay trips off the circuit as soon as a current higher than the set threshold is sensed by it.

This relay has a relay coil that carries current from the current transformer which is connected to the main circuit or bus bar. The current transformer reduces the amount of current through the line which can be safely handled by the relay.

Under normal working conditions, the current through the CT which goes into the relay coil is such that the magnetic field produced by the coil isn't enough to attract the handle which goes through the relay coil. The handle is restrained by a control spring whose force is higher than the attraction force of the relay coil electromagnet.

As soon as the current in the main bus bar rises beyond the set threshold, the current transformer sends a higher current to the relay coil. This current causes the relay coil to energize highly enough to attract the handle. As it is clear from the image above, the handle causes the circuit of the trip coil to complete which is connected to a battery. The trip coil thus breaks the circuit and avoids any overcurrent situation.

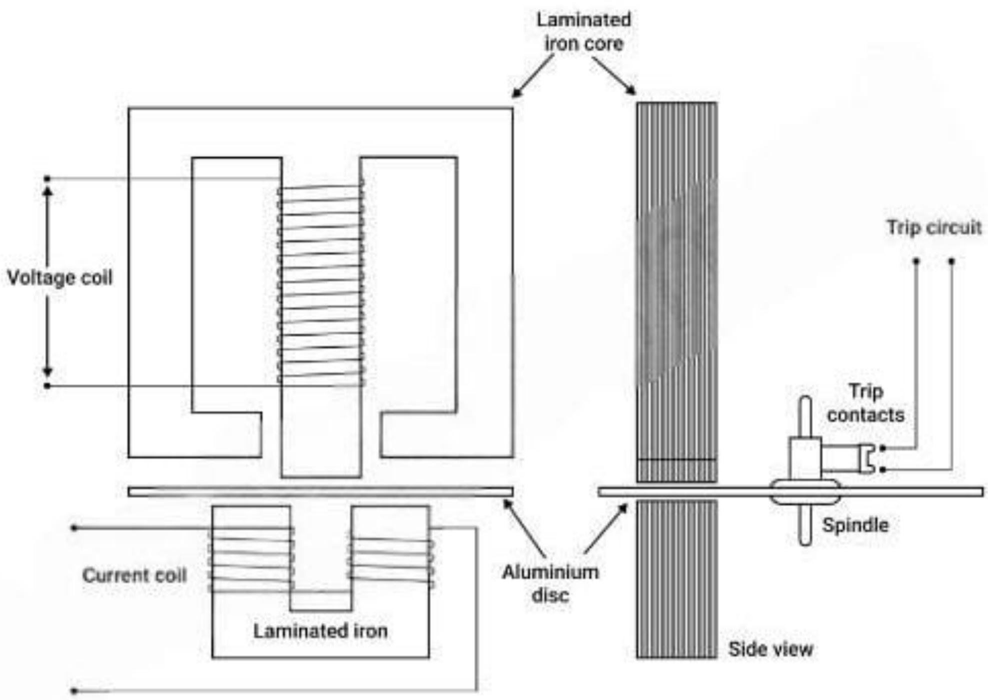
The threshold limit of current can be set by the Plug Setting Multiplier (PSM) of the relay which is a multiplier of the full-load current of the circuit. These relays work instantly without any intentional delay (except the physical limitations) and hence these are called instantaneous relays.

(a) Explain why it is necessary to have reverse power protection for alternators intended for parallel operation (6)
(b) (i) Sketch a reverse power trip (5)
(ii) Explain briefly the principle on which the operation of this power trip is based and how tripping is activated (5)

Apr 2025 - 1 | **Aug 2024** | **Jul 2024** | **Dec 2022** | **Oct 2020**

(a) Necessity of Reverse Power Protection for Alternators in Parallel Operation:
Reverse power protection is essential to safeguard alternators in parallel operation from the adverse effects of reverse power flow. When the prime mover of an alternator fails to provide sufficient torque, the alternator starts acting as a motor and draws power from the busbar—a condition known as the motoring effect. This situation can cause significant damage to the prime mover, as it may overspeed due to the additional energy supplied by the alternator. Such overspeed can lead to mechanical failures, including damaged shafts and broken turbine blades.
Furthermore, the reverse power effect imposes additional loads on other alternators in the system. These alternators may overload and trip due to excessive power demands, potentially leading to a blackout that compromises the safety and operational reliability of the vessel. The alternator subjected to reverse power may also lose its residual magnetism, impairing its ability to generate power effectively when restored.
To mitigate these risks, a reverse power relay is installed. This relay monitors the direction of power flow and trips the circuit breaker if reverse power exceeds a preset threshold (typically 10% of full load). The relay incorporates a time delay to prevent tripping due to transient conditions during synchronization or other short-term disturbances.

(b) (i) Sketch of reverse power trip:



(ii) Principle of operation and tripping activation
The reverse power relay operates on the principle of detecting the direction of power flow using the interaction of magnetic fields. The voltage coil generates a magnetic field lagging

the voltage by approximately 90°, while the current coil produces a magnetic field proportional to the load current. Both fields interact with the aluminum disc, inducing eddy currents that create a torque.

During normal power flow, the torque rotates the disc in one direction, keeping the trip contacts open. When power reverses, the direction of the torque changes, causing the disc to rotate in the opposite direction. This rotation closes the trip contacts, activating the breaker trip circuit and disconnecting the alternator.

A time delay (typically 5 seconds) prevents the breaker from tripping due to transient power surges during synchronization. Reverse power settings range from 2–6% for turbine-driven alternators and 8–15% for diesel-driven alternators, accounting for the differences in prime mover characteristics.

(a) How protection is provided for electrical short circuit. (4)
(b) Describe the construction and operation of HRC fuses. (8)
(c) What are the advantages of HRC fuses. (4)

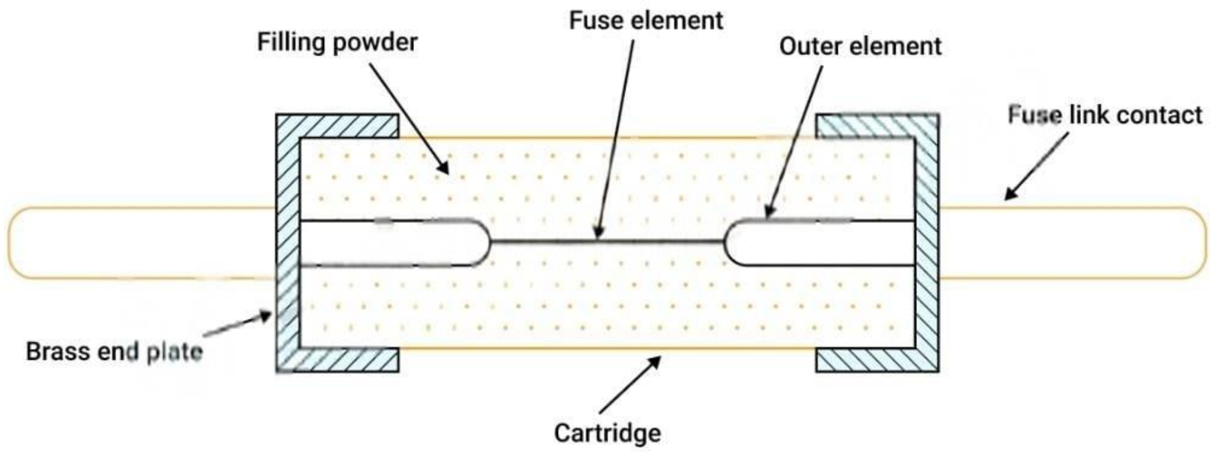
Feb 2025 | Nov 2024 | Jun 2024 | Jan 2023

(a) Three methods of short-circuit protection:
Fuses are one of the simplest forms of overcurrent protection. They operate on the principle of the heating effect of electric current. A fuse is made of a thin metallic wire with a low melting point and non-combustible material. When an excessive current flows through the circuit, it generates heat, causing the fuse to melt and thereby interrupting the circuit. This effectively protects the circuit components from damage. Fuses are commonly used as backup protection against short circuits in motors and for cable protection.

An electronic overcurrent relay uses advanced microprocessor-based technology combined with temperature sensors or current transformers to sense the current flowing through a circuit. These relays often employ a Positive Temperature Coefficient (PTC) thermistor to detect overheating conditions. When the temperature or current exceeds the set threshold, the relay trips and interrupts the circuit. This type of relay is always used in combination with a contactor and is connected in line with the motor, allowing the entire motor current to flow through it. Electronic overcurrent relays are particularly suited for applications where motors need to start and stop frequently, offering reliable and precise protection.

(b) Construction:
An HRC fuse (High Rupturing Capacity fuse) is designed to carry short-circuit current for a limited time and blow off when a fault occurs. The fuse body is made of high-strength materials like ceramic or glass. The enclosure is tightly sealed to prevent atmospheric interference. The ends of the fuse are capped with metal and connected to a fusible silver wire. The wire is surrounded by silica sand, which acts as an arc-quenching medium. HRC fuses are consistent, with faster breaking times for high fault currents and slower breaking times for lower fault currents.

Operational principle:
Under normal conditions, the current passing through the fuse does not produce enough heat to melt the element. During a fault, the element melts before the fault current reaches its peak, interrupting the circuit. For sustained overloads, eutectic material in the fuse dissolves over time, eventually breaking the element. In short-circuit conditions, the thinner sections of the fuse element melt quickly, stopping the current flow and protecting the circuit.



(c) The advantages of these fuses include the following:

- These are cheaper as compared with other types
- Easy to design and very simple
- Maintenance is not necessary
- High breaking capability
- The performance of this is consistent.
- Easy operation
- The inverse time characteristic is suitable for overload protection

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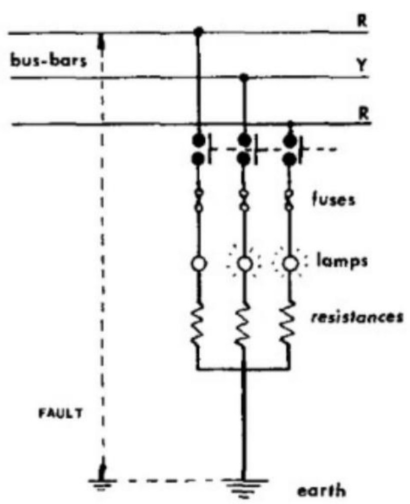
(a) Explain, with the aid of a sketch, the principle of operation of an earth leakage detection system. (8)
(b) Explain why an insulated neutral system is used extensively on-board ships. (4)
(c) State, with reasons, why a single earth fault on an insulated neutral system should always be cleared as soon as possible (4)

Sep 2024 - 1

(a)



A.C. earth fault lamps

(b) Reason for using an insulated system

The priority requirement on board the ship is to maintain the continuity of the electrical supply to equipment if a single earth fault occurs. On an insulated system, one earth fault does not interrupt the supply but raises a warning on the earth's detection system. This allows the operator to locate and clear the fault.

Advantages of insulated neutral system

- It avoids the risk of loss of essential services like steering gear
- One earth fault doesn't interrupt the supply but an earth fault detection system will give a warning

(c) While using an insulated neutral electrical system, when a fault occurs, the equipment is not disconnected.Instead what happens is that a warning light/alarm will be triggered on the earth fault indicator panel, but the equipment on that circuit will still operate.

Should a second fault occur on the other phase wire, then the safety trip devices would be activated, and the equipment would no longer operate. It is therefore important to repair a single earth fault as quickly as possible, to ensure safety.

With reference to a three phase shipboard electrical distribution system;
(a) Enumerate the advantages of an insulated neutral system:
(b) Enumerate the disadvantages of an insulated neutral system;
(c) Compare the use of an insulated neutral system as opposed to the use of an Earthed neutral system with regard to the risk of electric shock from either system.

Feb 2025 | **Nov 2024** | **Jun 2024** | **Jul 2023**

(a) Advantages of an insulated neutral system:

- In the event of a single earth fault, no earth fault current flows through the ship's hull due to the insulated neutral, minimizing fire hazards.
- The hull does not carry current, ensuring safety from electrical currents passing through the structure.
- A single earth fault does not cause generator breaker tripping, avoiding sudden blackouts or operational disruptions.
- Harmonic currents caused by third harmonics in the generated voltage are prevented from flowing through the neutral, protecting the generator windings from overloading.

(b) Disadvantages of an insulated neutral system:

1. Only one system voltage (line-to-line) is possible, unlike earthed neutral systems which also provide line-to-neutral voltages.
2. While an earth fault alarm and phase indicator are triggered, locating the exact fault location requires a time-consuming trial-and-error process.
3. In cases of inductive or capacitive faults to earth, surge voltage can rise 3.5 to 4 times the system voltage, risking insulation failure and system collapse.

(c) How the earthed neutral system is earthed:
A metallic resistor is inserted between the neutral point and the ship's hull to limit earth fault current.
The resistor's value is determined by:

$$R = \frac{V}{\sqrt{3}}$$

Where,
V = Line voltage,
I = Full load current.
Metallic resistors are used for their stability, low maintenance, and ability to prevent arcing grounds.

(d) Comparison of Shock Risk:

The risk of electric shock is considered equally dangerous in both earthed and insulated neutral systems. In an insulated system, normal leakage currents from capacitance and surface leakage, along with the possibility of earth faults, mean that touching live parts still carries a considerable shock risk. Similarly, in an earthed system, line-to-neutral voltages (even those as low as 110 or 250 volts) can be lethal under certain shipboard conditions, making neither system inherently safer regarding electric shock than the other. Appropriate safety precautions are essential for both systems.

(a) State the conditions, which must be satisfied before an a.c. generator can be paralleled with live bus-bars. (4)
(b) Sketch a lamp-bright configuration for synchronizing lamps (8)
(c) Discuss the advantages & disadvantages of the lamps-bright system over the lamps-dark system. (4)

Feb 2025 | **Nov 2024** | **Jun 2024**

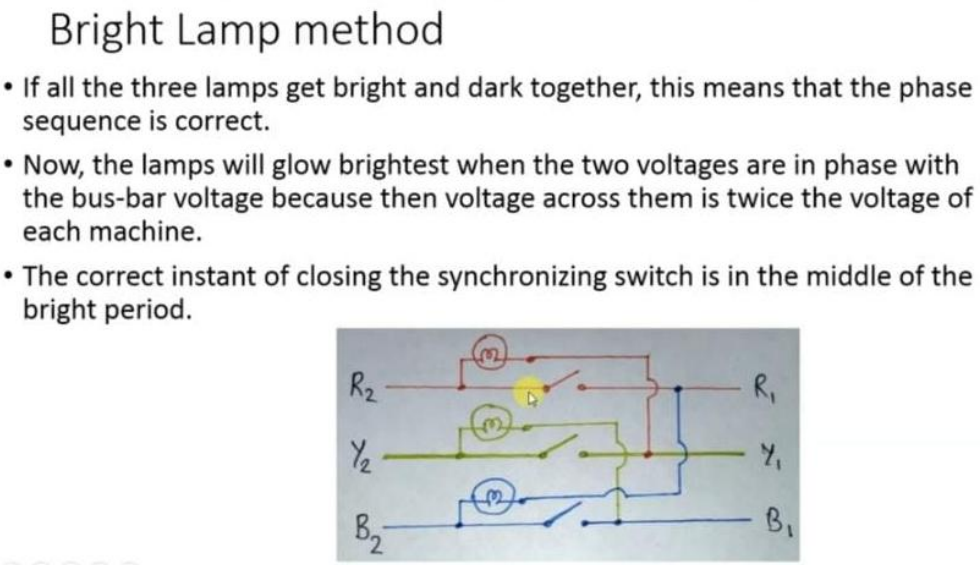
(a) The requirement for synchronisation is the incoming machine should be

- Voltage should be equal to or slightly higher than the busbar voltage (check from voltmeter)
- Frequency should equal or slightly higher than the busbar voltage (check from frequency meter)
- There should be no phase angle between the incoming and running generator. (Checked by synchroscope)
- When the above criteria are met, the circuit breaker of the incoming generator is closed.

(b) Lamp-bright configuration for synchronizing lamps:

- A cheap method for synchronization by using 3 lamps is called synchronizing lamps method.
- By using these three lamps, it is easy to check the condition for synchronization.
- This method is generally used for low-power machines.
- When a generator is rotated at its rated speed by using a prime mover, then it is ready to connect to the infinite busbar by adjusting the field current of the infinite busbar to get its terminal voltage equal to the busbar voltage.
- Voltage may vary from 0 V to twice the phase voltage, so it is required to use a suitable lamp.

Three bright lamp method



For this method, all three lamps are connected in parallel to the switches A1 to B2, B1 to C2 and C1 to A2.
If all the phases are connected properly, all lamps will be bright and dark at the same time.
If not flicker at the same time, the phase sequence is not corrected so need to change the phase and observe until all lamps flicker at the same time.
These 3 lamps flicker at a rate that is equal to the difference in frequency of incoming machine and busbars.
Now, the frequency of the incoming machine needs to be adjusted so that it will equal to busbar's frequency which is known by observing these 3 lamps.
Adjusting the frequency until the lamps flicker at a slow rate (i.e. less than one bright period per second). Finally, all switches are closed in the middle of the bright period

(c) Advantages & disadvantages of the lamps-bright system over the lamps-dark system:Advantages:

- The lamps-bright system is more accurate than the lamps-dark system because the lamps are much more sensitive to changes in voltage at their maximum brightness than when they are dark.
- This makes it easier to identify the exact moment of synchronization.
- The midpoint of the bright period in the lamps-bright system can be identified more easily compared to the dark lamp method.
- This provides a clearer indication of when to close the circuit breaker.
- The lamps-bright system allows for more effective synchronization and closing of the breaker, as the exact moment of synchronization can be easily identified.

Disadvantages:

- There is a possibility of inaccuracies in synchronizing and closing the breaker in the lamps-bright system, especially if the lamps become dark or flicker due to fluctuations in voltage.
- This can lead to errors in timing the closure of the breaker, potentially causing disruptions or damage.
- The lamps in the bright lamp system become dark at about half of their rated voltage. As a result, there is a risk that the synchronizing switch might be turned off even when a phase difference between the machines exists, leading to incorrect synchronization.
- There is a risk of filament burnout in the lamps due to the continuous operation at maximum brightness. This could result in the failure of the lamps and the loss of synchronization indication.

State the conditions, which must be satisfied before an A.C. generator can be paralleled with live bus bars. (8)
(b) After an A.C. generator has been paralleled explain how the following are achieved for the incoming generator:
(i) Correct kW load sharing (4)
(ii) Correct load current when the generator has power factor different to the other generators. (4)

Aug 2023

(a) The requirement for synchronisation is the incoming machine should be

- Voltage should be equal or slightly higher than the busbar voltage (check from voltmeter)
- Frequency should equal or slightly higher than the busbar voltage (check from frequency meter)

- There should be no phase angle between the incoming and running generator. (Checked by synchroscope)
- When the above criteria is met, the circuit breaker of incoming generator is closed.

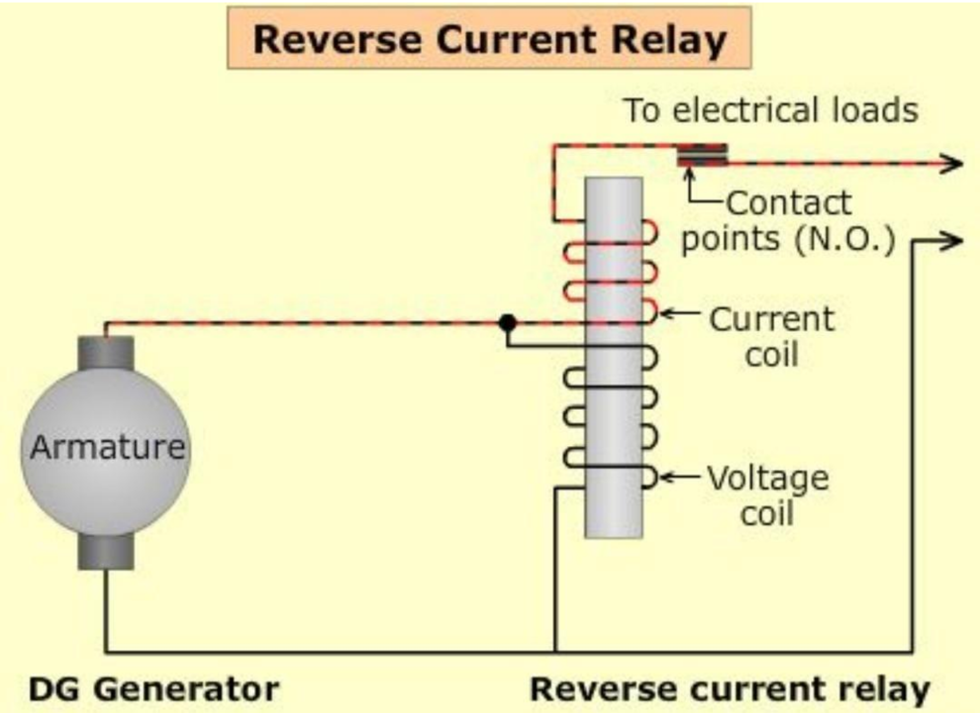
(b) (i) Correct kW Load Sharing: This is achieved by adjusting the speed governor of the incoming generator to match the speed of the other generators already connected to the bus bars. By synchronizing the rotational speed, the generators share the load proportionally based on their ratings.

(ii) Correct Load Current when the Generator has a Different Power Factor: If the power factor of the incoming generator differs from the other generators, it can be adjusted by controlling the reactive power output of the generator. This is typically achieved by adjusting the excitation level of the generator to control the flow of reactive power. By matching the power factor, the load current can be correctly shared among the generators without overloading or underloading any particular unit.

(a) Sketch a reverse current trip. (8)
(b) Explain briefly how the reverse current trip operates. (4)
(c) Explain why there is a time delay incorporated before the reverse current trip operates. (4)

Mar 2023 **Aug 2022**

(a)



(b) The relay consists of two coils on one core and a spring-controlled armature. One voltage coil is in parallel with the generator voltage and the current coil is in series with the generator. When the generator reaches normal operational voltage the voltage coil is energized. Its flux overcomes the controlling spring. This closes the contacts of the relay and the load is fed if the generator voltage is comparatively higher. The flux developed by the forward current aids the voltage flux.
When the output voltage of the generator goes below the voltage value of the other running generator or the battery, we have current discharging from the battery. The reverse current situation occurs. The flux of the reverse current opposes the flux of the voltage. The total flux

in the core is reduced, the relay drops off due to the action of the controlling spring and the generator is disconnected from the other running generator or the battery.

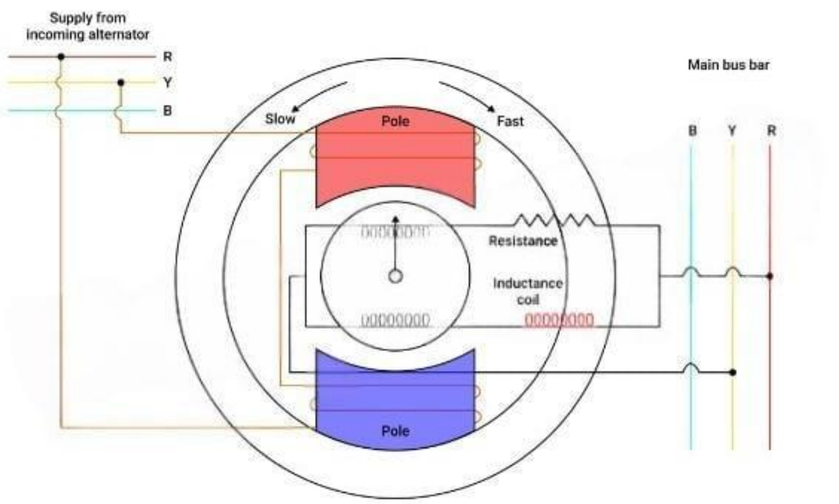
(c) Time delay:
Time delay is needed for reverse current relay trips in D.C generators since it is likely that reverse current surges can happen whilst paralleling the D.C incoming generator with the running D.C generator or the battery if the incoming D.C generator's voltage is a bit less than the running one. If a time delay is not given the incoming generator may trip instantaneously. In the case of the reverse power relay of alternators, a time delay of 5 seconds avoids tripping due to likely reverse power surges whilst synchronizing when the alternator frequency is a bit less than the running one while synchronizing. The settings of the RPP relay are 8% to 10% for diesel prime movers and 2% to 6% for turbine prime movers.

(a) (i) Describe with the aid of a sketch the operation of a synchroscope.
(ii) State the information obtained from it. (8)
(b) Suggest a substitute in the event of synchroscope and standby light failure. (8)

Aug 2023

(a) Synchroscope: The operation of connecting an alternator with another machine or a running bus is called synchronization and is normally carried out with the help of a synchroscope. The rotation of direction of the synchroscope pointer is determined by the speed or frequency of the incoming machine. If the ‘incoming alternator’ is rotating faster than the ‘running alternator’ the pointer rotates clockwise and vice versa. The breaker is closed just before the pointer reaches the middle position of the synchroscope.

Working Principle The synchroscope works on the principle of AC motor. It has two poles connected across any two phases of the incoming machine and the armature windings supplied from the similar two phases in the bus-bars. The armature consists of a resistance and an inductance coil in parallel. The inductance is provided to shift the current flow through itself by 90° relative to current in the resistance provided. These currents are fed through slip-rings to the two armature windings and produces a rotating magnetic field in combination with the field in the poles. The polarity of the poles will alternate north south according to changes in the incoming machine. The rotating field will react with the poles and rotate the rotor clockwise or anti-clock wise. The synchronism is indicated when the pointer is at middle alternate north south according to the phases of the incoming machine. The rotating field will react with the poles and rotate the rotor clockwise or anti-clock wise. The position of the fast and slow which shows that incoming machine is in phase with the switchboard bus-bars.



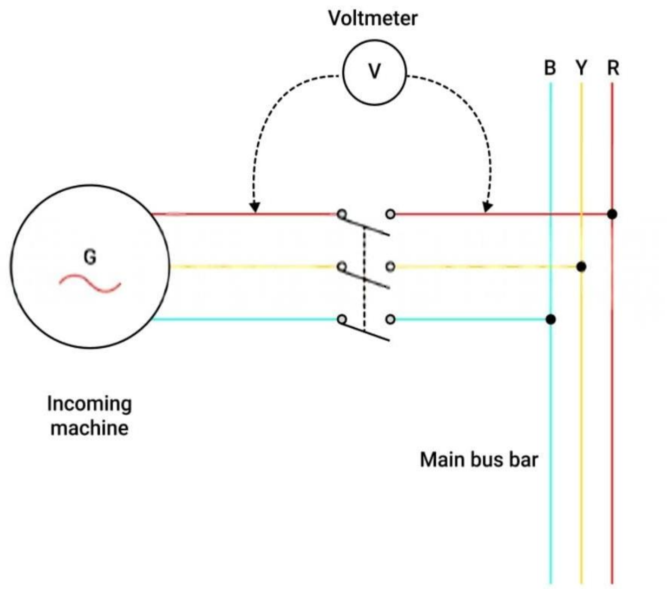
(b) In the event of a synchroscope failure, a substitute procedure involves using a voltmeter with a voltage measurement range at least two times the rated voltage of the alternator:

- Connect the voltmeter across any one open pole of the incoming generator circuit breaker. These terminals are usually available at the synchroscope terminals.
- Adjust the generator speed until the voltmeter very slowly fluctuates from zero to maximum.
- Close the breaker when the voltmeter indicator passes through zero.

(c) Substitute:
Incase the synchroscope fails & the standby light failure occurs, then connect a voltmeter between one pole of the open incoming generator & the corresponding pole of the main bus bar.

Diagram showing an incoming generator (with phases R, Y, B) connected to a voltmeter, which is also connected to the main bus bar (with phases R, Y, B).
Adjust the generator speed until the voltmeter very slowly fluctuates from zero to maximum.

Close the breaker when the voltmeter indication passes through zero.An analogue voltmeter is used as the pointer & scale is easier to follow than a digital type.



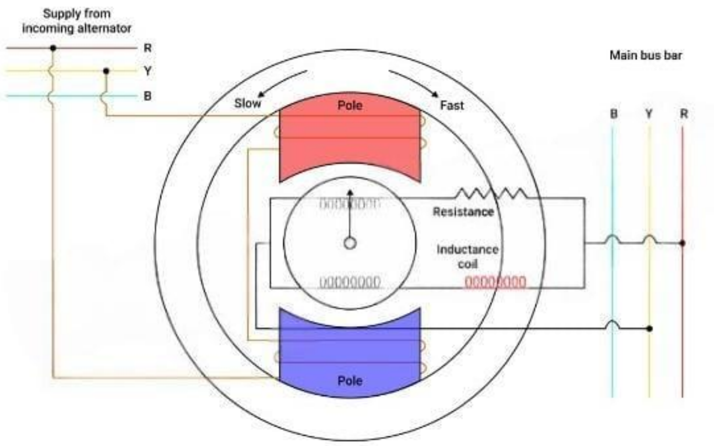
(a) How is the Synchroscope connected for paralleling operation of alternator? (8)
(b) Explain lamp bright method used to parallel alternators. (8)

Jun 2023

(a) Connecting an alternator with another machine or a running bus is called synchronisation and is normally carried out with the help of a synchroscope. The speed or frequency of the incoming machine determines the rotation of the direction of the synchroscope pointer. If the 'incoming alternator' is rotating faster than the 'running alternator' the pointer rotates clockwise and vice versa. The breaker is closed just before the pointer reaches the middle position of the synchroscope.

Working Principle: The synchroscope works on the principle of the AC motor. It has two poles connected across any two phases of the incoming machine and the armature windings supplied from the similar two phases in the bus bars. The armature consists of a resistance and an inductance coil in parallel. The inductance is provided to shift the current flow through itself by 90° relative to the current in the resistance provided. These currents are fed through slip-rings to the two armature windings and produce a rotating magnetic field in combination with the field in the poles. The polarity of the poles will alternate north-south according to changes in the incoming machine. The rotating field will react with the poles and rotate the rotor clockwise or anti-clockwise. The synchronism is indicated when the pointer is in the middle alternating north-south according to the phases of the incoming machine. The rotating field will react with the poles and rotate the rotor clockwise or anti-clockwise. The position of the fast and slow which shows that the incoming machine is in phase with the switchboard bus-bars.

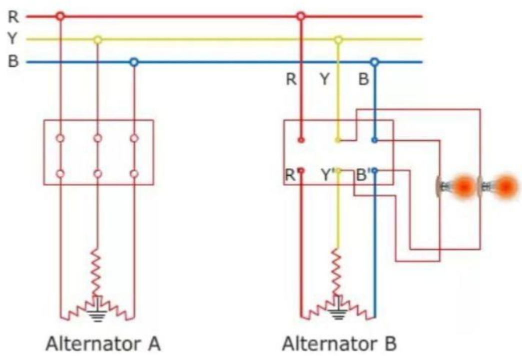
Note: In synchroscope, one of the coils in the armature is fed through an inductor while the other is fed through a resistor. The rotating armature has two coil windings perpendicular to each other. The field produced by the coils rotates the magnetic armature pointer at a speed relative to the frequency of the bus bar supply. The coils produce a single-phase rotating field. The synchronization process should be done before connecting two systems like a generator to the power grid or between generators of the same plant.



(b) Lamps can be connected across the circuit breaker or isolating links of the new machine before the latter is closed on the busbar. Test lamps can be connected directly to the bus bar and alternator connections as shown. Let the running alternator be A and the incoming alternator be B. The voltages of the busbar and the incoming alternator oppose each other. Because the two lamps connected across the Y and R phases are connected in 180-degree out-of-phase conditions. The voltages on the lamps are zero. Hence, these two lamps will be dark.

During the condition between zero to 180 degrees out of condition, the lamps will be dimming and brightening simultaneously. Hence, both lamps will burn at the brightest at synchronism. The alternators are in perfect synchronism when both lamps are simultaneously bright. Thus, the incoming alternator can be synchronised and connected with the running alternator.

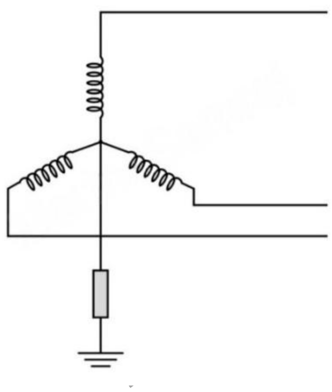
Bight lamp method diagram:



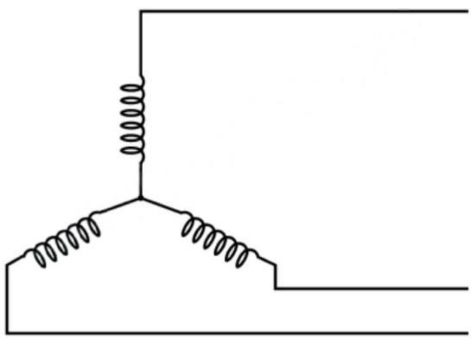
Explain with the aid of simple circuit diagram the grounded power distribution system and isolated power distribution system (16)

May 2023 - 2

Grounded Power Distribution Systems:
In a grounded power distribution system, the neutral is connected to earth, providing a path for fault currents in the event of a single earth fault. The protective devices respond to disconnect the faulty equipment. The neutral can be solidly earthed or earthed through a resistor to limit fault currents. Here's a simple circuit diagram example for a grounded system:



Isolated (Ungrounded) Power System:
In an isolated power system, the neutral is not connected to earth, allowing continuous operation in the presence of a single earth fault. The protective trip does not function unless there is a second earth fault, which is considered equivalent to a short circuit through the earth. Here's a simple circuit diagram for an isolated power system:



(a) What is the purpose of Preferential Tripping system on ship's electrical network? (6)
(b) Explain the various stages of preferential trips with the loads connected to those stages (10)

Dec 2024 - 1 **Mar 2025**

(a) A preferential trip is a kind of electrical arrangement on the ship that is designed to disconnect the non-essential circuit i.e. non-essential load from the main bus bar in case of partial failure or overload of the main supply

The non-essential circuits or loads on ships are air conditioning, exhaust and ventilation fans, and galley equipment which can be disconnected momentarily and can be connected again after fault finding

The main advantage of the preferential trip is that it helps in preventing the operation of the main circuit breaker trip and loss of power on essential services and thus prevents blackout and overloading of the generator.

(b) Preferential trips operate after a fixed time delay, causing non-essential loads to be shed. When the generator load reaches 110%, preferential Trip comes into operation as follows

First Stage Preferential Tripping (PT1):

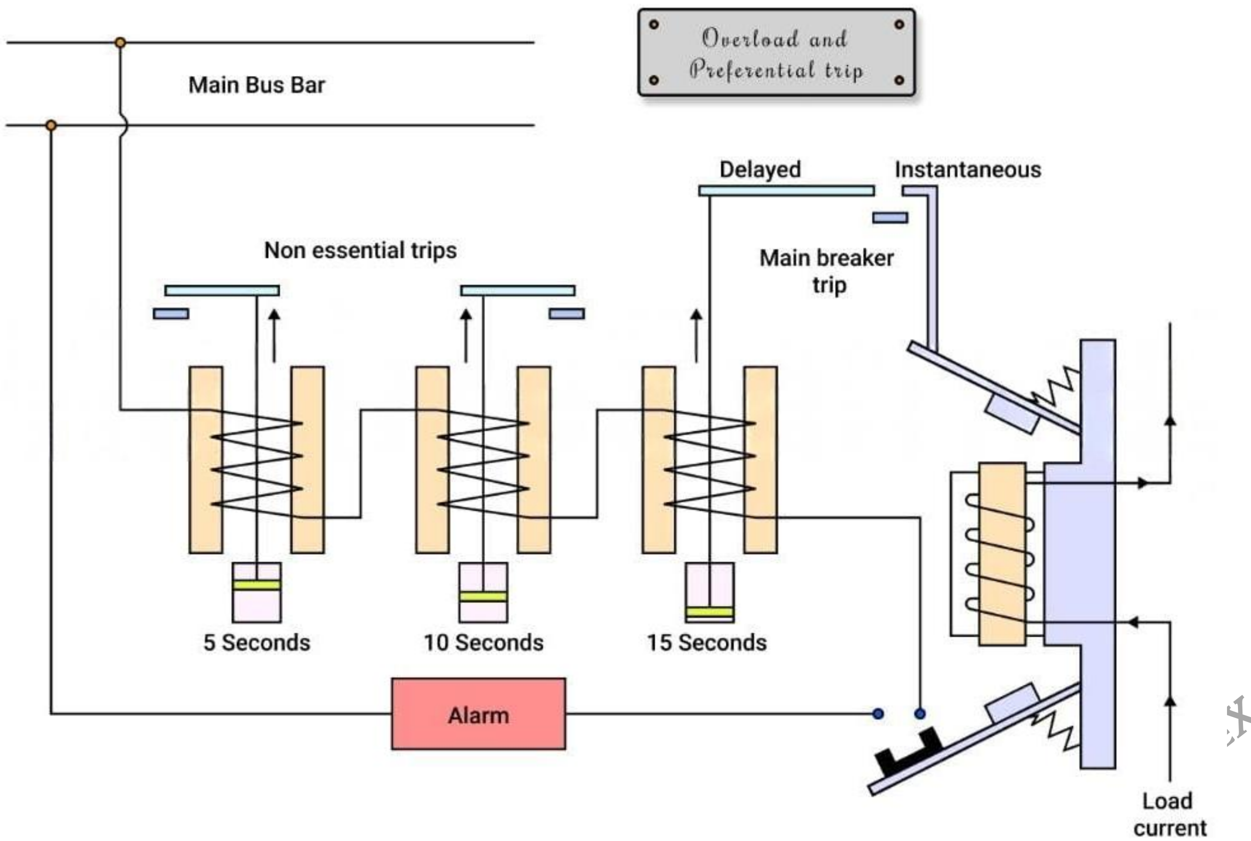
- Initiated when the current on a running generator exceeds 100% of the generator rating for a period of 5 seconds.
- Protects against overcurrent by releasing the 1st stage preferential tripping.
- Shut down non-essential loads (air-conditioning, entertainment, accommodation fans, cargo hold fans, amplifiers, etc.) to reduce the generator load

Second Stage Preferential Tripping (PT2):

- Initiated if the current on a running generator continues to exceed 100% of the generator rating for an additional 5 seconds.
- Shut down additional loads such as cargo hold vent fans and packaged air conditioning units. (service required for running the ship properly, leaving loads of top priority services to maintain propulsion and navigation) if the generator load is still high

Third Stage Preferential Tripping (PT3):

- Initiated if the current on a running generator persists in exceeding 100% of the generator rating for 15 seconds.
- Shut down the main generator as the last action, if the load is still too high, it may be due to a short circuit or insulation breaking.



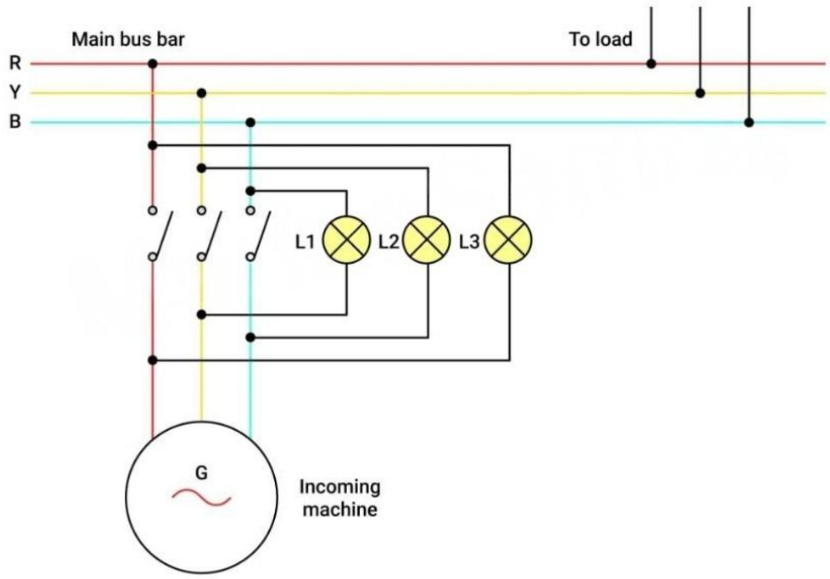
(a) State the conditions, which must be satisfied before an A.C. generator can be paralleled with live bus-bars (4)
(b) (i) Sketch a lamp-bright configuration for synchronizing lamps (4)
(ii) State the advantages of the lamp-bright system (4)
(iii) State the disadvantages of the lamp-dark system (4)

Sep 2024 - 2	Apr 2024 - 2	Apr 2025	Jan 2023	Aug 2022

(a) The requirement for synchronisation is the incoming machine should be

- Voltage should be equal or slightly higher than the busbar voltage (check from voltmeter)
- Frequency should equal or slightly higher than the busbar voltage (check from frequency meter)
- There should be no phase angle between the incoming and running generator. (Checked by synchroscope)
- When the above criteria is met, the circuit breaker of incoming generator is closed.

(b)



(i) Advantages of Lamps-Bright System:

- The lamps-bright system is more accurate than the lamps-dark system because the lamps are much more sensitive to changes in voltage at their maximum brightness than when they are dark. This makes it easier to identify the exact moment of synchronization.
- The midpoint of the bright period in the lamps-bright system can be identified more easily compared to the dark lamp method. This provides a clearer indication of when to close the circuit breaker.
- The lamps-bright system allows for more effective synchronization and closing of the breaker, as the exact moment of synchronization can be easily identified.

(ii) Disadvantages of Lamps-Dark System:

- The lamps become dark at about one third of the rated voltage. Hence, faulty synchronizing may be done in dark period.
- The lamp filament might burn out.
- The flicker of the lamps does not indicate which machine has the higher frequency.
- Using this method it is not possible to find out that the machine is slow or fast.
- This method is not applicable for high voltage alternators, because lamp ratings are normally low.

What is a short circuit and how may a short circuit develop in: (16)
(a) A generator, and
(b) The external circuit, and what is the usual result in each case? How may the occurrence of short-circuit be minimized?

Aug 2022

(a) Short circuit is an electrical circuit in a device of lower resistance than that of a normal circuit, especially one resulting from the unintended contact of components and consequent accidental diversion of the current: Short circuit inside a generator or motor or transformer winding occurs due to failure or damage of insulation between two phase windings normally in overhang portion. Short circuit is the extreme case of fault, when the two phases of a poly system or phase & neutral of a single phase are directly shorted with negligible resistance. The short circuit current will be the maximum in such cases. In the distribution systems, three phase cables are the common locations for phase faults. Bus-bar cubicles are possible locations. The short circuit in the external circuit of generators could be either at the bus-bar inside the switchboard or in any of the outgoing feeder circuit. Bus-bar fault could be clue to failure of supporting insulators of the bus bars and due to entry of vermin shorting two phases. Whereas outgoing feeders can have short- circuit due to shorting at load points or within the equipment.

(b) Avoiding of Short Circuit and Earth Faults in Transformers, Alternators and Motors

- This kind of failures can be avoided by maintaining the winding insulation in good order by not allowing the winding to overheat.
- This is done by controlling the load current within rated current and maintaining good ventilation.
- Periodical cleaning of the windings to remove oils and dusts is also essential to prevent winding faults. Regular checks, running within limits, periodical maintenance and condition monitoring can minimize the occurrence of faults.

(a) What is synchronizing an alternator. (4)
(b) Explain the conditions to be satisfied for synchronisation. (12)

Feb 2023

(a) Synchronizing an alternator refers to the process of matching the voltage, frequency, and phase angle of the alternator with that of the electrical grid it is connected to. This is important to ensure a stable and efficient power transfer between the alternator and the grid. Failure to synchronize the alternator can cause damage to both the alternator and the grid.

During the synchronization process, the alternator is brought up to the same voltage and frequency as the grid, and the phase angle is adjusted until the two systems are in phase with each other. Once synchronization is complete, the alternator can be safely connected to the grid to supply power.

(b) The conditions to be satisfied for synchronizing two generators are:

- Voltage should be equal to or slightly higher than the busbar voltage (check from voltmeter)
- Frequency should equal or slightly higher than the busbar voltage (check from frequency meter)
- There should be no phase angle between the incoming and running generator. (Checked by synchroscope)

- Look at the dial indicator on the synchro panel. The indicator should be rotating in the clockwise direction.
- Operate the governer switch in such a way that the pointer slowly comes to 12 'O' clock position by rotating in clockwise direction.
- When the pointer is at the 11 'O'clock position, close the circuit breaker of incoming generator
- The circuit breaker of the incoming generator will close. The pilot indicating lamp will change from red to green
- Operate the incoming generator's governor switch to slowly increase the load on the generator till the active and reactive loads of both generator equalize.
- After putting the generator on load, switch off the synchroscope.

Draw a diagram showing the essential connection of two compound generators A and B coupled to common bus bars for parallel operation. If A is running on the bus bars and supplying all the load, describe the process of bringing B into commission and adjusting it to take its share of the load. (16)

Sep 2022

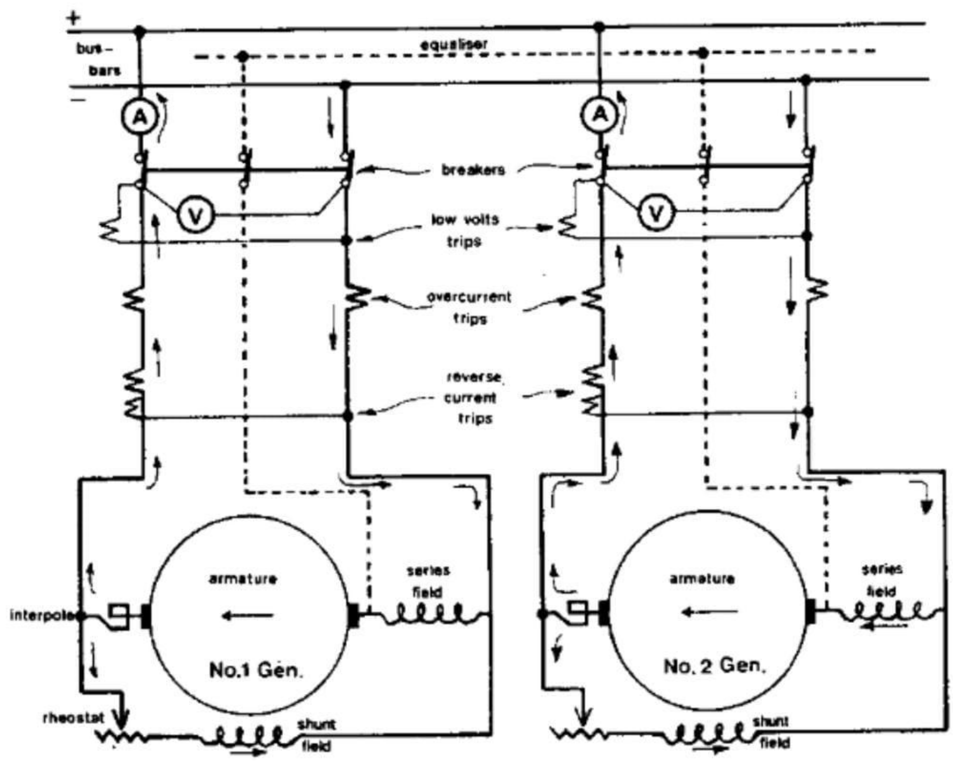


Figure 7.7 *Generators in parallel with equalising connection*

(a) Brief the conditions to be satisfied for synchronizing (8)
(b) Explain about the working of a synchroscope with the help of a sketch (8)

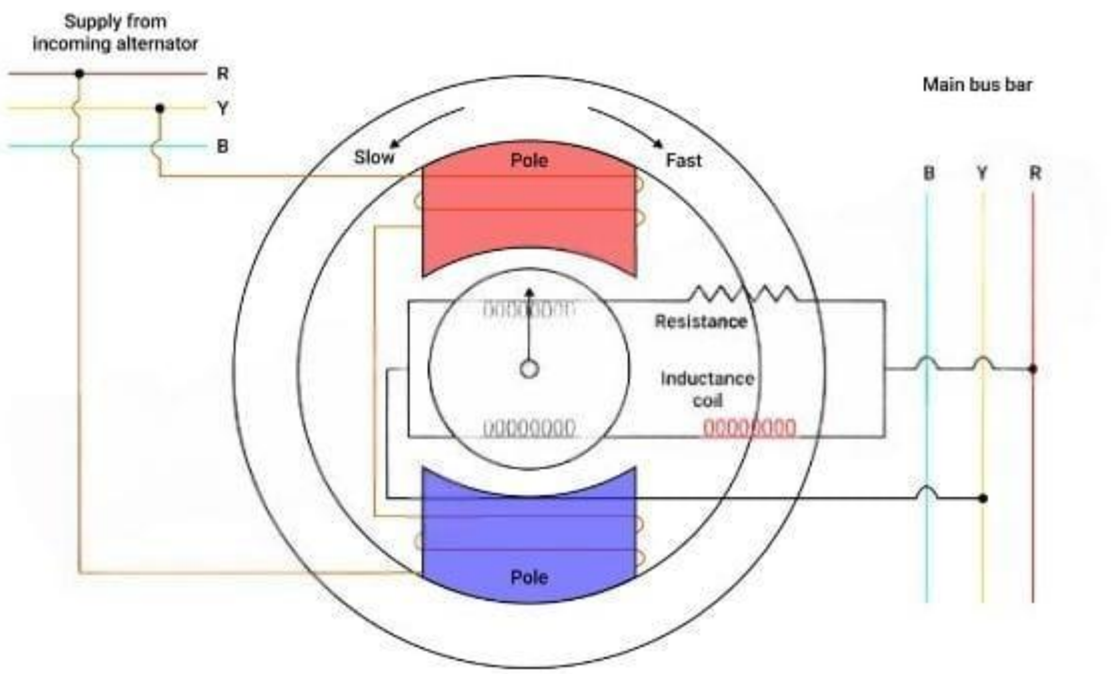
Jul 2022 **Nov 2022**

(a) Conditions to be satisfied before synchronizing

1. Their phase sequences to be the same. If the phase sequence of the incoming alternator and the running bus are not the same, the synchronism should never be done. This is the very first condition. Once this is established during commissioning, there is no need to check it every time.

2. The bus bar and incoming machine voltages should be equal Differences of voltage between the running and incoming machines at the moment of paralleling, will cause currents to flow in a similar manner to an internal circulating effect; but small differences in voltage up to 5 per cent are unimportant.
3. The frequency of the two supplies should be the same A difference in frequency indicates that the amount of stored energy in the rotor of the incoming machine is either greater or less than the alternator running already. Therefore if paralleling is carried out when a frequency difference exists, a surge will take place, the synchronizing torque developed being sufficient to correct the difference in momentum. The condition is one which will give rise to oscillation called „hunting", which will normally be damped out by the rotor losses.
4. The phase angle between the two systems should be within 6 degrees. A difference in phase between the running and incoming machines at the moment of paralleling will produce a synchronizing current of the phase angle difference, and therefore of the resultant voltage available for the production of synchronizing currents. This condition can be avoided only when the frequency of the two supplies are the same and the phase sequences are also same.
5. If the switch/breaker contacts can be closed when all the above conditions are satisfied, it is the perfect synchronizing. No disturbances to the incoming alternator or to the running system will be produced.

(b)



The synchroscope consists of a small motor with coils on the two poles connected across two phases. Let's say it is connected in red and yellow phases of the incoming machine and armature windings supplied from red and yellow phases from the switchboard bus bars.

- The bus bar circuit consists of an inductance and resistance connected in parallel.
- The inductor circuit has the delaying current effect by 90 degrees relative to current in resistance.
- These dual currents are fed into the synchroscope with the help of slip rings to the armature windings which produces a rotating magnetic field.
- The polarity of the poles will change alternatively in north/south direction with changes in red and yellow phases of the incoming machine.

- The rotating field will react with the poles by turning the rotor either in clockwise or anticlockwise direction.
- If the rotor is moving in clockwise direction this means that the incoming machine is running faster than the bus bar and slower when running in anticlockwise direction.
- Generally, it is preferred to adjust the alternator speed slightly higher, which will move the pointer on synchroscope is in clockwise direction.
- The breaker is closed just before the pointer reaches 12 o clock position, at which the incoming machine is in phase with the bus bar.

High Voltage

- **Notes:**

(a) What is high voltage and what are the high voltage equipment? (6)
(b) Briefly explain the safety requirements of high voltage systems (10)

Jun 2023

(a) Definition of High Voltage :
In the marine field, high voltage (HV) is typically considered to be any voltage above 1000V (>1000V). Voltages below or equal to 1000V are categorized as low voltage (LV).
High voltage systems are often employed in applications with high electrical power demands, such as electric propulsion and bow thrusters. One advantage of high voltage systems is the reduction in current for a given power, as per Ohm's law.
High voltage equipment :
The following are the high voltage equipment which require High voltage installations.

- Generators
- High voltage switch board with protection devices which gear and instruments
- High voltage motors for compressor air conditioner propulsion and thrusters
- High voltage cable
- Step down transformer high voltage to low voltage for low voltage consumers
- High voltage 6.6 KV to 2.9 KV step down transformer for motor and propulsion converter

(b) Safety Requirements of High Voltage Systems:

- High voltage systems use special circuit breakers, which can be air, gas, or vacuum breakers. These breakers are designed to handle the specific challenges associated with high voltages.
- To minimize the size of earth fault currents, high voltage systems often incorporate a neutral earthing resistor. This resistor helps manage and control the flow of fault currents.
- High voltage equipment utilizes advanced insulating materials like Micalastic. These materials are chosen for their superior insulating properties and reliability.
- High voltage equipment is designed to have a long insulation life, typically targeted at around 20 years. This is crucial for ensuring the reliability and safety of the system over an extended period.
- Special relays are deployed for overall circuit protection in high voltage circuits. These relays play a crucial role in detecting and responding to abnormal conditions or faults.
- Earthing procedures are essential for high voltage maintenance. These procedures are typically outlined in an Electrical Permit to Work, ensuring that proper safety measures are followed during maintenance activities.
- Safety declarations, such as declaring earthing down for maintenance, are a fundamental aspect of high voltage safety protocols. These declarations help in communicating and coordinating safety measures during maintenance operations.

Instrumentation & control

- **Notes:**

(a) Explain open loop contol system and closed loop control system with suitable examples (8)
(b) What are the merits and demerits of the two systems? (8)

May 2024 | **Apr 2025 - 1** | **Aug 2024**

a) Open loop control system:
An open loop control system is the one in which the output signal is NOT fed back to the input of the system. Therefore, an open loop control system is also referred to as a non-feedback control system.

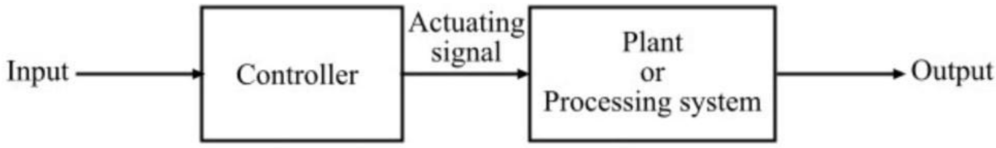


Figure 1 - Open Loop Control System

In the case of an open loop control system, the output has NO control over the control action of the system. Thus, the open loop control system follows its input signals regardless of the final results. The input is supplied to the controller, which produces an actuating signal (or control signal). This actuating single is supplied to the plant or processing system, which is to be controlled.
The major disadvantage of an open loop control system is that it is poorly equipped to handle the disturbances, which may reduce its ability to complete the desired task.

E.g. The clothes dryer is one of the examples of the open-loop control system. In this, the control action can be done physically through the operator. Based on the clothing's wetness, the operator will fix the timer to 30 minutes. So after that, the timer will discontinue even after the machine clothes are wet. The dryer in the machine will stop functioning even if the preferred output is not attained. This displays that the control system doesn't give feedback. In this system, the controller of the system is the timer.

Closed loop:
A closed-loop control system is the one in which the output signal is fed back to the input of the system. Therefore, in a closed-loop control system, the control action is a function of the desired output signal.
The main components of a closed loop control system are – the controller, plant, error detector or comparator and feedback element, which are connected together. The error detector accepts the input signal and feedback signal to produce an error signal, which is the difference between input and feedback signals. The feedback signal is the sample of the output of the overall system.
Now, the error signal is supplied to the controller to produce an actuating signal that controls the plant or processing system to produce desired results. Therefore, in the closed-loop control system, the input of the system is automatically adjusted to produce the desired response from the system.

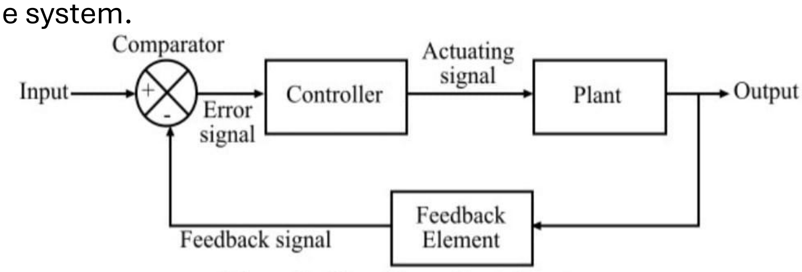


Figure 2 - Closed Loop Control System

The best example of a closed-loop control system is AC or air conditioner. The AC controls the temperature by evaluating it with the nearby temperature. The evaluation of temperature can be done through the thermostat. Once the air conditioner gives the error signal, it is the main difference between the room and the surrounding temperature. So, the thermostat will control the compressor. These systems are accurate, expensive, reliable, and require high maintenance.

(b) Merits and demerits:

Open Loop Control System	Closed-Loop Control System
In this system, the controlled action is free from the output	In this system, the output mainly depends on the controlled act of the system.
This control system is also called a Non feedback control system	This type of control system is also called a feedback control system
The components of this system include a controlled process and controller.	The components of this kind of system include an amplifier, controlled process, controller and feedback
The construction of this system is simple	The construction of this system is complex
The consistency is non-reliable	The consistency is reliable
The accuracy of this system mainly depends on the calibration	These are accurate due to feedback
The stability of these systems are stable	The stability of these systems are less stable
The optimization in this system is not possible	The optimization in this system is possible
The response is fast	The response is slow

Advantages of Closed Loop Control System

- Closed loop control systems are more accurate even in the presence of non-linearity.
- Highly accurate as any error arising is corrected due to presence of feedback signal.
- Bandwidth range is large.
- Facilitates automation.
- The sensitivity of system may be made small to make system more stable.
- This system is less affected by noise.

Disadvantages of Closed Loop Control System

- They are costlier.
- They are complicated to design.
- Required more maintenance.
- Feedback leads to oscillatory response.
- Overall gain is reduced due to presence of feedback.
- Stability is the major problem and more care is needed to design a stable closed loop system.

Advantages of Open Loop Control System

- Simple in construction and design.
- Economical.
- Easy to maintain.
- Generally stable.
- Convenient to use as output is difficult to measure.

Disadvantages of Open Loop Control System

- They are inaccurate.

- They are unreliable.
- Any change in output cannot be corrected automatically.

(a)Describe an electric telegraph system and describe its operation. (16)

Aug 2023

An electric telegraph system allowed for the transmission of text-based messages over long distances using electrical signals. It relied on a circuit that included a telegraph key (transmitter), a wire, and a sounder (receiver). By sending pulses of electricity through the wire, operators could create a code of short and long signals (dots and dashes, like Morse code) that represented letters and numbers, enabling the transfer of information.
Here's a breakdown of the system's operation:
1. Transmitter (Telegraph Key): The sender used a telegraph key, a switch that controlled the flow of electrical current. Pressing the key completed the circuit, sending an electrical pulse along the wire.
2. Wire Connection: A wire, often part of a larger network, connected the transmitter to the receiver.
3. Receiver (Sounder): At the receiving end, the electrical pulse activated an electromagnet, which in turn attracted a movable part (like a lever or armature).
4. Creating the Code: The sender controlled the duration of the electrical pulses. Short pulses were interpreted as "dots," and longer pulses as "dashes".
5. Decoding the Message: The receiver would interpret these dots and dashes, translating them back into letters and numbers using a pre-defined code, like Morse code.
6. Example: If the sender wanted to transmit the letter "A", they would send a dot followed by a dash. At the receiving end, the operator would hear a short click (dot) followed by a longer click (dash) and recognize it as the letter "A".

Plant Maintenance System

- **Notes:**

With reference to the condition monitoring of electrical machinery:
(a) State with reasons TWO important parameters that may be recorded (8)
(b) Explain how the parameters are measured and what defects may be revealed (8)

Dec 2022 | **Apr 2025-1** | **Aug 2024** | **May 2024-2**

(a) Two important parameters that may be recorded for condition monitoring of electrical machinery on board a ship are:

Temperature: Monitoring the temperature of electrical machinery is crucial as it can provide valuable insights into the health of the equipment. Electrical machinery, such as motors, generators, and transformers, generate heat during operation. By recording and analyzing the temperature, abnormal heating patterns or excessive temperature rise can be detected. High temperatures may indicate issues such as inadequate cooling, insulation degradation, bearing problems, or overloading, which can lead to equipment failure if not addressed.

Vibration: Vibration analysis is another important parameter for monitoring the condition of electrical machinery. Vibration sensors are used to measure the magnitude, frequency, and patterns of vibrations produced by rotating or moving components. Excessive vibration can indicate misalignment, imbalance, bearing wear, mechanical looseness, or other faults within the machinery. By monitoring vibration levels, deviations from normal behavior can be identified, allowing maintenance personnel to take corrective actions before serious damage occurs.

(b) Measurement and Defects Revealed:

- **Vibration:** Vibration can be measured using transducers such as accelerometers, velocity pick-ups, and seismic transducers. These transducers are installed on the machine casing, bearing housing, or rotor to detect vibrations at various frequencies. Different types of faults can be revealed through vibration analysis. For example:
- **Imbalance:** A peak at the shaft speed frequency indicates an imbalance in the rotating machinery.
- **Misalignment:** Typically, vibrations at 1X, 2X, and 3X the shaft speed frequency indicate misalignment issues.
- **Bearing Damage:** Higher frequency peaks between 2 KHz and 5 KHz, depending on shaft speed and transducer resonance, can indicate bearing damage.

Electrical Problems:

- Synchronous frequency and sidebands in the vibration signal can reveal electrical issues.
- Gear Damage: Gear mesh frequency and its harmonics indicate gear damage, depending on shaft speed and the number of gear teeth.
- Cracked or Bent Shaft: Vibrations at 2X and 3X the shaft speed frequency may indicate the presence of a cracked or bent shaft.
- Temperature: Temperature can be measured using thermocouples or infrared cameras. These sensors are installed in the vicinity of the bearings or electrical components to monitor temperature changes. The recorded temperatures can reveal potential defects such as:
- Bearing Failure: Rising temperatures in the bearings indicate potential bearing failure due to increased friction.
- Insulation Deterioration:
- Temperature rise on the outside surface of an insulating material can indicate insulation deterioration, signaling a need for inspection or replacement.
- Overload or Loose Connections: Hot spots on electrical panels detected by infrared cameras can indicate overload or loose connections.

Power distribution system

- **Notes:**

(a) Explain how fluorescent tubes power factor is improved. (6)
(b) A fluorescent lamp taking 80-watt 0.7power factor lagging from a 230v, 50-Hz supply is to be connected to unity power factor. Determine the value of the correcting approach require (10).

Dec 2022 | **Oct 2024** | **May 2024**

(a) Fluorescent tube power factor can be improved by using power factor correction techniques such as adding capacitor banks or using electronic ballasts. These methods help offset the reactive power consumed by the fluorescent tubes, resulting in a higher power factor. Capacitor banks store energy and release it to counteract the inductive reactive power, while electronic ballasts regulate the power delivered to the tubes more efficiently. These measures reduce power losses, improve energy efficiency, and optimize the utilization of the electrical system's capacity.

(b) Power of the tube = 80 watts
Supply voltage = 230 V
$\cos \phi = 0.7$
$\sin \phi = 0.714$
$P = VI \cos \phi = 80$
$\therefore I = \frac{80}{(230 * 0.7)} = 0.4969A$
current through the capacitor = reactive component of line current
$= I \sin \phi$
$= 0.4969 * 0.714$
$I_C = 0.3548$ A
Also, Voltage $V = I_C * X_C$
$\therefore X_C = \frac{V}{I_C} = \frac{230}{0.3548} /= 648.25\ \Omega$
$\therefore X_C = \frac{1}{2\pi fC} = 648.25b\ \Omega$
$\therefore C = \frac{1}{(648.25 * 2 * 3.14 * 50)} = 4.912*10^{-6}$ Farads
Capacitor to be added = 4.912 μF

(a) State the relationship between impedance, voltage and current. (6) (b) The filament of a 230V lamp takes a current of 0.261A when working at its normal temperature of 2000°C. The temperature coefficient of the tungsten filament material can be taken as 0.005 Ohms/Ohms at 0° C/C. Find the approximate current which flows at the instant of switching on the supply of the cold lamp, which can be considered to be at a room temperature of 20°C (10

Nov 2022 | **Apr 2025-1** | **Aug 2024** | **May 2024-2** | **Aug 2022**

(a) Impedance is the effective resistance of an electric circuit or an electric circuit component whose resistance changes with a different frequency of AC. Impedance can also be due to the combined effect of ohmic resistance and reactance. Impedance is represented by the letter 'Z'.
Since impedance is a frequency- dependent resistance, then the relationship between voltage current and impedance can be defined by Ohm's law as
V = I Z
Where,

- V is the voltage drop across the impedance,
- I is current across the impedance, and
- Z is the impedance,

Although V = I Z is the scalar equation as we know impedance is a function of frequency, then it can also be defined as $V_{w} = i_w z_w$

Impedance can be defined for any two- port passive network which can contain a resistor, capacitor, or inductor. When the network is condensed into one component, the voltage drop across that component is the impedance voltage.

(b) Given:

Voltage = 230V

Current = 0.261A

Temperature = 2000°C

Temperature co-efficient = 0.005

To find: current at 20°C

Resistance of lamp at 2000°C

$R_{hot} = \frac{V}{I} = \frac{230}{0.261} = 881.2\Omega$

Resistance, R_o $R_{hot} = Ro(1+T_{hot})$ $881.2 = R(1+ (0.005 \times 2000))$ $R = 80.1\Omega$

Resistance at 20°C $R_{20} = R(1+aT_{cold}) = 80.1(1+0.005 \times 20)$ 88.11Ω

Current at 20°C $I_{20} = \frac{V}{R20} = \frac{230}{88.11} = 2.61A$

(a) Explain the factors which govern the variation of resistance of conductors. (6)

(b) A 2-core cable, each core of which is 300 m long and of uniform cross-sectional area of 150 mm2 is fed from one end at 240V. A load of 200A is taken off from the centre of the cable and a load of 100A from the far end. Calculate the voltage at each load. A single-core cable of similar material 880 m in length and of uniform cross-sectional area of 50mm2 has a resistance of 0.2192. (10)

Oct 2022

(a) The resistance of a conductor is determined by the following factors:

- The length of the conductor: The longer the conductor, the greater the resistance.
- The cross-sectional area of the conductor: The larger the cross- sectional area, the lower the resistance.
- The type of material: The resistivity of different materials varies.
- The temperature: The resistance of most materials increases with temperature.

The resistance of a conductor can be calculated using the following equation:

$$R = \frac{Þ L}{A}$$

where:

R is the resistance in ohms

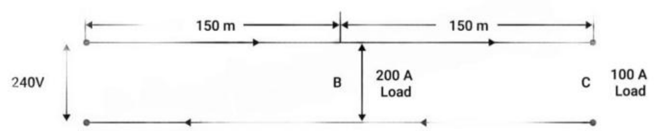
Þ is the resistivity of the material in ohm- meters

L is the length of the conductor in meters

A is the cross-sectional area of the conductor in square meters

The resistivity of a material is a measure of how difficult it is for current to flow through the material. The resistivity of different materials varies widely. For example, the resistivity of copper is 1.68 x 10-8 ohm meters, while the resistivity of iron is 10.0 x 10-8 ohm-meters.

(b)



Given:
l = 300m
A = 150 mm^2
V = 240 V
A single core cable of similar material with 880 m long and 50 m^2 area has resistance 0.2190
We know that R = $\frac{\rho I}{A}$
i.e., R ρ I ; Rρ $\frac{1}{A}$
∴ the resistance of 880 m wire,
0.219 = $\frac{\rho * 880}{50 * 10-6}$ =1.244 * 10^{-8} Ωm
Hence the resistance of 150 m long 150 m m^2 wire is
R=$\frac{1.244*10-8 *150}{150*10-6}$
=0.0124Ω
Total current in the wire (AB) = 200 + 100 =300A
Total resistance in the wire (AB) = 2 * 0.0124= 0.0248Ω
Voltage drop in length of (AB) = IR = 300* 0.0248= 7.44V
Voltage in 200 A load = 240 V -7.44 V = 232.56V
Voltage drop in section BC = 1/3 of AB(since the current is 1/3 rd)
= 1/3 * 7.44
= 2.48V
∴ Voltage in 100 A load = 232.56 - 2.48 = 230.08V

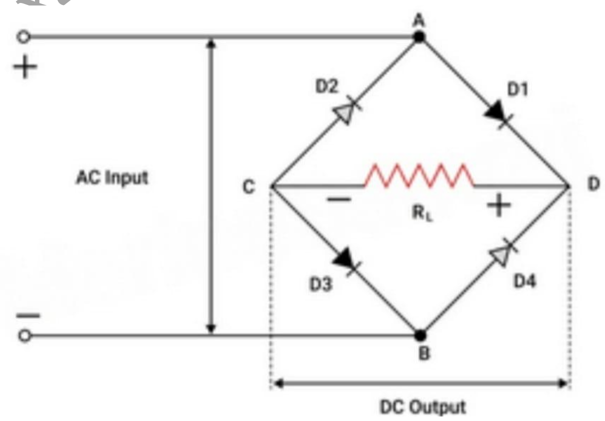
Rectifier

- **Notes:**

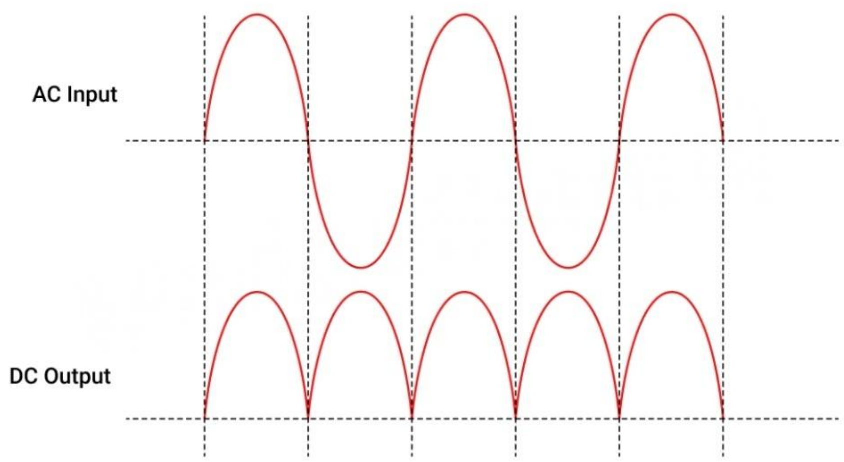
(a) With the aid of a circuit diagram explain the working of Bridge rectifier.(8)
(b) Compare the performance of Bridge rectifier with Full wave and Half wave rectifier. (8)

May 2023-2 | **Sep 2024-1** | **March 2024**

a) When an AC signal is applied across the bridge rectifier, terminal A becomes positive during the positive half cycle while terminal B becomes negative. This results in diodes D1 and D3 becoming forward biased while D2 and D4 becoming reverse biased.
During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D2 and D4 to become forward biased and diode Dl and D3 to be reverse biased.



During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D2 and D4 to become forward biased and diode Dl and D3 to be reverse biased.
From the figures given above, we notice that the current flow across load resistor RL is the same during the positive and negative half-cycles. The output DC signal polarity may be either completely positive or negative. In our case, it is completely positive. If the diodes' direction is reversed, we get a complete negative DC voltage.
Thus, a bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal.
The output waveforms of the bridge rectifier are shown in the below figure.



(b) Efficiency:

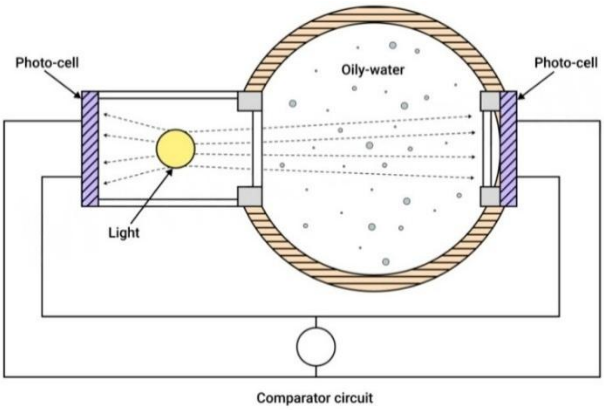
- **Bridge Rectifier:** The bridge rectifier has higher efficiency compared to both full-wave and half-wave rectifiers. This is because it utilizes all four diodes in the bridge configuration, allowing for full utilization of the input AC voltage.

- **Full-Wave Rectifier:** The full-wave rectifier has higher efficiency compared to the half-wave rectifier.but lower efficiency compared to the bridge rectifier. It uses two diodes to rectify both halves of the AC input cycle.
- **Half-Wave Rectifier:** The half-wave rectifier has the lowest efficiency among the three. It utilizes only one diode, resulting in significant power loss as half of the input AC cycle is not utilized.

Voltage Output:

- **Bridge Rectifier:** The bridge rectifier provides a full-wave rectified output with a higher average DC voltage compared to both full-wave and half- wave rectifiers. It effectively utilizes both halves of the input AC cycle, resulting in a higher voltage output.
- **Full-Wave Rectifier:** The full-wave rectifier also provides a full-wave rectified output but with a lower average DC voltage compared to the bridge rectifier. This is due to the voltage drop across the two diodes used in the rectification process.
- **Half-Wave Rectifier:** The half-wave rectifier provides a half-wave rectified output, resulting in the lowest average DC voltage among the three rectifier types.

  Ripple Content:
- **Bridge Rectifier:** The bridge rectifier has the lowest ripple content in the output waveform. This is because it utilizes both halves of the input AC cycle, resulting in a smoother output.
- **Full-Wave Rectifier:** The full-wave rectifier has higher ripple content compared to the bridge rectifier but lower than the half-wave rectifier. The ripple frequency is twice the input frequency.
- **Half-Wave Rectifier:** The half-wave rectifier has the highest ripple content among the three. It only rectifies one half of the input AC cycle, leading to a more significant ripple in the output waveform.



(b) The inputs that are recorded are:

1. Instantaneous rate of discharge in liter/nm.
2. Total Quantity
3. Date & time
4. Position of the ship (incorporated in the latest models)

(c) The system has to perform multiple duties. Not only the oil content of the effluent to be measured, a difficult enough task but the discharge rate of the pumps over a wide range of output and the speed of the ship must also be recorded. A computer is needed to transfer input into output i.e. total quantity of oil and instantaneous rate of discharge must be identified. It is difficult to monitor oil content of water; considering the small concentrations of oil involved and the many disturbing factors such as widely varying properties of oil, other contaminants in water, and a hostile environment for the equipment.

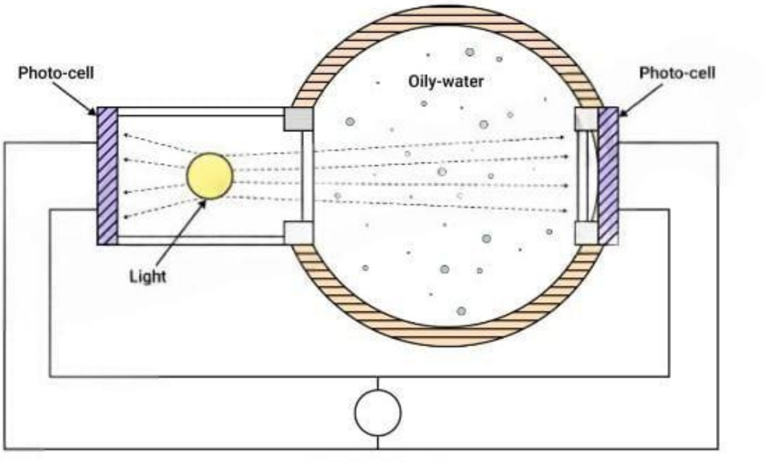
Special electrical practice

- **Notes:**

With reference to oil monitoring of bilge and tanker ballast discharges:
(a) Describe with the aid of a sketch, the general arrangement of an oil monitoring system (10)
(b) State the inputs that are recorded (3)
(c) Explain the difficulties encountered with the efficient operation of the oil monitoring system. (3)

Jan 2023

(a) Direct light absorption: Bilge or ballast water passing through a sample chamber can be monitored by a strong light shining directly through it and on to a photo-cell. Light reaching the cell decreases with increasing oil content of the water. The effect of this light on the photo-cell compared with that of direct light on the reference cell to the left of the bulb can be registered on a meter calibrated to show oil content.



(b) The inputs that are recorded are:
- Instantaneous rate of discharge in liter/nm.
- Total Quantity
- Date & time
- Position of the ship (incorporated in the latest models)

(c) The system has to perform multiple duties. Not only the oil content of the effluent to be measured, a difficult enough task but the discharge rate of the pumps over a wide range of output and the speed of the ship must also be recorded. A computer is needed to transfer input into output i.e. total quantity of oil and instantaneous rate of discharge must be identified. It is difficult to monitor oil content of water; considering the small concentrations of oil involved and the many disturbing factors such as widely varying properties of oil, other contaminants in water, and a hostile environment for the equipment.

Steering & stabilisers

- **Notes:**

(a) What are the safety devices provided on the steering gear system? (10)
(b) What is the significance of the shaft-hull earthing device on the shafting? (6)

Dec 2024 | Mar 2025

(a) Steering gear safeties are mechanisms integrated into the steering gear system to protect the vessel's steering mechanism from potential damage, ensure safe operation, and alert the crew to any issues.

Hydraulic Safeties:
1. Level Switch: Monitors the hydraulic oil level in the tank, triggering low-level and low-low-level alarms.
2. Relief Valve: Prevents overpressure in the hydraulic system by releasing excess pressure.
3. Manual Bypass Valve: Allows manual override or bypass of the hydraulic system in case of failure.
4. Low-Pressure Valve: Alerts if hydraulic pressure drops below safe operating levels.
5. High Lube Oil Temperature Cut-Out: Shuts down the system if lubrication oil temperature exceeds safe limits.
6. Low-Level Cut-Out: Shuts down the hydraulic system if the oil level falls below a critical point.

Electrical Safeties:
- **Electrical and Mechanical Stopper for Rudder:** Prevents the rudder from moving beyond safe limits.
- **Electrical Motor Overload Alarm:** Warns if the steering motor is drawing excessive current.
- **Power Failure Alarm:** Alerts the crew in case of a loss of power to the steering system.
- Self-Starting after Power Failure: Automatically restarts the steering gear after a power outage.
- **Short-Circuit Trip:** Cuts power to the system in the event of a short circuit.
- **Phase Failure Alarm:** Detects loss of one or more phases in a three-phase electrical supply.
- **7.200% Insulation in Motor:** Ensures the motor has double insulation for added protection.

Other Safety Devices for the Steering System:
- **Hunting Gear:** Used to reduce oscillations in the steering gear system.
- **Buffer Spring:** Helps to absorb shock and prevent mechanical damage.
- **Double Shock Valve:** Provides protection against hydraulic shock in the system.

(b) A turning propeller shaft on a ship becomes electrically insulated from the hull by the lubricating oil film in the bearings and by the use of non-metallic bearing materials in the tail shaft. When the shaft is insulated in this way an electrical potential can be measured between the shaft and the hull and this can accelerate corrosion in the ship.
If the ship has a system of cathodic protection, whether it is sacrificial anode or an impressed current system, the shaft insulation will prevent the propeller and the boss from receiving protection.

The electrical potential between the shaft and the hull can also cause a heavy current to flow in bearings when the oil film breaks down or is contaminated with seawater.
This current can cause deep pitting of the bearing surface. Excessive wear on the shaft bearings can often be traced to this cause.

Now in addition it's necessary to reduce the spark erosion causing the excessive wear on main engine metal bearings and this shaft earthing is the most appropriate method.
All the troubles can be avoided and cathodic protection can be extended to the propeller if the shaft is properly earthed with a propeller shaft slip ring. The effectiveness of the shaft earthing system should ensure a maximum contact resistance of no greater than 0.001 ohms for a water filled bearing and 0.01 ohms for an oil filled bearing.
The shaft earthing assembly comprises a pair of high silver content / graphite compound brushes mounted in balanced brush holder, running on a silver alloy slip ring.

(a) What are the protections provided for the electrical equipment of ship's steering gear? (12)
(b) Describe steering gear tests and drills (4)

June 2023

(a) As per regulation 29 & 30 of SOLAS, the following protections are to be provided for electrical equipment of steering gear.

- Each electric or electro-hydraulic steering gear comprising of one or more power units shall be served by at least two exclusive circuits fed directly from the main switch board, however, one of the circuits may be supplied through the emergency switchboard.
- Short circuit protection and an overload alarm shall be provided for electrical circuits, motors and control-circuits. Protection against excess current, including starting current, if provided, shall be for not less than twice the full load current of the motor or circuit with a time- delay to permit the passage of starting current.
- In the event of a failure of electrical power supply to the motors or control circuits, an audio-visual alarm shall be provided at the navigation bridge and machinery space
- Further, indicators for running indication of the motors of electric and electro-hydraulic steering gear must be installed in a suitable location.
- Main and auxiliary steering gear power units shall be arranged to restart automatically when power is restored after a power-failure.
- In the event of failure of electrical power to the circuits or motors or control circuits of steering gear, an alternative course of emergency alternative source of emergency power shall be provided automatically within 45 sec.
- For motors used in operation of electro hydraulic steering gears, fuses, overload alarm and power failure alarm are provided as protective devices.

(b) Steering Gear Tests and Drills:
To prevent accidents due to steering gear failure, regulations and guidelines are provided by the International Maritime Organization (IMO) and SOLAS (Safety of Life at Sea). Chapter 5, Regulation 26 of SOLAS 74 outlines the following tests and drills that must be carried out:

- The Main Steering Gear: The steering gear and its connecting linkages should be visually inspected. The rudder should be given full movement based on the steering gear capability.
- The Auxiliary Steering Gear
- The Remote Steering Gear Control System
- The Steering positions located on the Navigation Bridge
- The Emergency Power Supply
- All rudder angle indicators
- All alarms of Steering Gear control system and its power
- Quarterly Emergency Steering Drills
- Tests on direct control from the Steering Gear room

- Tests on Communications between Steering Gear Control - Room and Navigation Bridge
- Operation of alternative power supplies.

Transformer

- **Notes:**

(a) Explain how excitation of the rotor is produced and supplied. (6)
(b) A 25 kVA, single phase transformer has 250 turns on the primary and 40 turns on the secondary winding. The primary is connected to 1500 V, 50 Hz mains calculate: (10)
(i) Secondary emf
(ii) Primary and secondary current on full load
(iii) Maximum flux in the core.

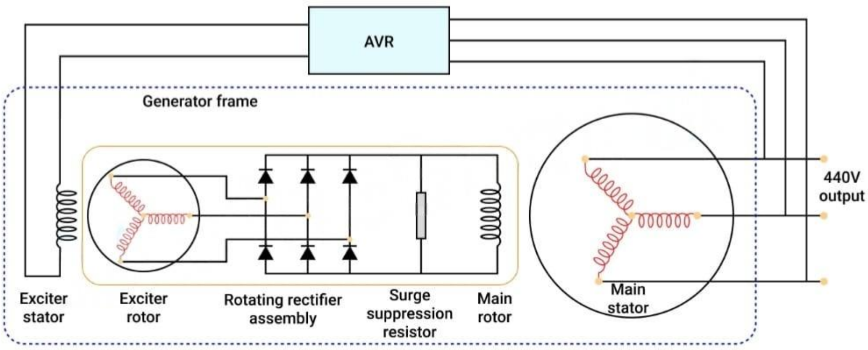
Feb 2025

(a) In an AC generator, excitation of the rotor is a process that involves creating a magnetic field in the rotor, leading to the generation of alternating current in the stator windings. Excitation is necessary to induce the flow of electric current within the generator.

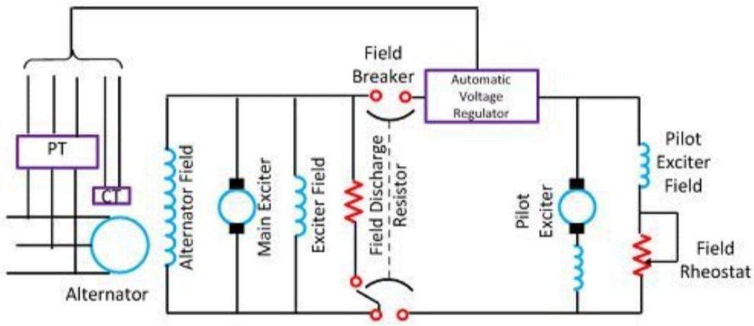
There are typically two main types of excitation systems in AC generators: brushless excitation systems and brush excitation systems.

Brushless Excitation System: In brushless excitation systems, the rotor is equipped with a rotating field winding. The excitation process involves the following steps:

- **AC Voltage Generation:** The stator windings of the generator produce an initial AC voltage. This voltage is often derived from an auxiliary AC power source or from the generator itself during initial startup.
- **Rectification:** The AC voltage is then rectified into DC voltage by a rectifier system. This system usually includes diodes or thyristors (SCRs) that convert the AC voltage into a unidirectional flow of current.
- **Rotor Excitation:** The DC voltage is supplied to the rotor winding, creating a magnetic field. This field induces an electromotive force (EMF) in the stator windings, leading to the generation of AC power.
- **Voltage Regulation:** The excitation system may include a control mechanism to regulate the DC voltage supplied to the rotor. This control ensures that the generator output voltage remains stable and within the desired range.



- **Brush Excitation System:** In brush excitation systems, the rotor is equipped with a direct current (DC) field winding. The excitation process involves the following steps:
- **External DC Source:** A separate DC source, often a DC generator or a rectified DC power supply, provides the initial excitation to the rotor.
- **Rotor Winding Excitation:** The external DC source supplies a constant DC voltage to the rotor's field winding, creating a strong and steady magnetic field.
- **AC Voltage Generation:** As the rotor rotates within the stator windings, the magnetic field induces an AC voltage in the stator windings, generating electrical power.
- **Voltage Regulation:** Similar to the brushless excitation system, a control mechanism is employed to regulate the DC voltage supplied to the rotor, ensuring stable generator output.



DC Excitation System

(b) Given:

$P=25kVA = 25\times10^3 VA$

N1=250

N2=40

V1=1500

F=50Hz

To find:

(i) Secondary emf(V2)

$\frac{N1}{N2} = \frac{V1}{V2}$

V2=V1×N2/N1

$=1500\times \frac{40}{250}$

V2=240V

(ii) Primaryandsecondarycurrent(I1andI2)(ii)Primaryandsecondarycurrent(I1andI2)

P=VI

$P=V_1I_1$

$I_1=P/V1$

$I_1= \frac{25\times103}{1500}$

$I_1=16.667A$

$P= V_2I_2$

$I_2= \frac{25*103}{240}$

iii) Max Flux in core:

Use induced voltage formula and solve for φm

V_2= φm*4.44*N_2*f

$$\varphi m = \frac{V2}{4.44*N2*f}$$

$$\varphi m = \frac{240}{4.44*40*50}$$

φm = 0.027wb

(a) The current transformer (CT) and potential transformer (PT) or voltage transformer are both measuring devices. List their shipboard application. (6)

(b) Sketch and describe any one type of current transformer. (10)

Dec 2024-1 **Mar 2025**

(a) Both CTs and PTs are used in ship electrical systems for measurement, protection, and control. Their applications include:

Current Transformer (CT) Applications:

- **Protection Relays:** Used in circuit breakers for overcurrent, short circuit, and earth fault protection.
- **Ammeter Readings:** Provides scaled-down current readings for monitoring electrical load.
- **Power Management System:** Helps in load sharing, synchronization, and power factor correction.

Potential Transformer (PT) Applications:

- **Voltage Monitoring:** Used to step down high voltage for measurement and protection.
- **Synchronizing Generators:** Helps in generator synchronization by providing reference voltage.
- **Protective Relays:** Used in overvoltage, undervoltage, and frequency protection circuits.

(b) There are mainly three types of current transformer.

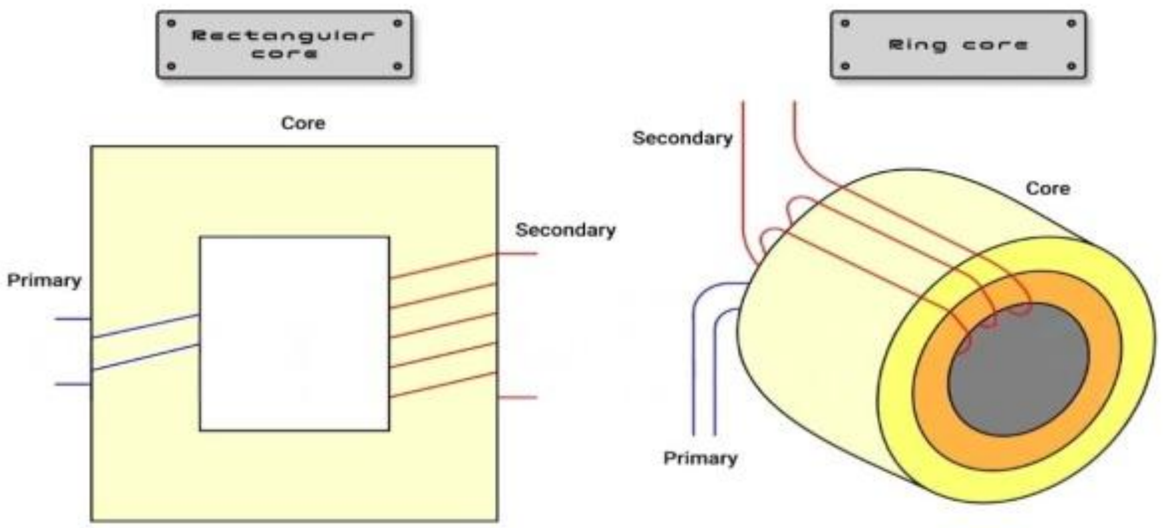
- Wound transformer
- Bar type current transformer
- Toroidal current transformer

Wound Type Current Transformer:

In this transformer, the primary winding is composed inside the transformer. The primary winding had a single turn and connected in series with the conductor that measured the current. The wound transformer is mainly used for measuring the current from 1 amps to 100 amps.

The core of the current transformer is built up with lamination of silicon steel. For getting a high degree of accuracy the Permalloy or Mumetal is used for the making cores. The primary windings of the current transformers carry the current that is to be measured, and it is connected to the main circuit. The secondary windings of the transformer carry the current proportional to the current to be measured, and it is connected to the current windings of the meters or the instruments.

The primary and the secondary windings are insulated from the cores and each other. The primary winding is a single turn winding (also called a bar primary) and carries the full load current. The secondary winding of the transformers has a large number of turns.



(a) Describe a simple single phase transformer. (6)
(b) A 15 KVA, 440/110-volt, 50Hz cycle/sec, single-phase transformer has primary and secondary resistances of 0.12 ohm and 0.0077 ohm respectively. The iron loss of the transformer is 0.16 kW. Calculate the efficiency of the transformer (10)
(i) On full load unity power factor
(ii) On 80 per cent full load at a power factor of 0.9 lagging

Dec 2023 **Mar 2023** **Sep 2022**

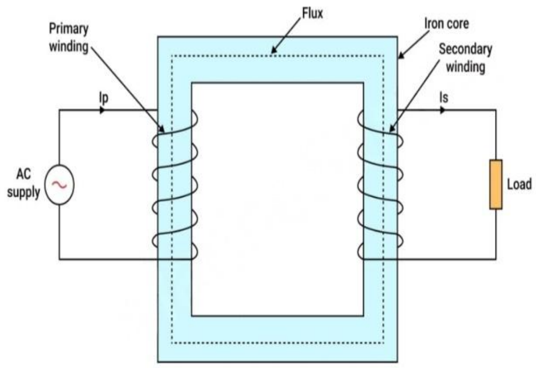
(a) A transformer is static equipment which transforms electric power of one circuit into electric power of the same frequency of another circuit.

The basic principle of a transformer is mutual (electromagnetic) induction between two circuits linked by a common magnetic flux possessing high mutual inductance. Transformer ratio is the ratio of voltage in secondary windings to the voltage in primary windings.

Turns ratio is the ratio of number of turns in secondary windings to the number of turns in primary windings. If the turns ratio or transformer ratio is greater than 1, the transformer is said to be a step up transformer. If it is less than 1, it is said to be a step down transformer.

When the transformer is under no-load conditions, the primary input current magnetizes the core and supplies iron losses in the core. Equivalent circuit model is used to describe the no-load operation of transformer.

Iron loss and copper loss are the two main types of energy losses of transformers. Iron loss is divided into hysteresis loss and eddy current loss.



(b)Given:

Iron loss = 160w

kVA rating = 15k VA

V_1= 440V, R_1= 0.12Ω

V_2= 110v, R_2= 0.0077Ω

(i) $\eta f1 = \frac{x*kVA*cos\phi}{x*kVA*cos\phi + x2Pcu+Pi}$

X=1; cosϕ =1

$I_1 = \frac{P}{V1} = \frac{15k}{440}$ = 34.09A

$P_{cu1} = I_1^2 R_1$

= 34.09^2*0.12 = 139.45W

$I_2 = \frac{P}{V2} = \frac{15k}{110}$ = 136.36A

$P_{cu2} = I_2^2 R_2$

= 136.362* 0.0077 = 143.17W

$\eta f1 = \frac{1*15*1}{1*15*1+0.13945+0.143317+0.16}$ = 97.13

ii) η =80

x= 0.8, cos ϕ =0.9

$\eta_{80} = \frac{0.8*15*0.9}{0.8*15*0.9+((0.8)2.(0.13945+0.1431))+0.16}$

= 96.94

(a) What are the effects of voltage and frequency changes on transformer functioning? (8)
(b) State the various energy losses in transformers. (8)

Sep 2023

(a) Effects of Voltage and Frequency Changes on Transformer Functioning:
Voltage Changes:

- **Iron Loss:** Varied proportionally to the square of voltage (V^2).
- **Copper Loss:** Varied as V^2 for constant KVA output.
- **Efficiency:** Decreased at fractional loads with an increase in voltage.
- **Efficiency at Full Load:** Increased with an increase in voltage and vice versa.
- Regulation: Varied as V^2 but decreased with an increase in voltage for constant KVA output.
- **Temperature:** Increased for the constant KVA output scenario.
- **Winding Temperature:** Decreased with an increase in voltage and vice versa.
  Frequency Changes:
- **Iron Loss:** Eddy current losses are directly proportional to square of frequency and the hysteresis losses are Directly proportional to the frequency.
- **Copper Loss:** Unaffected by changes in frequency.
- **Efficiency:** As the core losses at Higher frequencies are greater, efficiency decreases with increase in frequency.
- **Regulation at Unity Power Factor:** Not affected because IR drop is independent of frequency.
- **Regulation at Low Power Factor:** Decreased with a decrease in frequency and vice versa.
- **Total Loss:** Greater at lower frequencies.
- **Temperature:** Increased with a decrease in frequency.

(b) Various Energy Losses in Transformers:

- Iron Loss (Hysteresis loss & Eddy current loss): Occurs due to the continuous reversal of magnetization in the transformer core. Primarily dependent on the frequency of the alternating current.
- Copper Loss: I^2R Loss in the winding resistance, increases with the square of the current, contributing to resistive heating.
- Stray Loss (Leakage Flux Loss): Occurs due to the leakage of magnetic flux from the core, causing energy loss.

- Dielectric Loss: Results from the energy dissipated as heat in the insulating materials, especially in the transformer's insulation system.

(a) Discuss the open circuit and short circuit test performed for transformer.
(b) The primary and secondary windings of a 30 KVA, 6000/230 V, 1hp transformer have resistance of 10 Ω and 0.016 Ω respectively. The reactance of the transformer referred to the primary is 34 Ω. Calculate the primary voltage required to circulate full load current when the secondary is short circuited. What is the power factor on the short circuit?

Aug 2023

(a) Open Circuit Test:
The primary purpose of the open circuit test, also known as the no-load test, is to determine the core losses and exciting current when the transformer is under no-load conditions. To carry out open circuit test, proceed as follows:
- Connect the transformer to a variable AC voltage source.
- Keep the secondary winding open-circuited.
- Gradually increase the voltage until the rated voltage is reached.
- Record the input voltage, current, and power.

Short Circuit Test:
The short circuit test, also known as the impedance test or the full-load test, is conducted to determine the copper losses and leakage reactance of the transformer under full-load conditions. Short circuit test is described as follows:
- Connect the transformer to a variable AC voltage source.
- Short-circuit the secondary winding.
- Gradually increase the voltage until the rated current is reached.
- Record the input voltage, current, and power.

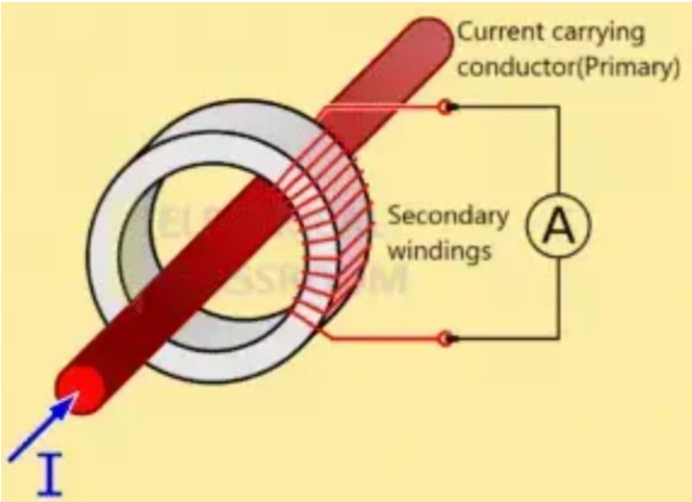
(b)
Transformation ratio,K= $\frac{230}{6000} = \frac{23}{600}$
Equivalent resistance referred to primary, R_{01} = R1 +$\frac{R2}{K2}$
$10+0.016(600/23)^2=20.89\Omega$
Equivalent reactance referred to primary,,$X_{01}=34\Omega$
Equivalent impedance referred to primary, $Z_{01}= \sqrt{(R_{01})^2+(X_{01})^2}$
$=\sqrt{(20.89)2+(34)2}= 39.904\Omega$
Full-load primary current,,$I_1 = \frac{\text{RatedKVA}\times 1000}{\text{V1}}$
$= \frac{30\times 1000}{6000}$ =5A
Primary voltage required to circulate full load current when the secondary is short-circuited
$V_s=I_1Z_{01}$
5×39.904=199.52V
Power factor on short circuit:
PF(Cosϕ)=($\frac{\text{Ra}}{\text{Za}}$)=($\frac{20.89}{39.90}$)
$\text{Cos}\varphi$ = 0.52

(a) List the applications of CT and PT (Current and voltage transformers) (6)
(b) Sketch and describe any one type of current transformer (10)

May 2023

(a) Current Transformers: A current transformer is a type of instrument, used to measure or sense large alternating currents by scaling it to a smaller, safer and measurable value. It transforms the primary current to a proportional secondary value in terms of magnitude and phase. Current transformers are available in various sizes and shapes and are used as an interface between high currents and measuring/sensing devices. They are also known as CTs.

It is difficult to make measurement devices such as an ammeter or a wattmeter(kWh) meter and protection relays that can carry hundreds or thousands of amperes. Also, higher voltage levels make these devices dangerous to connect. These barriers can be overcome using a CT. The turns ratio of a current transformer is made such that the full load current in it's primary give a secondary current of either 5A or 1A.



Voltage transformer: A potential transformer (PT) is a static device used to step down high voltages to measurable levels in order to facilitate measurement and controllability. Low voltages are easy to measure and can be used to operate protection relays.

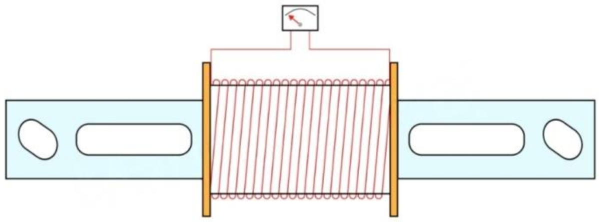
The electric power is transmitted and distributed at various high voltages. These voltages need to be stepped down to the rated voltage of measurement devices for voltage measurements. Also, measurement devices cannot be directly connected to high voltage circuits for measurement. In addition to that, it improves the compatibility of standard measuring devices.

Applications of CT:
- Monitoring the circuit current and power
- Monitoring the power grid operation and operating protection early

Applications of PT:
- Power source
- Measure and operating protective relay.

(b) Bar-Type Current Transformer:
In a bar-type current transformer, the primary winding consists of a single bar of suitable size, forming an integral part of the transformer itself. The core assembly surrounds the primary bar, and the secondary winding is wound on the core. The primary bar passes through the central opening of the core. This design allows the primary conductor (bar) to pass through the transformer, providing a convenient means of sensing the current without the need for a

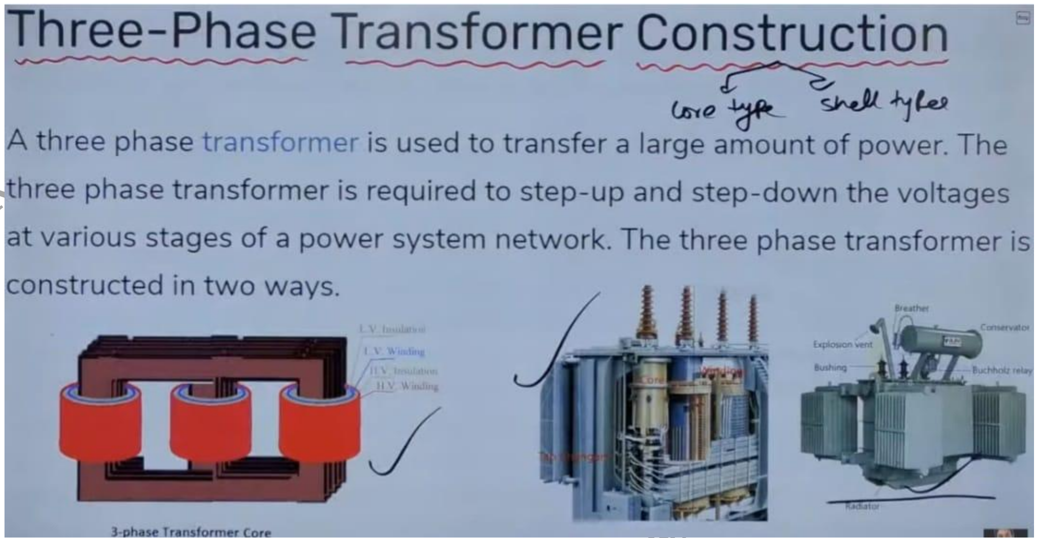
separate primary winding. Bar-type current transformers are often used in applications where it is feasible to pass the primary conductor through the transformer, such as in busbar systems.



(a) Explain the construction of three phase transformers and their four main types of connections. (10)
(b) Explain the procedure of terminal identification of single phase and three phase induction motor. (6)

Nov 2022

(a) The Three-Phase Transformer is a transformer made up of three sets of primary and secondary windings. They operate as an electrical system that has three phases. The three-phase transformers can be constructed in two ways, one is three identical single-phase transformers are connected to form a three-phase transformer bank, or else a single unit of a three-phase transformer with the windings of three phases wound on a single core.



The types of connections in a 3-phase transformer:

- **Delta-Delta (Δ-Δ) Connection:** Both primary and secondary windings are connected in a delta (Δ) configuration.
- **Delta-Star (Δ-Y) Connection:** The primary winding is connected in a delta (Δ) configuration, while the secondary winding is connected in a star (Y) configuration.
- **Star-Delta (Y-Δ) Connection:** The primary winding is connected in a star (Y) configuration, while the secondary winding is connected in a delta (Δ) configuration.
- **Star-Star (Y-Y) Connection:** Both primary and secondary windings are connected in a star (Y) configuration.
- **Open Delta (V-V) Connection:** Only two transformers are used to create a three-phase connection, typically in a delta (Δ) configuration.

(b) Three-phase induction motor:
Using a multimeter set to the resistance (ohms) mods, Measure the resistance of terminals and note the reading. 1. Set the multimeter to the ohms setting. 2. Touch the red probe to one

of the terminals and the black probe to the other terminal. 3. Record the resistance reading. 4. Repeat steps 2 & 3 for the other two terminals. 5. The terminal with the highest resistance is the start terminal. 6. The terminal with the lowest resistance is the run terminal. 7. The terminal with the resistance in between the start and run terminals is the common terminal.

(a) Give a brief outline about general maintenance of transformers (4)
(b) Explain about transformer rewinding and testing of transformer oil (4)
(c) A why jacketed fuel pipes are employed, 1100/220V, 50Hz, single-phase transformer has a leakage impedance of (0.1 + j0.40) ohm for the H.V winding and (0.006 + j0.015) ohm for the L.V winding. Find the equivalent winding resistance, reactance and impedance referred to the H.V and L.V sides (8)

Jul 2022

(a) General Maintenance - Transformers

- The insulation resistance should be measured with megger periodically. All the windings to earth need to be meggered individually. Meggering between windings is also essential.
- Polarisation Index (P.I) value (I.R value at 10 min divided by I.R. value at one minute) of the winding insulation shall be checked.
- Connection points should be checked for tightness observing for any hot spots.
- The D.C resistance value of the windings should be measured in all taps.
- All the parts including windings shall be cleaned and inspected for any signs of physical damage or spot heating.
- Gaskets in the covers shall be checked and must be securely placed back.

(b)

Transformer Rewinding:

Transformer rewinding is the process of removing the damaged or burnt windings of a transformer and replacing them with new windings using copper or aluminium wire. It is done when the transformer windings get short-circuited, overheated, or aged. Proper insulation, correct turns ratio, and tight winding are essential to restore the transformer's performance.

Testing of Transformer Oil:

Transformer oil is tested to ensure its dielectric strength, moisture content, acidity, and insulating properties are within safe limits.

Common tests include:

- BDV (Breakdown Voltage) Test: Checks the oil's ability to withstand high voltage without breaking down.
- Moisture Content Test: Water in oil reduces insulation; measured using a Karl Fischer titrator.
- Acidity Test: Detects oil degradation by measuring acidic content.
- Interfacial Tension & Flash Point Tests are also conducted for safety and quality control.

(c) Given:

R1= 0.1Ω, X1=0.4Ω, V1=1100V
R2=0.006Ω, X2=0.015Ω, V2=220V

Turns ratio, $K=\frac{V2}{V1}=\frac{220}{1100}=\frac{1}{5}=0.2$

(i)

Referred to HV side(primary)

Equivalentresistance, $R_{01}= R_1+R_2' = R_1+\frac{R2}{k2}$

$R_{01}= 0.1+\frac{0.006}{(0.22)} = 0.1+0.15$

R_{01}=0.25Ω

Equivalentreactance,X_{01}= X_1+X_2‘=X_1+($\frac{X2}{k2}$)

X_{01}=0.4+ $\frac{0.015}{(0.22)}$ =0.4+0.375

X_{01}=0.775Ω

Impedance, Z_{01}= $\sqrt{R201} + X201$

=$\sqrt{0.252} + 0.7752$

Z_{01}= 0.8143 Ω

Refering to the LV sode(secondary)

Resistance, R_{02} = R_2 +R_1 = R_2+R_1*K^2

=0.006+0.1* $(0.2)^2$

R_{02} = 0.01 Ω

Reactance , X_{02} = X_2 +X_1 = X_2+X_1*K^2

=.015+ 0.4*$(0.2)^2$

X_{02} = 0.031 Ω

Impedence, Z_{02} = $\sqrt{R202} + X202$

Z_{02}= $\sqrt{0}.012 + 0.0312$

Z02= 0.0326 Ω

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others

- **Notes:**

(a) Compare Direct current with Alternating current. (6)
(b) With respect to alternating voltage wave form, explain the following terms: Time period, Frequency, Cycle, Peak Value, Peak to peak value. (10)

Oct 2023

(a) Comparisiion of DC with AC

Direction of Current:
- DC: Electrons flow in one direction, maintaining a constant polarity.
- AC: Electrons periodically change direction, resulting in a reversal of polarity.
- DC: Voltage remains constant with a fixed polarity.
- AC: Voltage alternates, switching between positive and negative polarities.

Power Transmission:
- DC: Suitable for short-distance power transmission.
- AC: Efficient for long-distance power transmission due to the ability to change voltage levels using transformers.

Power Losses:
- DC: Power losses are more significant in long-distance transmission.
- AC: Power losses are comparatively lower over long distances.

Transmission Efficiency:
- DC: High-voltage direct current (HVDC) systems improve efficiency for long-distance transmission.
- AC: Better suited for local distribution.

Transformer Usage:
- DC: Transformers cannot be used for direct current; conversion to AC is required.
- AC: Transformers efficiently change voltage levels in AC systems.

Devices and Appliances:
- DC: Batteries, electronic devices, and some motors operate on DC.
- AC: Common in household appliances, lighting, and most electric motors.

Frequency:
- DC: Frequency is not applicable as it involves a constant flow.
- AC: Frequency represents the number of cycles per second (Hertz).

Safety:
- DC: Generally considered safer for low-voltage applications.
- AC: High-voltage AC can be more dangerous due to the potential for stronger shocks.

Generation:
- DC: Generated by batteries, solar cells, and certain types of generators.
- AC: Produced by most power plants for grid distribution.

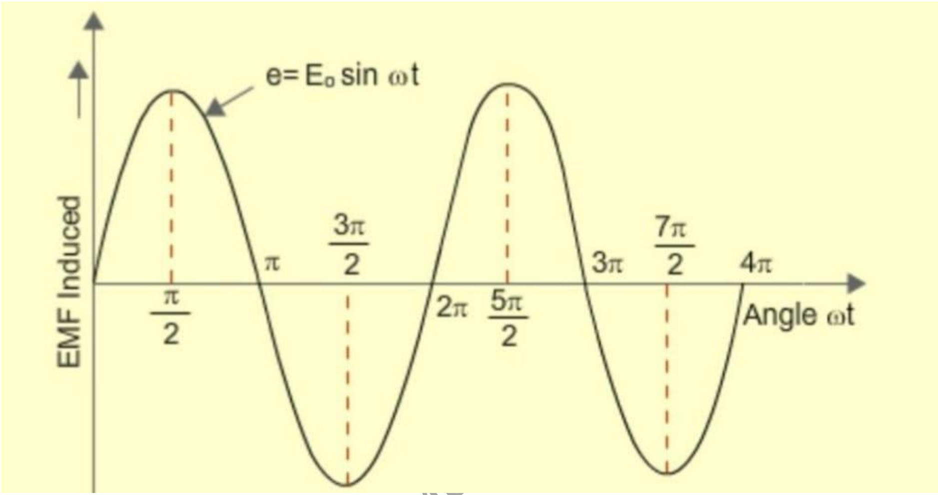
Waveform Shape:
- DC: Has a constant, unidirectional waveform.
- AC: Waveform can vary (e.g., sinusoidal, square, triangular).

(b) Sine Wave The EMF can be represented by a sine wave as in image below, where E0 represents the maximum value of the EMF and e is the instantaneous value.

Time period: The time period of an alternating quantity is the time required to complete one cycle.

Frequency Frequency of the alternating quantity is the number of cycles per second, and its unit is hertz (Hz). It is denoted by f. Hence, the frequency of an alternating quantity is the reciprocal of the time taken for one cycle(T). Frequency = no. of cycles/ second or in hertz

For instance, 60 cycles or Hertz means that the cycle is repeated 60 times a second.



Cycle Each repetition of a variable quantity, recurring at equal intervals, is termed a cycle. A combination of positive and negative values is called a cycle. A cycle is also specified in terms of angular measure, wherein one complete cycle is said to spread over 360° or radians.

Peak value: The maximum instantaneous value measured from zero is the peak value.

Peak-to-peak value: The maximum variation between the maximum positive instantaneous value and the maximum negative instantaneous value is called the peak-to-peak value. For sinusoidal EMF it is twice the peak value.

(a) Explain the working of a Megger with the aid of its internal circuit. (12)
(b) What safety measures are taken while using a Megger? (4)

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(a) Megger works on the principle of electromagnetic attraction. It is used to measure the insulation resistance. The armature of the generator is rotated by the hand-driven crank lever. The clutch mechanism is designed at a predetermined speed, which facilitates the generator to maintain a constant speed and hence the constant voltage while testing.

The two coils A and B constitute a moving coil voltmeter and an ammeter, both are combined to form one instrument.

The 'hot' terminal of the equipment whose Insulation resistance has to be measured is connected to terminal X. Terminal Y is connected to the body of the equipment which is generally grounded.

When the crank handle is rotated the voltage is generated in the generator, the generated voltage is applied to the voltage-coil A through resistance R1.

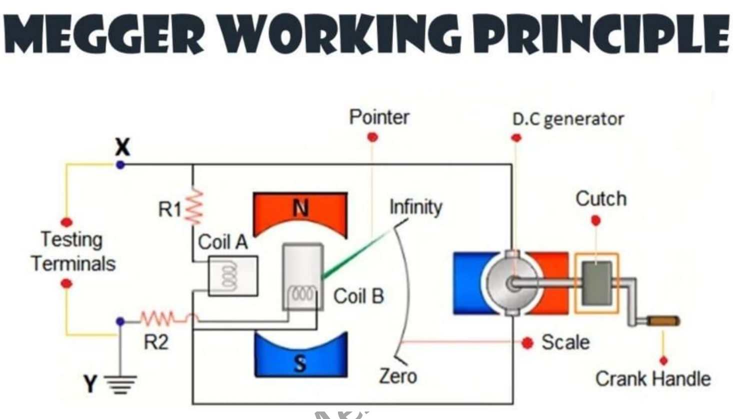
When terminals X and Y are free initially, no current flows through coil B. The torque produced by the coil A rotates the moving element to show infinity.

While testing the terminals X and Y are connected across the terminal and body of the machine for measurement. Now the current passes through the deflecting coil B.

The deflecting torque produced by coil B interacts with the torque of coil A and rotates the moving element to indicate the resistance value.

The voltage generated by this instrument is around 500V. Megger meters are available to generate 1000V, 2500V and 5000V also.

High-voltage meggers are either motor-operated or power-operated.



(b) Safety measures to take when using a Megger:

- Always wear safety glasses when using a Megger.
- Make sure that the Megger is properly grounded.
- Do not touch any live wires or terminals when using a Megger.
- Use the correct test leads for the voltage you are testing.
- Do not exceed the rated voltage of the Megger.
- Disconnect the power to the equipment you are testing before using a Megger.
- Be aware of the potential for arc flash when using a Megger.
- If you are not sure how to use a Megger, consult the manufacturer's instructions or have a qualified electrician help you.