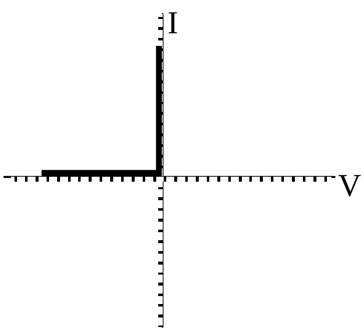
SJE(PAPER-II) -2018 MAINS
OFFLINE TEST SERIES

Electrical Engineering **Full Length Mock Test-1**

Solutions

01(a).

Sol: In an idealized p-n junction, if the junction is reverse biased, the current flowing through it is zero. This ideal diode starts conducting at 0V and for any positive voltage an infinite current flows and the diode acts like a short circuit. The I-V characteristics of an ideal diode are shown below:



The axes of the graph below shows both positive and negative values and so intersect at the centre. The intersection has a value of zero for both current (the Y axis) and voltage (the X axis). The axes +I and +V (top right) show the current rising steeply after an initial zero current area. This is the forward conduction of the p-n junction diode when the anode is positive and cathode negative.

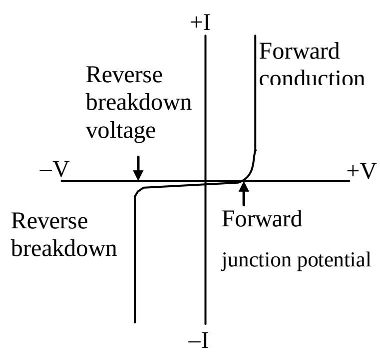
Initially no current flows until the applied voltage is at about the forward junction potential, after which current rises steeply showing that the forward resistance (I/V) of the diode is very low; a small increase in voltage giving a large increase in current.

The V and I axes show the reverse biased condition (bottom left). Here we see that although the voltage increases hardly any current flows. This small current is called the leakage current of the p-n junction diode and is typically only a few micro-amps with germanium diodes and even less in silicon.

If a high enough reverse voltage is applied however there is a point (called the reverse breakdown voltage) where the insulation of the depletion layer breaks down and a very high current suddenly flows. In most diodes this breakdown is permanent and a diode subjected to this high reverse voltage will be destroyed.

In Zener diodes however, this point is used to give the diode its special ability to stabilise the applied voltage: If the voltage increases at this point heavy current flows and reduces the voltage.

The breakdown in a Zener diode is not destructive due to its special construction.

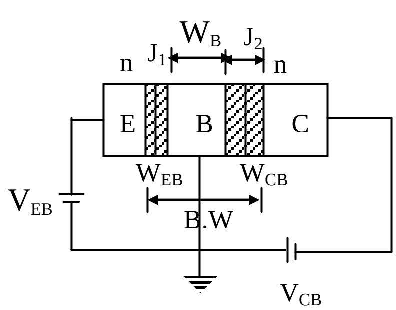


01(b).

Sol: Concept of Early effect:

In the active region, the emitter –base junction is forward biased and collector- Base junction is reverse-biased.

Pictographically representation of the figure is as shown below:



W_{EB} = Emitter Base width

W_{CB} = Collector Base width

W_B = Base width

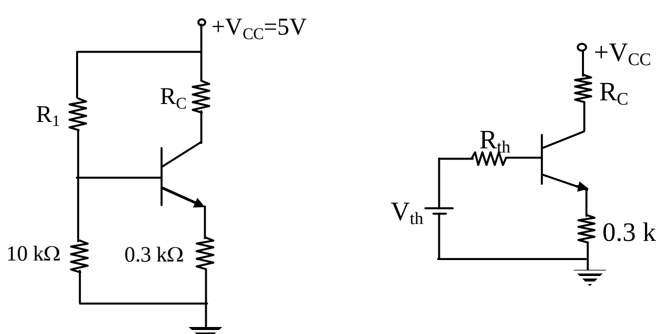
The width of the emitter base junction is less than the collector base width. When V_{CB} is increased the effective base width decreases and the deflection region of the junction 'J_2' increase there by increasing the charge gradients in the base and decreasing the Recombination rate. As the charge gradients are increasing, the emitter current 'I_E' increases. As still the reverse bias voltage (V_{CB}) increases, beyond certain voltage cut in voltage there is a drastic increase in 'Emitter current. This modulation is called Early Effect.

Due to early effect,

- Effective base width decreases
- Recombination rate in base region decreases. Base transport factor β^* and also 'α' increases.
- Concentration gradient of minority carriers is increased with in base and due to this current of minority carriers injected across the emitter junction increases with increase V_{CB} voltage.
- As V_{CB} increases to very high values, the junction 'J_2' overlaps with the base width and hence it results the phenomenon called punch through.

01(c).

Sol: Convert the given circuit into it's equivalent Thevenin's circuit.



$$V_{th} = \frac{V_{CC}(10k)}{R_1 + 10k}; R_{th} = \frac{(10k)R_1}{10k + R_1}$$

Apply KVL at the input loop:

$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$

$$\frac{5\times10\,k}{R_1+10\,k}-I_B\left(\frac{(10k)R_1}{10k+R_1}\right)-0.7-(\beta+1)I_B(0.3\,k)=0 \text{ .... (1)}$$

Given $I_C = 1mA$

We know that, $I_C = \beta I_B$

$$\Rightarrow I_B = \frac{I_C}{\beta} = \frac{1}{100} = 0.01\,mA$$

Putting value of β in equation (1),

$$\frac{5\times10\,k}{R_1+10\,k}-\left(\frac{10\,R_1}{R_1+10\,k}\right)(0.01)-0.7-0.303=0$$

$$\frac{50\,k-0.1R_1}{R_1+10\,k}=1.003$$

$50\text{ k} - 0.1\ R_1 = 1.003\ R_1 + 10.03\text{ k}$

$\Rightarrow \quad R_1 = 36.23\ k\Omega$

Apply KVL outer loop

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$5 - R_C \times 10^{-3} - 2.5 - 0.303 = 0$

$\Rightarrow \quad R_C = 2.197\ k\Omega$

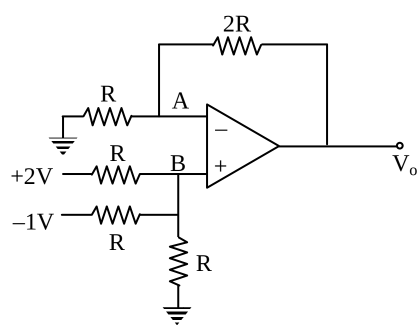
01(d).

Sol: Voltage at B = Voltage at A

$$\frac{V_B-2}{R}+\frac{V_B+1}{R}+\frac{V_B}{R}=0$$

$$3V_B - 1 = 0 \Rightarrow V_B = \frac{1}{3}$$

$$\frac{V_A-0}{R}+\frac{V_A-V_0}{2R} = 0$$



$$3V_A = V_0 \Rightarrow 3\times\frac{1}{3} = V_0$$

$$V_0 = 1V$$

02(a).

Sol: Percentage regulation of transformer = (%R) $\cos\phi_2 \pm$ (%X) $\sin\phi_2$

Max. regulation occurs at only lag pf load

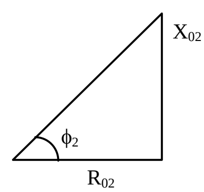
Hence % regulation = (%R) $\cos\phi_2$ + (%X) $\sin\phi_2$

Condition for Maximum Regulation is $\frac{d(\%\text{Reg})}{d\phi_2} = 0$

$$\phi_2 = \tan^{-1}\frac{(\%X)}{(\%R)} \text{ lag}$$

$$= \tan^{-1}\left(\frac{X_{02}}{R_{02}}\right)\text{lag}$$

Impedance triangle at maximum regulation is show in figure



From the above, pf of load corresponding to maximum regulation = $\cos\phi_2 = \frac{\%R}{\%Z}; \sin\phi_2 = \frac{\%X}{\%Z}$

$$\therefore \text{Max. Regulation} = (\%R)\left(\frac{\%R}{\%Z}\right) + (\%X)\left(\frac{\%X}{\%Z}\right)$$

$$= \frac{(\%R)^2 + (\%X)^2}{\%Z} = \%Z$$

02(b).

Sol: **Given data:** Output = 37 kW, Efficiency = 0.9

$$\therefore \text{Losses} = 37\left(\frac{0.1}{0.9}\right) = 4111 \text{ W}$$

At this load, stator copper loss = rotor copper loss = (stator) iron loss = W watts

Let mechanical loss (friction and windage) = W_m watts

Then $3W + W_m = 4111$ ……………….. (1)

On no load, the currents will be small and copper losses can be neglected. But stator iron loss and mechanical loss will remain unchanged.

So, $W + W_m$ = the no load loss.

It is given that $W_m = \frac{1}{3}(W + W_m)$

Solving, 3.5 W = 4111

$\Rightarrow$ W = 1174.6 watts and W_m = 587.3 W

Rotor copper loss = 1174.6 W

Rotor input = shaft output + rotor copper loss + mechanical loss = 38761.9 W

Slip s = Rotor copper loss/rotor input

$= \frac{1174.6}{38761.9} = 0.0303.$

02(c).

Sol: We know that $\theta_{elec} = \frac{P}{2}\theta_{mech}$.

Therefore, pole shoe subtends an angle $40 \times \frac{6}{2} = 120°$ electrical

Flux per pole = (air–gap area under one pole shoe) × (uniform flux density)

$$= \left(\frac{2\pi rl}{P} \times \frac{120}{180}\right) \times 0.6 = \frac{2\pi \times 0.2 \times 0.5}{6} \times \frac{2}{3} \times 0.6 = 0.042\,\text{Wb}$$

Total armature turns = 240 × 2 = 480.

This gives total armature conductors, Z = 480 × 2 = 960

Generated e.m.f at No-load, $E_a = \frac{\phi ZNP}{60A} = \frac{0.042 \times 960 \times 1200 \times 6}{60 \times 6} = 806.4\text{V}$

INDIA

02(d).

Sol: A synchronous machine operates satisfactorily if the mechanical speed of the rotor equal to the stator field speed. i.e.**,** if the relative speed between the rotor and stator speed is zero.

Any departure from these conditions gives rise to synchronizing forces, due to this rotor will oscillate about its new equilibrium position.

The synchronous machine oscillates about the operating point, due to:

1. sudden change in load
2. a fault in the supply system
3. a sudden change in field current
4. The load or drive containing harmonic torques

This oscillatory behavior of the synchronous machines is known as hunting.

The effects of hunting:

(i) It produces severe mechanical stress and fatigue in the shaft.

(ii) It causes great surges in current and power flow

(iii) It increases machine losses and thus the temperature rise of the machine.

The undesirable phenomenon of hunting, can be guarded against in three ways:

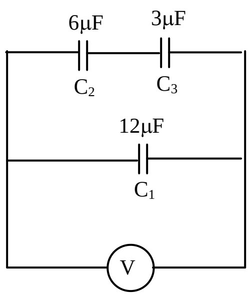
(a) by using flywheel

(b) by designing the synchronous machine with suitable synchronizing power coefficient or stiffness factor and

(c) by the employment of damper winding.

3(a).

Sol: Let ‘V’ volts be applied to the system



$$V_{C2} = V\left(\frac{3}{9}\right) = 6 \text{ (max)}$$

$\Rightarrow$ V = 18 V

$\therefore$ Voltage across 12 μF capacitor becomes 18 V it is not acceptable.

$$V_{C3} = V\left(\frac{6}{9}\right) = 3 \text{ (max)}$$

$\Rightarrow$ V = 4.5 V

It is acceptable for all capacitors

Therefore, the maximum safe voltage across the combination is 4.5 V

Equivalent capacitance of combination

$$C_{equ} = C_1 + (C_2 \| C_3)$$

$$= 12 + \frac{6\times3}{6+3} = 14\ \mu F$$

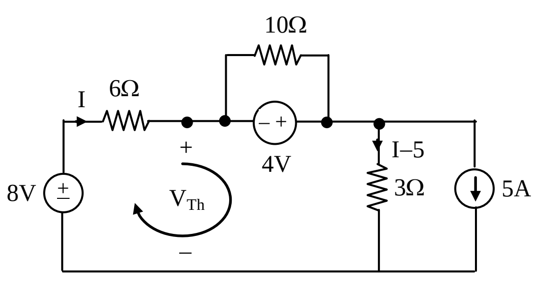
The total charge stored by the circuit is

$$C_{equ} = Q/V$$

$$\Rightarrow Q = 14 \times 4.5 = 63\ \mu C.$$

03(b).

Sol: To find V_{Th}:



By applying KVL to the above loop

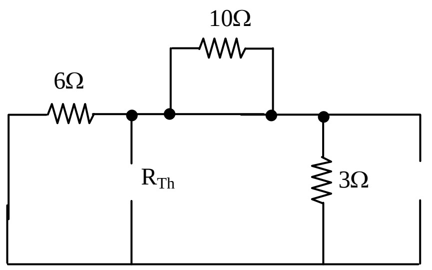
$$-8 + 6I - 4 + 3(I - 5) = 0$$

$$9I = 27$$

$$I = 3$$

$$V_{Th} = 8 - 3 \times 6 = -10$$

To find R_{Th} :



10 Ω is negligible and 6 Ω and 3 Ω are in parallel.

$$R_{Th} = \frac{6\times 3}{6+3} = 2\ \Omega$$

Maximum power transferred is

$$\frac{V_{Th}^2}{4R_{Th}} = \frac{10^2}{4(2)} = 12.5\ \text{W}$$

∴ Maximum power transferred = 12.5 W

3(c).

Sol:

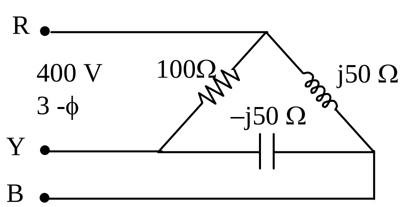


Fig.1

The unbalanced load is shown in Fig. 1. Power is consumed only in 100 Ω resistor.

Power consumed in the delta connected unbalanced load shown in Fig.1 is given by

$$P_1 = \frac{V_{ph}^2}{R} = \frac{(400)^2}{100} = 1600W$$

The star connected load with 'R_x' in each phase is shown in Fig.2.

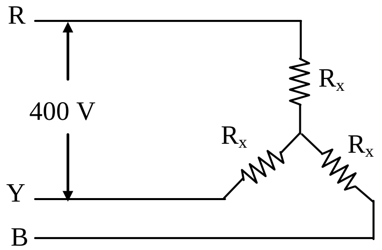


Fig.2

Power consumed in balanced star connected load as in Fig.2 is

$$P_2 = 3 \times \left[\frac{\left(\frac{400}{\sqrt{3}}\right)^2}{R_x}\right] = \frac{400^2}{R_x}$$

But given $P_1 = P_2$

$$\therefore \quad 1600 = \frac{400^2}{R_x}$$

$$\therefore \quad R_x = \frac{400 \times 400}{1600} = 100\ \Omega$$

3(d).

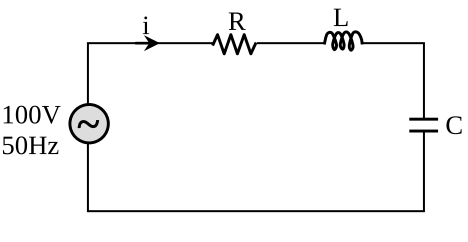
Sol: Voltage across capacitor = V_C

Voltage across inductor = V_L

At resonance condition $V_L = -V_C$

$100\text{ V} = V_R + V_L + V_C$

$V_R = 100$ V



Given current i = 5 A

$\therefore$ i × R = 100 V

$$R = \frac{100}{5} = 20\ \Omega$$

Given $|V_L| = |V_C| = 200$ V

$V_L = i \times \omega L = 200$ V

$$L = \frac{200}{5 \times 2\pi f} = \frac{200}{5 \times 2 \times \pi \times 50} = 0.1273\text{ H}$$

$V_C = \dfrac{i}{\omega C} = 200$ V

$$\frac{5}{2\times\pi\times f\times 200}$$

C = 79.57 μF

4(a).

Sol: Pumped Storage Plant: Pumped Storage Plants are a special type of power plants which work as ordinary hydro power plants for part of the time and when such plants are not producing power, they can be used as pumping stations which pump water from tail race to the head race. Thus, pumped storage plants can operate only if these plants are inter-connected in a large grid.

This plant consists of two ponds, one at a high level and other at a low level with power house near the low level pond. The two ponds are connected through a penstock as shown in figure. It is an ingenious way of conserving the limited water resources on the one hand and balancing the load on the distribution system, on the other hand. The plant operates as a source of electric energy during peak hours and a sink during off-peak hours.

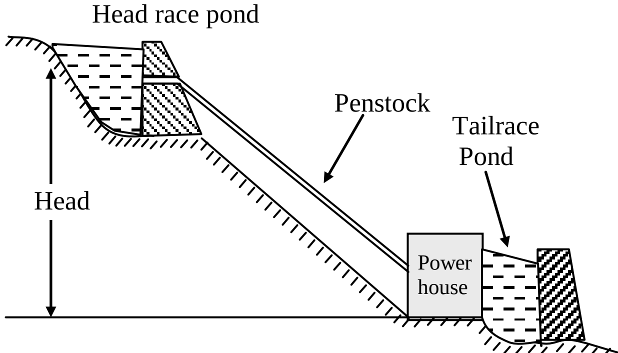


Fig. Pumped storage plant

The pumped storage plant plays very important role in large interconnected system. While generating, the turbine drivers the electric generator and in the reverse operation, the generator runs as a motor driving the turbine, which, now acts as a pump.

4(b).

Sol: Diversity factor: It is defined as the ratio of sum of the individual maximum demands to simultaneous maximum demand on power station. Maximum demand on power station will be less that the sum of individual maximum demands of consumers. Therefore Diversity factor always be greater than 1. If diversity factor is high, cost of power generation will be less and vice versa.

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demand on power station}}$$

Load factor: It is defined as the ratio Average load to maximum load during a given particular period. Load factor is always less than 1 because Average demand is smaller than maximum demand. Higher the load factor, lesser will be the cost per unit generation and vice versa.

$$\text{Load factor} = \frac{\text{Average load (demand)}}{\text{Maximum load (demand)}}$$

If Plant is in operation for 't' hours, then

$$\text{Load factor} = \frac{\text{Average load} \times \text{'t' hours}}{\text{Maximum load} \times \text{'t' hours}}$$

$$\text{Load factor} = \frac{\text{Units generated in 't' hours}}{\text{Maximum demand} \times \text{'t' hours}}$$

Plant capacity factor: It is defined as the ratio of actual energy generated to maximum possible energy that could have been generated during a particular period and this factor is an indication of the reserve capacity of the plant. Always plant capacity factor will be less than 1 because Average demand is smaller than plant capacity.

$$\text{Plant capacity factor} = \frac{\text{Actual energy generated}}{\text{Maximum energy that could have been generated}}$$

$$= \frac{\text{Average demand} \times \text{'t' hours}}{\text{Plant capacity} \times \text{'t' hours}}$$

Plant use factor: It is defined as the ratio of actual energy generated to the product of plant capacity and the number of hours for which the plant was in operation. Plant use factor which affects the cost of energy.

$$\text{Plant use factor} = \frac{\text{Actual number of units that are generated}}{\text{Plant capacity} \times \text{number of hours plantis actually in operation}}$$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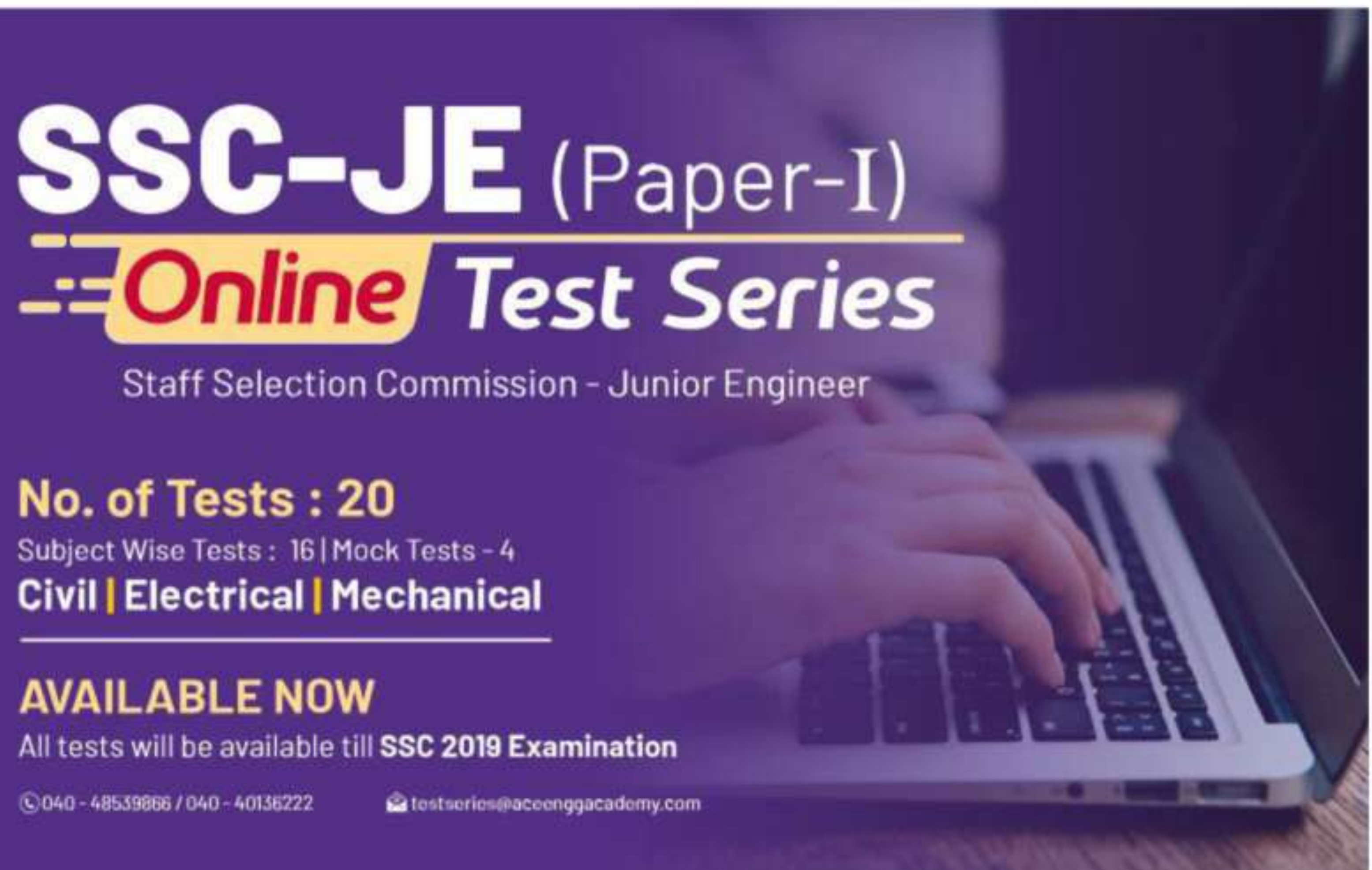
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4(c).

Sol: Biased differential relay as shown in figure(a) and it is also called as percentage differential protection.

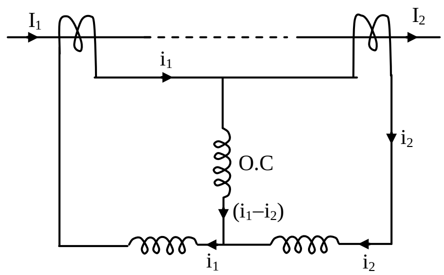


Figure: Biased differential relay

The relay consists of an operating coil and a restraining coil. The operating coil is connected to the mid point of the restraining coil. The operating current is variable quantity because of the restraining coil. Normally, no current flows through the operating coil under external fault condition. But due to the dissimilarities in C.T.S, the differential current through the operating coil is $|i_1 - i_2|$ and the equivalent current in restraining coil is $\frac{|i_1 + i_2|}{2}$.

The torque developed by the operating coil is proportional to the ampere turns i.e, $T_0 \propto |i_1 - i_2|\, n_o$ where n_o is the number of turns in the operating coil. The torque due to restraining coil $T \alpha \frac{|i_1 + i_2|}{2} n_r$ where n_r is the number of turns in the restraining coil. When the torque due to operating coil exceeds the torque due to the restraining coil, this relay operates.

$$|i_1 - i_2| n_0 \geq \frac{|i_1 + i_2|}{2} n_r \qquad \frac{|i_1 - i_2|}{\frac{|i_1 + i_2|}{2}} \geq \frac{n_r}{n_0}$$

The operating characteristics of percentage differential relay as shown in figure (b).

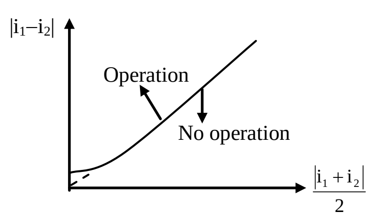


Fig.(b): operating characteristics of percentage differential relay

It is clear from the characteristic that except for the effect of the control spring at low currents, the ratio of the differential operating current to the average restraining current is a fixed percentage. This is why it is known as percentage differential relay.

The relay settings for transformer protection are kept higher than those for alternators. The typical value of alternator is 10% for operating coil and 5% for bias. The corresponding values for transformer may be 40% and 10% respectively.

4(d).

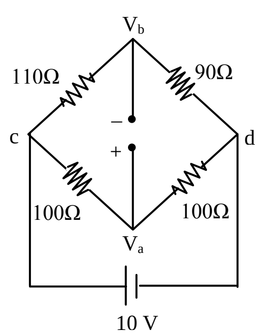
Sol: **Ferranti effect:** A long transmission line has large capacitance. If long transmission line is open circuited or lightly loaded at receiving end, the magnitude of voltage at receiving end becomes higher than the sending end voltage due to the charging current of the line. This phenomenon is called **Ferranti effect**.

If the reactive power generated at a point is more than the reactive power absorbed, then the voltage at the point becomes higher than the normal value and vice-versa. At receiving end, voltage is controlled by controlling the reactive power.

By using suitable compensation device (i.e. shunt reactor) with lightly loaded long line at receiving end, voltage at the receiving end is controlled there by Ferranti effect is reduced.

5(a).

Sol: The given bridge is unbalanced and the voltage across galvanometer can be obtained as



$V_{th} = V_a - V_b$

$$= \frac{10\times100}{100+100} - \frac{10\times90}{110+90} = \frac{100}{200} = \frac{1}{2}\text{V}$$

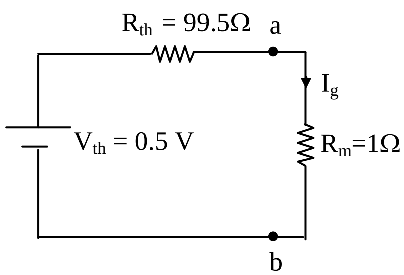
R_{th} = ?

$R_{th} = (100 \parallel 100) + (110 \parallel 90)$

$= 50 + 49.5 = 99.5\Omega$

∴ The thevinin's equivalent model

Galvanometer current



Galvanometer current

$$I_g = \frac{V_{th}}{R_{th} + R_m}$$

$$= \frac{\frac{1}{2}}{99.5+1} = 4.975\,\text{mA}$$

5(b).

Sol: Yes, one wattmeter reads negative when pf angle is more than 60°

Ex: $W_1 = 2000W$, $W_2 = -500W$,

$$\cos\phi = \cos\left[\tan^{-1}\left\{\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right\}\right]$$

$$= \cos\left[\tan^{-1}\left\{\sqrt{3}\left(\frac{2000+500}{2000-500}\right)\right\}\right]$$

$= 0.327$

$\therefore \phi = \cos^{-1}(0.327) = 70.9°$

5(c).

Sol: Given I = – 8 + 6 $\sqrt{2}$ sin (ωt + 30°)

If this current passed through a centre zero PMMC meter, it will read –8Abecause it reads only average value.

Moving iron meter always reads RMS value of waveform

So

$$I_{rms} = \sqrt{(-8)^2 + \left(\frac{6\sqrt{2}}{\sqrt{2}}\right)^2}$$

$$= \sqrt{100} = 10$$

So moving iron meter will read 10 A.

5(d).

Sol: DVM: A digital voltmeter (DVM) displays the value of a.c or d.c voltage being measured directly as discrete numerals in the decimal number system.

(ii) Advantages:

1. Digital meters offer very high input resistance in the order of MΩ.
2. Digital meters cause minimum loading on the quantity to be measured due to their high resistance and in turn they provide a reading with less error.
3. Digital meters offer better Accuracy in the order of $\pm$ 0.005%.
4. Digital meters offer superior resolution in the order of 1:10^6

   There are no moving parts in digital meters, hence no frictional errors.
5. Digital meters offer facilities like over ranging, auto ranging, auto polarity.
6. Digital meters display the measured value on a digital readout. As such, the reading speed of user increases; and observational errors will be eliminated.

   Digital meters can be programmed & well suited for computerized control.
7. In digital meters, output can be further processed (like storage) since it is available in digital form (like pulses or BCD code or 7 – segment code). This digital output can be directly fed into memory of modern digital instruments.

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06.(a)

Sol: 1. There must be some residual magnetism in generator poles. Due to retentivity property, all magnetic materials posses some amount of flux called "Residual magnetism", which is (5−10) % of rated value.

2. The connections of the field winding should be such that the field current strengthens the residual magnetism. If field terminals are wrongly connected, then separate the field terminals and excite with a low voltage for some time to re-establish residual magnetism. This process is called field flashing.

3. The resistance of the field circuit should be less than the critical resistance (Critical Resistance (R_c) is the total field resistance above which the generator fails to build up it's voltage). In other words, the speed of the generator should be higher than the critical speed. Critical speed is the speed of the generator below which it fails to build up it's voltage without any external resistance in field circuit.

4. When the generator build–up voltage under load condition, the load resistance must be more than the critical load Resistance (R_{LC}).

   If the resistance of the load is below critical load resistance, the generator fails to build up it's voltage because the load resistance is less than the equivalent shunt field resistance and then the armature current is more, more demagnetizing effect of armature reaction which may nullify the residual magnetism.

6(b).

Sol: Magnetostriction:

- The change in the dimensions of a material (i.e., strain produced in it) whenever it is magnetized is called magnetostriction.
- The deformation is different along different directions. It depends on the strength of the applied magnetic field and nature of the material only, and is independent of the direction of the field.
- The magnetostriction coefficient is defined as the change in length per unit length of the crystal in the direction of magnetization.

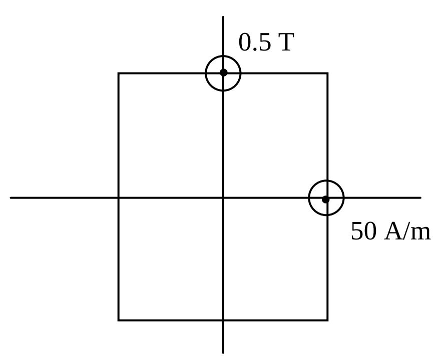
- The crystal length changes because when the direction of magnetization is made to change, a rearrangement of atoms takes place slightly which changes the length. This rearrangement is to keep the magneto crystalline anisotropy at minimum value.
  The change in length is about 1 part per million (ppm).
- Magnetostriction is a reversible effect because when the magnetic field is reduced, the atoms come back to initial positions to keep the anisotropy energy minimum.

Factors influencing hysteresis loss:

- The actual shape and size of the loop depend on the composition and internal structure.
- If the defects and impurities are less, domain wall motion becomes more and more reversible and the area of the hysteresis loop becomes smaller.
- The permeability and hysteresis loss depend on the physical condition and chemical purity of the sample. If the initial permeability is high, the hysteresis loss is low and vice – versa.
- Ferromagnetic crystals when cold worked, experience deformation and hence permeability decreases and hysteresis increases.
- Impurities affect the regular geometric pattern of the crystals and are harmful to magnetic properties. The main impurities in the materials used for transformer cores and electrical machinery are Carbon, Sulphur, Oxygen and Nitrogen.
  Carbon is most detrimental and the amount of Carbon is kept below 0.01% in commercial materials.

06(c).

Sol:



Hysteresis losses $= 100 \times 1 = 100\ J/m^3$

Volume, $= (\pi d) \times$ cross sectional area

$= \pi \times 1.6 \times 10^{-2} \times 0.25 \times 10^{-14}$

$= 1.256 \times 10^{-6}\ m^3$

Hysteresis losses $= 100 \times 1.256 \times 10^{-6}$

For one cycle $= 125.6 \times 10^{-6}$ Joule

For 50 cycles $= 50 \times 125.6 \times 10^{-6}$

$= 62.8 \times 10^{-4}$ joules

06(d).

Sol: Length of the core (l_c) = 39.8 cm

Length of the air gap (l_a) = 0.2 cm

We know

$MMF = R_M\,\phi$

$NI = R_M\,\phi$

$$\phi = \frac{NI}{R_M}$$

Where R_M = reluctance

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

$$B = \frac{NI}{R_M A}$$

$$B \propto \frac{1}{R_M}$$

Case-1:

Permeability of the core (μ_c) = ∞

$$(R_M)_1 = R_1 + R_2 = \frac{\ell_c}{\mu A} + \frac{\ell_a}{\mu_0 A}$$

$$(R_M)_1 = 0 + \frac{0.2}{\mu_0 2}$$

Case-2:

Permeability of the core (μ_c) =1000 μ_0

$$(R_M)_2 = R_1 + R_2 = \frac{39.8}{10^3\mu_0 A} + \frac{0.2}{\mu_0 A}$$

$$(R_M)_2 = \frac{1}{\mu_0 A}[0.2398]$$

$$\frac{B_1}{B_2} = \frac{(R_M)_2}{(R_M)_1}$$

$$B_2 = \frac{(R_M)_1}{(R_M)_2} = \frac{0.2}{0.2398} = 0.83$$

06(e).

Sol: Lambert's cosine law:

According to this law illumination E is directly proportional to the cosine of the angle made by the normal to the illuminated surface with the direction of incident flux.

Let F be the flux incident on the surface area A

When the surface is turned back through an angle θ, then flux incident on it is Fcosθ

Hence, illumination of the surface is $E = \frac{F\cos\theta}{A}$

$$E = \frac{I\cos\theta}{r^2} \text{ ; Here I = current}$$

The units is lumens per unit area

Lamp efficiency:

It is defined as the ratio of luminous flux to the power input

Units are lumens/watt.

Luminous intensity:

Luminous intensity in a given direction is the luminous flux emitted by the source per unit solid angle. Its SI unit is candela.