MADE EASY PUBLICATIONS

POSTAL BOOK PACKAGE 2027

ELECTRICAL ENGINEERING

CONVENTIONAL PRACTICE SETS VOLUME - III

CONTENTS

■■■■

ELECTRIC MACHINES

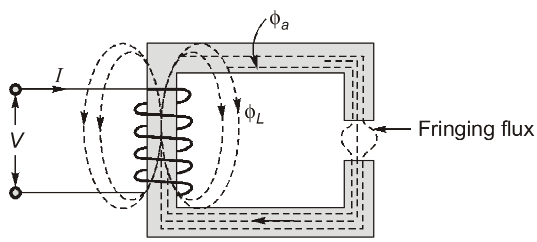
CONVENTIONAL PRACTICE SETS

1 CHAPTER Magnetic Circuits, Electromechanical Energy Conversion

Q.1 Explain the difference between fringing flux and leakage flux.

Solution:

Consider the magnetic circuit given below:



Of the total flux generated by the coil, some flux ϕ_L does not follow the intended path of the magnetic circuit. This flux cannot be used for any purpose. This flux is called as the leakage flux.

When the flux enters the airgap, it acquires a bulging shape. The amount of the bulging is direction proportional to the length of the airgap. Bulging increases, the effective area of the airgap and reduces flux density in it. This effect is called as fringing and the flux in the bulge is called as fringing flux.

Q.2 In an electromagnetic relay, functional relation between the current in the exciting coil, the position of armature x and the flux linkage Ψ is given by

$$i = 2\Psi^3 + 3\Psi(1 - x + x^2), \quad x > 0.5$$

Find the force on the armature as a function of Ψ.

Solution:

$$i = 2\Psi^3 + 3\Psi\,(1 - x + x^2)$$

Field energy stored,

$$W_f(\Psi, x) = \int_0^{\Psi} i(\psi)\,d\Psi = \int_0^{\Psi} [2\Psi^3 + 3\Psi(1 - x + x^2)]\,d\Psi = \frac{2\Psi^4}{4} + 3\frac{\Psi^2}{2}(1 - x + x^2)$$

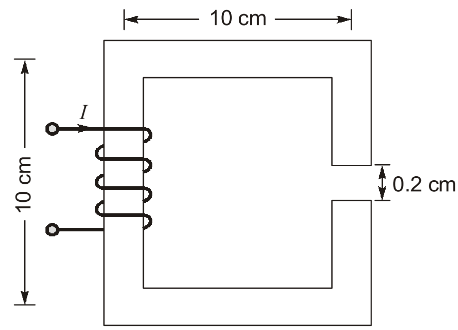
Magnetic force is given by,

$$\therefore \qquad f_e = \frac{\partial W_f(\Psi, x)}{dx} = -\frac{\partial}{x}\left[\frac{\Psi^4}{2} + \frac{3\Psi^2}{2}(1 - x + x^2)\right]$$

$$= -\left[0 + \frac{3\Psi^2}{2}(0 - 1 + 2x)\right] = \frac{3\Psi^2}{2}(1 - 2x)$$

For $x > 0.5$, f_e is negative, therefore f_e acts to decrease the field energy stored at constant flux linkage.

Q.3 The magnetic circuit shown below has uniform cross-sectional area and air gap of 0.2 cm. The mean path length of the core is 40 cm. Assume that leakage and fringing fluxes are negligible. When the core relative permeability is assumed to be infinite, the magnetic flux density computed in the air gap is 1 tesla. With same Ampere-turns, if the core relative permeability is assumed to be 1000 (linear), then determine the flux density in the air gap.



Solution:

Air gap length, $l_{ag} = 0.2$ cm,

Mean length of magnetic path, $l_m = 40$ cm

Given, $B_0 = 1$ Tesla

$$\phi = \frac{\text{mmf}}{\Re}$$

For same mmf, $\phi \propto \frac{1}{\Re}$

In case-1: $\Re_1 = \frac{l_m}{\mu_0 A} = \frac{l_{ag}}{\mu_0 A} + \frac{l_m}{\mu_0 \mu_r A}$

As $\mu_r = \infty$

$$\therefore \quad \Re_1 = \frac{0.2 \times 10^{-2}}{\mu_0 A}$$

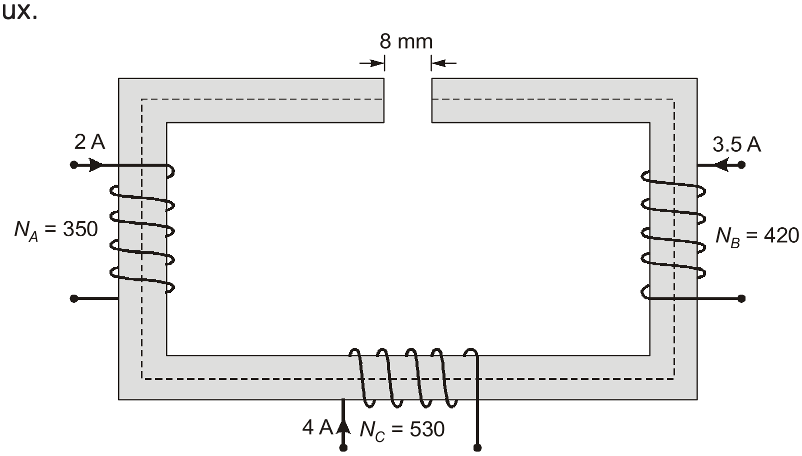
In case-2: $\Re_2 = \frac{l_{ag}}{\mu_0 A} + \frac{l_m}{\mu_0 \mu_r A} = \frac{0.2 \times 10^{-2}}{\mu_0 A} + \frac{40 \times 10^{-2}}{1000 \mu_0 A} = \frac{0.24 \times 10^{-2}}{\mu_0 A}$

As, flux, $\phi = BA$, for uniform cross section area, $\phi \propto B$

Therefore, $B \propto \frac{1}{\Re}$

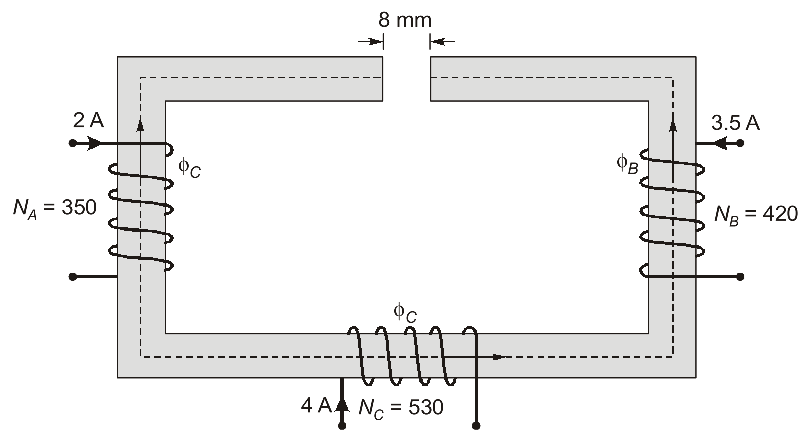
$$\therefore \quad B_2 = \frac{B_1 \times \Re_1}{\Re_2} \Rightarrow B_2 = \frac{0.2 \times 10^{-2} / \mu_0 A}{0.24 \times 10^{-2} / \mu_0 A} = 0.833 \text{ T}$$

Q.4 An iron core has mean length of a magnetic circuit of 120 cm, cross-section of 4 cm × 4 cm and relative permeability of 2470. A cut of size 8 mm in the core has been made. The three coils, *A*, *B* and *C* on the core have number of turns 350, 420 and 530 respectively and the respective currents flowing are 2 A, 3.5 A and 4 A. The direction of currents is shown in figure below. Find the air gap flux. Neglecting of flux.



Solution:

As shown in figure, the flux produce by coil *B* and *C* are in the same direction but that by coil *A* is in opposite direction.



Hence net available ampere turns

$$= AT_B + AT_C - AT_A = 420 \times 3.5 + 530 \times 4 - 350 \times 2 = 2890 \text{ AT}$$

Mean length of iron path, $l_i = 120 \text{ cm} = 1.2 \text{ m}$

Area of cross-section, $A = 4 \times 10^{-2} \times 4 \times 10^{-2} = 16 \times 10^{-4} \text{ m}^2$

Relative permeability of iron path,

$$\mu_r = 2470$$

Reluctance of iron path, $\Re_i = \dfrac{l_i}{\mu_0 \mu_r A} = \dfrac{1.2}{4\pi \times 10^{-7} \times 2470 \times 16 \times 10^{-4}} = 2.4163 \times 10^5 \text{ AT/Wb}$

Length of air gap, $l_g = 8 \times 10^{-3} \text{ m}$

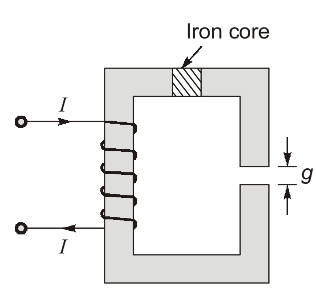
Reluctance of air gap, $\Re_g = \dfrac{l_g}{\mu_0 \mu_r A} = \dfrac{8 \times 10^{-3}}{4\pi \times 10^{-7} \times 1 \times 16 \times 10^{-4}} = 3.978 \times 10^6 \text{ AT/Wb}$

Total reluctance of the circuit

$$\Re = \Re_i + \Re_g = 4.219 \times 10^6 \text{ AT/Wb}$$

Flux in the air gap, $\phi = \dfrac{\text{Total available AT}}{\text{Total Reluctance}} = \dfrac{2890}{4.219 \times 10^6} = 684.996 \times 10^{-6} \text{ Wb} \Rightarrow \phi = 0.685 \text{ mWb}$

Q.5 For the magnetic circuit of figure below, length of iron path = 120 cm, g = 0.5 cm, area of cross-section of iron = 5 × 5 cm², μ_r = 1500, I = 2 A, N = 1000 turns.



Calculate and compare the field-energy stored and field-energy density in iron as well as in airgap. Neglect fringing and leakage flux.

Solution:

$$\text{Total reluctance} = \frac{\text{Length of iron path}}{\mu_0 \mu_r \times \text{Area}} + \frac{\text{Gap length}}{\mu_0 \times \text{Area}}$$

$$= \frac{120\times10^{-2}}{4\pi\times10^{-7}\times1500\times25\times10^{-4}} + \frac{0.5\times10^{-2}}{4\pi\times10^{-7}\times25\times10^{-4}}$$

$$= \frac{10^9}{4\pi\times25}\left[\frac{120}{1500}+\frac{0.5}{1}\right] = 1.8462\times10^6 \text{ A/Wb}$$

Flux, $$\phi = \frac{NI}{\Re} = \frac{1000\times2}{1.8462\times10^6}\text{ mWb} = 1.0833 \text{ mWb}$$

Field energy stored in iron $= \frac{1}{2}\phi^2 \times$ reluctance offered by iron path

$$= \frac{1}{2}[1.0833\times10^{-3}]^2 \times \frac{120\times10^{-2}}{4\pi\times10^{-7}\times1500\times25\times10^{-4}} = 0.14942 \text{ J}$$

Field energy stored in Air gap , $= \frac{1}{2}\phi^2 (\Re_{airgap})$

$$= \frac{1}{2}(1.0833\times10^{-3})^2 \times \frac{0.5\times10^{-2}}{4\pi\times10^{-7}\times25\times10^{-4}} = 0.93387 \text{ J}$$

Energy density in iron core $= \dfrac{\text{Energy stored in iron}}{\text{Volume of iron}} = \dfrac{0.14942}{120\times10^{-2}\times25\times10^{-4}} = 49.81 \text{ J/m}^3$

Energy density of air gap $= \dfrac{\text{Energy stored in air gap}}{\text{Volume of air gap}} = \dfrac{0.93387}{0.5\times10^{-2}\times25\times10^{-4}} = 74709.6 \text{ J/m}^3$

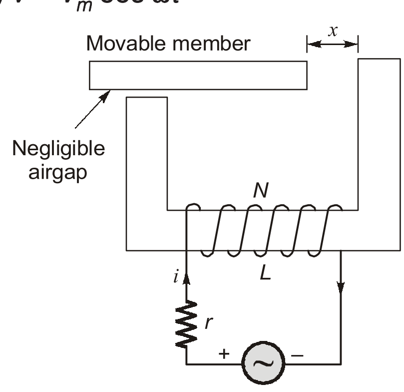
$$\frac{\text{Energy stored in air gap}}{\text{Energy stored in iron}} = \frac{0.93387}{0.14942} = 6.25$$

$$\frac{\text{Energy density in air gap}}{\text{Energy density in iron}} = \frac{74709.6}{49.807} = 1499.98 \approx 1500$$

This example demonstrates that most of the field energy is stored in the air gap.

Q.6 For the electromagnetic device shown in figure, the cross-sectional area normal to the flux is A and the reluctance is offered by air gap alone. Compute the average force on the movable member in terms of N, x, A, L etc.

When, (i) $i = I_m \cos \omega t$ (ii) $v = V_m \cos \omega t$



Solution:

(i) Reluctance, $$\Re = \frac{x}{\mu_0 A}$$

$$L_x = \frac{N^2\mu_0 A}{x}$$

$$W_f'(i,x) = \frac{1}{2}i^2 L_x = \frac{1}{2}i^2 \frac{N^2\mu_0 A}{x}$$

$$f_e = \frac{\partial W_f(i,x)}{\partial x} = \frac{-1}{2}i^2\frac{N^2\mu_0 A}{x^2} = \frac{-1}{2}\frac{N^2\mu_0 A}{x^2}(I_m\cos\omega t)^2$$

$$= \frac{-N^2\mu_0 A I_m^2}{2x^2}\cos^2\omega t = \frac{-N^2\mu_0 A I_m^2}{2x^2}\frac{(1+\cos 2\omega t)}{2}$$

$$f_{e\ avg} = \frac{-N^2\mu_0 A I_m^2}{4x^2}$$ (∵ Average vaue of cos $2\omega t$ is zero)

(ii)

$$v = V_m\cos\omega t$$

$$v = ir + L\frac{di}{dt}$$

$$i = \frac{V_m}{\sqrt{r^2+\omega^2L^2}}\cos\left(\omega t - \tan^{-1}\frac{\omega L}{r}\right)$$

$$f_e = -\frac{dW_f}{dx} = -\frac{d}{dx}\frac{\phi^2\Re}{2} = \frac{-\phi^2}{2}\frac{d\Re}{dx} = \frac{-\phi^2}{2}\frac{d}{dx}\frac{x}{\mu_0 A} = \frac{-\phi^2}{2\mu_0 A} = \frac{-(Ni)^2}{2\Re^2\mu_0 A}$$

$$= \frac{-N^2}{2\mu_0 A}\cdot\frac{V_m^2}{(r^2+\omega^2L^2)}\frac{\cos^2\left(\omega t-\tan^{-1}\frac{\omega L}{r}\right)}{\left(\frac{x}{\mu_0 A}\right)^2}$$

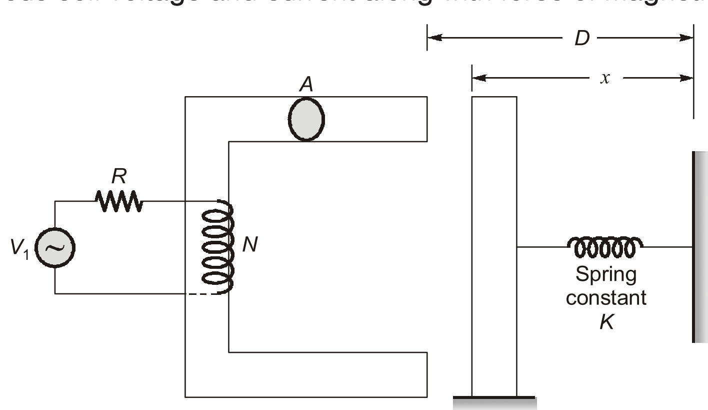
$$= -\frac{N^2 A\mu_0 V_m^2}{2(r^2+\omega^2L^2)\,x^2}\cos^2\left(\omega t-\tan^{-1}\frac{\omega L}{r}\right)$$

$$f_{e\ avg} = -\frac{N^2 A\mu_0 v_m^2}{4(r^2+\omega^2L^2)\,x^2} = \frac{-N^2\mu_0 A V_m^2}{4\left[r^2+\omega^2\left(\frac{N^2\mu_0 A}{x}\right)^2\right]x^2} = \frac{-N^2\mu_0 A V_m^2}{4\left[r^2x^2+\omega^2N^4\mu_0^2A^2\right]}$$

Q.7 For the electromechanical system shown below, the air-gap flux density under steady-state operating condition is given by

$$B(t) = B_m\sin\omega t$$

Find the instantaneous coil voltage and current along with force of magnetic field origin:



POWER SYSTEMS

CONVENTIONAL PRACTICE SETS

Page No. 106 - 220

1 CHAPTER

Performance of Transmission Lines, Line Parameters and Corona

Q.1 (a) A 220 kV, 20 km long, 3-phase transmission line has the following *ABCD* parameters: $A = D = 0.96\angle 3°$, $B = 55\angle 65°\ \Omega$/phase, $C = 0.5 \times 10^{-4}\angle 90°$ S/phase. Determine the charging current per phase.

(b) Find the surge impedance loading for 240 kV line

(i) If line is single circuit overhead line.

(ii) If line is double circuit overhead line.

Solution:

(a) Given,
$$V_L = 220 \text{ kV}$$
$$V_{ph} = \frac{220}{\sqrt{3}} \text{ kV}$$
$$\because \quad X_C = \frac{1}{Y} = \frac{1}{0.5\times 10^{-4}\angle 90°}\ \Omega$$

Charging current/phase,
$$I_C = \frac{Vph}{X_C} \Rightarrow I_C = \frac{220\times 10^3}{\sqrt{3}\left[\frac{1}{0.5\times 10^{-4}}\angle -90°\right]}$$
$$= \frac{220\times 10^3 \times 0.5\times 10^{-4}}{\sqrt{3}}\angle 90° = 6.35\angle 90° \text{ A}$$

(b) (i)
$$\text{SIL for a line} = \frac{|V|^2}{Z_s}$$

For single circuit overhead line,
$$Z_s = 400\ \Omega$$

Hence,
$$\text{SIL} = \frac{(240)^2\times 10^6}{400} = 144 \text{ MW}$$

(ii) For double circuit overhead line,
$$Z_s = 200\ \Omega$$

Hence,
$$\text{SIL} = \frac{(240)^2\times 10^6}{200} = 288 \text{ MW}$$

Note: In $\text{SIL} = \frac{|V|^2}{Z_s}$, *V* is line to line voltage.

Q.2 For a 220 kV line, $A = D = 0.94\angle 10°$, $B = 130\angle 73°\ \Omega$/ph, $C = 0.001\angle 90°$ S/ph. Determine the voltage regulation of the line if the sending end voltage of the line for a given load delivered at nominal voltage 240 kV?

Solution:

Given, Sending end voltage $= V_s = 240$ kV

$$\text{Full-load receiving end voltage} = (V_R)_{FL} = 220\text{ kV}$$

$$V_{s(\text{per phase})} = \frac{240}{\sqrt{3}}\text{ kV}$$

As we know, $V_{s(\text{per phase})} = AV_{R(\text{perphase})} + BI_R$

At no-load, $I_R = 0$

No-load receiving end voltage (per phase)

$$= (V_R)_{NL\ (\text{per phase})} = \frac{V_{s(\text{per phase})}}{A} = \frac{240}{\sqrt{3}\times 0.94} = \frac{255.32}{\sqrt{3}}\text{ kV}$$

No-load receiving end voltage (line to line) = $(V_R)_{NL} = 255.32$ kV

$$\%\text{ voltage regulation} = \frac{(V_R)_{NL}-(V_R)_{FL}}{(V_R)_{FL}}\times 100 = \frac{255.32-220}{220}\times 100 \approx 16\%$$

Q.3 Find the length of a 3-phase, 50 Hz, lossless power transmission line if at no load condition, line has sending end and receiving end voltages of 400 kV and 420 kV respectively.
(Assuming the velocity of traveling wave to be the velocity of light).

Solution:

$\because$ $V_s = AV_R + BI_R$

At no load, $I_R = 0$,

Hence, $V_s = AV_R$

$$400 = A \times 420$$

$$A = \frac{400}{420} = 0.9524$$

$$A = 1+\frac{YZ}{2} = 1+\frac{(r+j\omega L)(g+j\omega C)}{2}$$

For lossless line $r = 0$, $g = 0$

Then, $$A = 1-\frac{(\omega C)(\omega L)}{2}$$

$$\beta l = \sqrt{\omega L\, \omega C}$$

$$A = 0.9524 = 1-\frac{\beta^2 l^2}{2}$$

$$\beta l = 0.3085$$

$$\beta = \frac{0.3085}{l}$$

$\because$ $$\frac{V}{f} = \frac{2\pi}{\beta}$$

$$\frac{3\times 10^5}{50} = \frac{2\pi}{\left(\frac{0.3085}{l}\right)}$$

$$l = 294.59\text{ km}$$

Q.4 A transmission line has an electrical line length 9°. What is the length in km if it is a 50 Hz system? If frequency is 60 Hz, what is the length in km?

Solution:

$\because$ v = Velocity of propagation = 3×10^8 m/sec

Electrical line length = β

$$= \frac{9\times\pi}{180} \text{ rad}$$

Velocity, $\quad v = \lambda f$ and $\lambda = \dfrac{2\pi}{\beta}$

So, $\quad v = \dfrac{2\pi f}{\beta}$; $\quad \beta = \dfrac{2\pi f}{v}$

and $\quad \beta l = \dfrac{9\times\pi}{180}$

i.e. $\quad l = \dfrac{9\times\pi}{180}\times\dfrac{1}{\beta} = \dfrac{9\times\pi}{180}\times\dfrac{v}{2\pi f}$ ...(i)

$$= \frac{9\times\pi}{180}\times\frac{3\times10^8}{2\pi\times50} = 1.5\times10^5 \text{ m}$$

Length, $\quad l = 150$ km

If frequency is 60 Hz from (i), $\quad l = \dfrac{9\times\pi}{180}\times\dfrac{3\times10^8}{2\pi\times60} = 1.25\times10^5$ m $= 125$ km

i.e. if frequency increases at keep electrical line length constant then length of transmission line decreases.

Q.5 For a 400 km long transmission line, the series impedance is (0.0 + *j*0.5) Ω/km and the shunt admittance is (0.0 + *j*5.0) μ℧/km. Determine the magnitude of series impedance of the equivalent π-circuit of the line.

Solution:

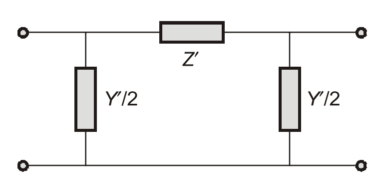
Given,

$$z = (0 + j0.5)\ \Omega/\text{km},$$
$$l = 400 \text{ km}$$
$$Z = zl = (0 + j200)\ \Omega$$
$$y = (0 + j5)\ \mu℧/\text{km},$$
$$Y = yl = (0 + j5)\times10^{-6}\times400 = (0 + j2\times10^{-3})\ ℧$$
$$\gamma l = \sqrt{ZY} = j\sqrt{(200\times2\times10^{-3})} = j0.6324$$
$$= \alpha l + j\beta l = 0 + j\beta l$$

Hence, $\quad \beta l = 0.6324$ radian

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{200}{2\times10^{-3}}} = 316.22\ \Omega$$

Equivalent π-network:



$$Z' = Z_C \sinh \gamma l$$
$$= Z_C \sinh(\alpha l + j\beta l)$$
$$= Z_C(\sinh \alpha l\cdot\cos\beta l + j\cosh\alpha l\ \sin\beta l)$$
$$= 316.22\left[\sinh(0)\times\cos\left(0.6324\times\frac{180}{\pi}\right) + j\cosh(0)\sin\left(\frac{0.6324\times180}{\pi}\right)\right]$$
$$= j316.22\sin(36.23°)$$

Thus, $\quad |Z'| = 187\ \Omega$

Q.6 A 220 kV, 3-phase line with 3.4 cm diameter conductor is built so that corona takes place if the line voltage exceeds 350 kV (rms). If the value of the potential gradient at which ionisation occurs can be taken as 30 kV/cm. Find the spacing between the conductors.

Solution:

Given that:

Radius of conductor, $r = \dfrac{3.4}{2} = 1.7$ cm

Dielectric strength of air, $g_0 = \dfrac{30}{\sqrt{2}} = 21.21$ kV/cm

Descriptive critical voltage to neutral,

$$V_{d0} = \frac{350}{\sqrt{3}} = 202.0726 \text{ kV}$$

Assume smooth conductor i.e irregularity factor $m_0 = 1$. Standard pressure and temperature for which air density factor, $\delta = 1$ and let spacing between conductors be dc cm

$$V_{d0} = g_0 \delta m_0 r \ln \frac{d}{r}$$

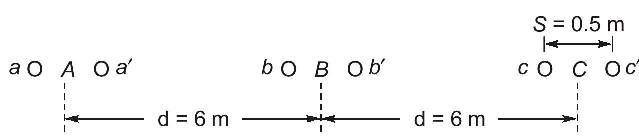
$$202.0726 = 21.21 \times 1 \times 1 \times 1.7 \ln \frac{d}{1.7}$$

$$\ln \frac{d}{1.7} = 5.60425$$

$$d = 1.7 \times 271.58 = 461.686 \text{ c.m} = 4.61686 \text{ m} \simeq 4.617 \text{ m}$$

Spacing between conductors, $d = 4.617$ m

Q.7 A 3-phase bundle conductor line with 2 conductors per phase with spacing of 50 cm phase to phase separation is 6 m in horizontal configuration. Find the inductive reactance of the line. Assume all conductors are ACSR with diameter of 4 cm.



Solution:

Given that,

Radius of each sub conductor $= \dfrac{4}{2} = 2$ cm

Geometric mean radius of each sub conductor,

$$r' = 0.7788\, r \Rightarrow r' = 0.7788 \times 2 \times 10^{-2} = 1.5576 \times 10^{-2} \text{ m}$$

Phase to phase separation, $d = 6$ m

Spacing between sub conductors of one phase,

$$S = 50 \text{ cm} = 0.5 \text{ m}$$

Geometric mean radius of bundle conductor,

GMR, $$D_s = \sqrt{r' \cdot S} = \sqrt{1.5576 \times 10^{-2} \times 0.5}$$

$$D_s = 0.8825 \times 10^{-1} = 0.08825 \text{ m}$$

$$D_{ab} = D_{bc} = \sqrt[4]{d_{ab} \cdot d_{ab'} \cdot d_{a'b} \cdot d_{a'b'}} = \sqrt[4]{6 \times 6.5 \times 5.5 \times 6} = 5.989 \text{ m}$$

$$D_{ca} = \sqrt[4]{d_{ca} d_{ca'} d_{c'a} d_{c'a'}} = \sqrt[4]{12 \times 11.5 \times 12.5 \times 12} = 11.9947 \text{ m}$$

$$D_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}} = \sqrt[3]{5.989 \times 5.989 \times 11.9947} = 7.549 \text{ m}$$

Inductance of bundle conductor line,

$$L = 0.2 \ln \frac{D_m}{D_s} \text{ mH/km} = 0.2 \ln \frac{7.549}{0.08825} \text{ mH/km} = 0.8898 \text{ mH/km}$$

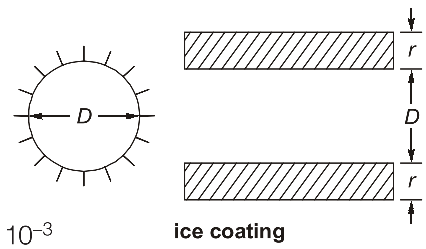
Inductive reactance of the bundle conductor line per phase,

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.8898 \times 10^{-3} \Rightarrow X_L = 0.2795\ \Omega/\text{km}$$

Q.8 A transmission line conductor having a diameter of 20 mm weights 0.67 kg/m. The span is 260 m. The wind pressure is 45 kg/m^2 of projected area with ice coating of 18 mm. The ultimate strength of the conductor is 4700 kg. Calculate maximum sag if safety factor is 2 and ice weighs 890 kg/m^3.

Solution:

Working Tension,
$$T = \frac{\text{Ultimate strength}}{\text{Factor of safety}}$$
$$T = \frac{4700}{2} = 2350 \text{ kg}$$



Weight of ice coating per meter length,
$$\omega_i = \text{Density of ice} \times \pi\, r\,(D + r)$$
$$\omega_i = 890 \times \pi \times 18 \times 10^{-3} \times (20 + 18) \times 10^{-3}$$
$$= 1.9124 \text{ kg}$$

Wind force per meter length of conductor
$$\omega_\omega = \text{wind pressure} \times (D + 2r) = 45 \times (20 + 2 \times 18) \times 10^{-3} = 2.52 \text{ kg}$$

Resultant force per meter length of conductor,
$$\omega_r = \sqrt{(\omega_c + \omega_i)^2 + \omega_\omega^2} = \sqrt{(0.67 + 1.9124)^2 + (2.52)^2} = 3.608 \text{ kg}$$

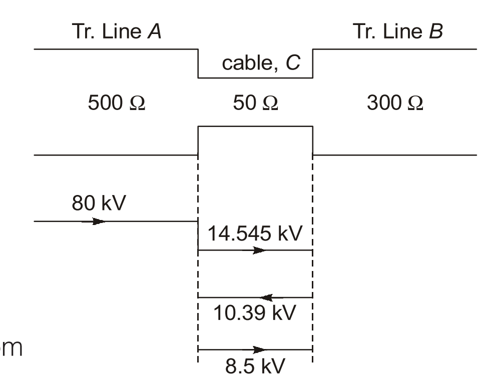
Maximum sag,
$$S = \frac{\omega_r L^2}{8T} = \frac{3.608 \times (260)^2}{8 \times 2350} = 12.974 \text{ m}$$

Maximum sag,
$$S \approx 13 \text{ m}$$

Q.9 A transmission line '*A*' is terminated by a cable wire '*C*' and cable is terminated with second transmission line '*B*'. The surge impedance of A, B and C are 500 Ω, 300 Ω and 50 Ω respectively.
A rectangular surge of 80 kV is travelling from transmission line towards cable wire '*C*'
Find:
(a) The voltage transmitted into the cable wire
(b) The voltage reflected from junction of *B* and *C*
(c) The voltage transmitted into cable due to the first reflected wave from the junction of *B*, *C* reaching to the junction of *A*, *C*.

Solution:

(a) The voltage transmitted into cable wire
$$V_C'' = \frac{2 \cdot Z_C}{Z_A + Z_C} \cdot V = \frac{2 \times 50}{500 + 50} \times 80$$
$$= 14.545 \text{ kV}$$



(b) The voltage reflected from *Jn B* and *C*
$$\frac{V_C'}{V_C''} = \frac{Z_B - Z_C}{Z_B + Z_C}$$
$$V_C' = \frac{300 - 50}{300 + 50} \times 14.545 = 10.39 \text{ kV}$$

(c) The voltage transmitted into cable due to 1st reflected wave from the *JN B*, *C* reaching to the Junction *A*, *C*.

i.e. Incident voltage in this case is 10.39 kV = V_{C_1}' (say)

So,
$$\frac{V_{C_2}'}{V_{C_1}'} = \frac{Z_A - Z_C}{Z_A + Z_C} \Rightarrow V_{C_2}' = \frac{500 - 50}{500 + 50} \times 10.39 = 8.5 \text{ kV}$$

POWER ELECTRONICS

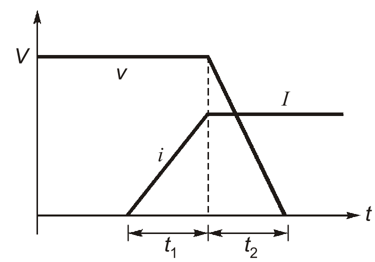
CONVENTIONAL PRACTICE SETS

Page No. 221 - 317

1 CHAPTER

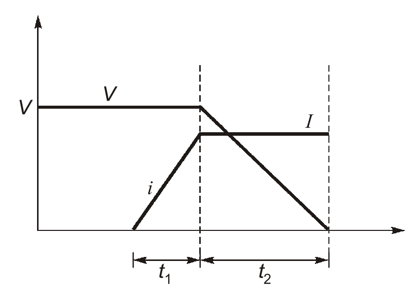
Power Semi-conductor Diode and Transistor

Q.1 The voltage across and current through a power semiconductor device switching transients are shown in the figure. Deduce the expression for the energy lost in the ON/OFF transition in terms of V, I, t and t_2.



Solution:

During t_1 interval voltage is constant (V), while current starts increasing. Thereafter, in t_2 interval voltage starts decreasing and becomes zero and current becomes constant (I), so the transition is turn on.



During t_1 interval:

$$\text{Power loss} = vi$$

$$\text{Energy loss, } E_1 = \int vi\,dt \; [= E_1(\text{Say})]$$

$\because$ v is constant in this interval,

$$\therefore \quad E_1 = V \cdot \int i\,dt$$

$$= V(\text{Area under } i\text{-}t \text{ curve in } t_1)$$

or

$$E_1 = V\left[\frac{1}{2} I t_1\right] = \frac{1}{2} V I t_1$$

During t_2 interval:

$$\text{Power loss} = vi$$

$$\text{Energy loss, } E_2 = \int vi\,dt$$

$\because$ i is constant in the interval $(=I)$

$$\therefore \quad E_2 = I \cdot \int v\,dt$$

$$= I(\text{Area under } v\text{-}t \text{ curve in } t_2)$$

or

$$E_2 = I\left(\frac{1}{2} Vt\right) = \frac{1}{2} V I t_2$$

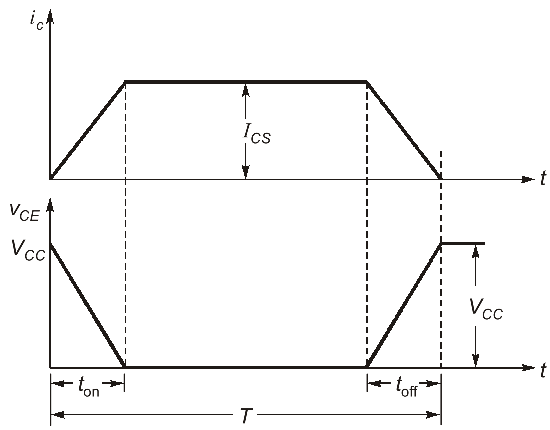
Therefore, total energy lost during ON transition,

$$E_{lost} = E_1 + E_2 = \frac{1}{2} V I t_1 + \frac{1}{2} V I t_2$$

or,

$$E_{lost} = \frac{1}{2} V I (t_1 + t_2)$$

Q2 Find the energy loss during switch-on and off intervals of a power transistor with switching characteristics as shown in the figure. Where I_{CS} = 80 A, V_{CC} = 220 V, t_{on} = 1.5 ms and t_{off} = 4 ms. Also determine the average power loss in the transistor if switching frequency is 2 kHz.



Solution:

From the switching characteristics given in the figure above.

$$\text{Energy loss during trun-on } (E_{\text{loss (on)}}) = \int_0^{t_{on}} i_c \cdot v_{CE}\, dt$$

$$= \int_0^{t_{on}} \left[\frac{I_{CS}}{t_{on}}\right] t \cdot \left(V_{CC} - \frac{V_{CC}}{t_{on}} t\right) dt$$

$$= \int_0^{t_{on}} \frac{I_{CS} V_{CC}}{t_{on}} \cdot t\, dt - \int_0^{t_{on}} \frac{I_{CS} V_{CC}}{t_{on}^2} \cdot t^2\, dt$$

$$= \frac{I_{CS} V_{CC}}{t_{on}} \cdot \frac{t_{on}^2}{2} - \frac{I_{CS} V_{CC}}{t_{on}^2} \cdot \frac{t_{on}^3}{3} = \frac{I_{CS} V_{CC}}{6} \cdot t_{on}$$

$$\therefore \quad E_{\text{loss(on)}} = \frac{80 \times 220}{6} \times 0.15 \times 10^{-3} \text{ Watt-sec.}$$

$$E_{\text{loss(on)}} = 0.44 \text{ Watt-sec.}$$

Similarly,

$$E_{\text{loss(off)}} = \frac{I_{CS} V_{CC}}{6} \cdot t_{off} \quad \text{or} \quad E_{\text{loss(off)}} = \frac{80 \times 220}{6} \times 0.4 \times 10^{-3} \text{ Watt-sec.}$$

$$\therefore \quad E_{\text{loss(off)}} = 1.17 \text{ Watt-sec.}$$

Average power loss in the power transistor for switching frequency of 2 kHz

= (Energy loss in ON and OFF switching) × Switching frequency

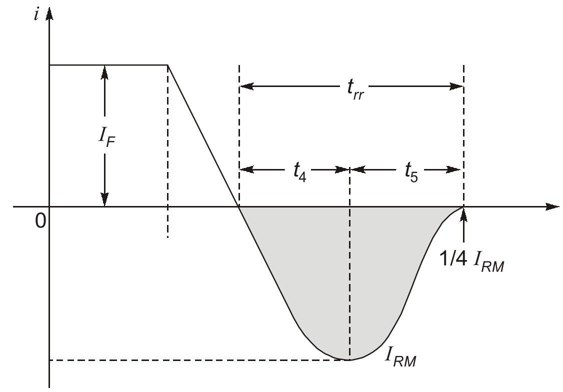
$$= \frac{I_{CS} V_{CC}}{6}(t_{on} + t_{off}) \times f = (0.44 + 1.17) \times 2 \times 10^3 = 3.22 \text{ kW}$$

Q3 For a power diode, the reverse recovery time is 3.9 μs and the rate of diode-current decay is 50 A/μs. For a softness factor of 0.3, calculate the peak inverse current and storage charge.

Solution:

Given, Reverse recovery time (t_{rr}) = 3.9 μs

$$\text{Softness factor} \left(\frac{t_5}{t_4}\right) = 0.3$$



$\therefore$ $t_5 = 0.3\ t_4$

$t_{rr} = t_4 + t_5 = 3.9\ \mu s$

or, $1.3\ t_4 = 3.9\ \mu s$

or, $t_4 = 3\ \mu s$

Given, $\dfrac{di}{dt} = 50\ A/\mu s$

The peak inverse current I_{RM} can be expressed as:

$$I_{RM} = t_4 \frac{di}{dt} = 3 \times 50 \text{ Amp.}$$

or, $I_{RM} = 150$ Amp.

Assuming reverse recovery characteristic to be triangular,

$$\text{Storage charge } (Q_R) = \frac{1}{2} I_{RM} \cdot t_{rr} = \frac{1}{2} \times 150 \times 3.9\ \mu C \quad \Rightarrow \quad Q_R = 292.5\ \mu C$$

$\therefore$ $I_{RM} = 150$ A and $Q_R = 292.5\ \mu C$

Q.4 **For the circuit shown in figure below, determine:**

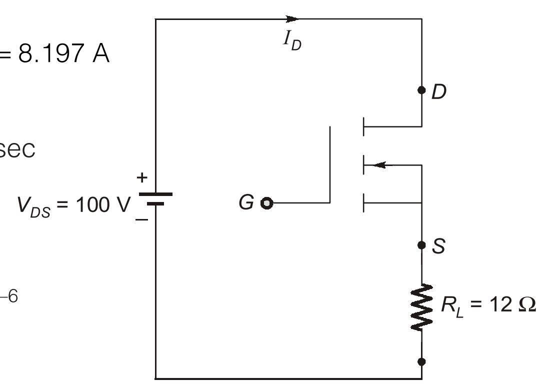
(a) Power loss in the on-state

(b) Power loss during the turn-on interval.

MOSFET parameters are: t_r = 2 ms, $R_{DS(on)}$ = 0.2 Ω, duty cycle (D) = 0.7 and f = 30 kHz.

Solution:

When MOSFET is on:



Drain current, $I_D = \dfrac{V_{DS}}{R_L + R_{DS(on)}} = \dfrac{100}{12 + 0.2} = 8.197$ A

Switching period, $T = \dfrac{1}{f} = \dfrac{1}{30 \times 10^3} = 33.333\ \mu sec$

Duty cycle $(D) = \dfrac{t_{on}}{T}$

$\therefore$ on time is given by, $t_{on} = D \cdot T = 0.7 \times 33.333 \times 10^{-6}$

$= 23.3331\ \mu s$

(a) Energy loss during on state,

$$E_{on} = I_D^2 R_{DS(on)} \cdot t_{on}$$

$$= (8.197)^2 \times 0.2 \times (23.3331 \times 10^{-6}) = 313.554\ \mu J$$

Now, power loss during on state,

$$P_{on} = E_{on} \cdot f$$

$$= 313.554 \times 10^{-6} \times 30 \times 10^3 = 9.4066 \text{ W}$$

(b) Energy loss during the turn-on [assuming triangular switching on characteristic]

$$E_{turn\text{-}on} = \frac{V_{DS} \cdot I_D \cdot t_r}{6} = \frac{100 \times 8.197}{6} \times 2 \times 10^{-6}$$

$$= 273.233\ \mu J$$

Power loss during turn-on,

$$P_{turn\text{-}on} = E_{turn\text{-}on} \cdot f = 273.233 \times 10^{-6} \times 30 \times 10^3$$

$$= 8.197 \text{ W}$$

■■■■