Q1. For the locomotive driven train

Let the weight of the locomotive = coach = W

$\therefore$ Weight on the driving wheels $= \frac{W}{20} \times 10$ kg

$$\therefore F_e = \frac{W}{2} C_\mu \text{ kg force}$$ — 3 marks

For the motorized coach configuration

Weight on the driving wheels of each motorized coach $= \frac{W}{20} \times 12$ kg

$$\therefore F_e = \frac{12}{20} W C_\mu \text{ kgF}$$ 4 marks.

As there are 3 motorized coaches the total tractive effort :

$$F_e \times 3 = \frac{12 \times 3}{20} W C_\mu \text{ kgF}$$ 1 mark

$\therefore$ % increment in tractive effort.

$$\frac{\frac{12 \times 3}{20} - \frac{1}{2}}{1/2} \times 100 \%.$$

$$= 260 \%.$$ 2 marks.

Q2. $T = K_e \phi I_a$

$$I_a = \frac{V_a - E_b}{R_a} = \frac{V_a - K_e \phi \omega}{R_a}$$

$$\therefore \quad T = K_e \phi \left\{ \frac{V_a - K_e \phi \omega}{R_a} \right\} = \frac{V_a K_e \phi}{R_a} - \frac{K_e^2 \omega \phi^2}{R_a}$$

The limiting condition occurs when $\frac{dT}{d\phi} = 0$

$$\frac{dT}{d\phi} = 0 \implies \frac{V_a K_e}{R_a} - \frac{2K_e^2 \omega \phi}{R_a} = 0$$

$$\implies V_a K_e - K_e 2 K_e \phi \omega = 0$$

If $\frac{I_a}{2}$ is taken as current and $R_{amax} = \frac{V_a}{I_a}$ deduct 2 marks

$$\text{or,} \quad K_e \left(V_a - 2 K_e \phi \omega \right) = 0$$

$$\text{or,} \quad V_a - 2E_b = 0 \; \text{or} \quad V_a = 2E_b$$

$$\therefore \quad R_{amax} = \frac{V_a - V_a/2}{I_a} = \frac{V_a}{2I_a}.$$

10 marks

Example.: Let $V_a = 100\text{V}$, $E_b = 50\text{V}$, $K_e\phi = 1$,

$I_a = 10\text{A}$. $\therefore R_{amax} = \frac{100-50}{10} = 5\,\Omega$

$\therefore$ Torque developed $= K_e \phi 10 \text{ Nm} = 10 \text{ Nm}$.

i) ϕ is reduced to 0.99 $\therefore K_e\phi = 0.99$.

$E_b = 49.5\text{V}$ (As speed has not changed as $\tau_{mech} \gg \tau_{elec}$)

$$\therefore I_a = \frac{100 - 49.5}{5} \text{ A} = 10.1 \text{ A}.$$

$\therefore \underset{(\text{at } t=0^+)}{T} = 0.99 \times 10.1 \text{ Nm} = \underline{9.99 \text{ Nm}}$ which is less than 10 Nm.

ii) ϕ is reduced to 0.1, $K_e\phi = 0.1$

$E_b = 0.1 \times 50\text{V} = 5\text{V}$, $I_a = \frac{100-5}{10} = 9.5\text{A}$.

$\therefore \underset{(\text{at } t=0^+)}{T} = 0.1 \times 9.5 \text{ Nm}$

$= 0.95 \text{ Nm}$. (less than 10 Nm)

Hence in both the extreme cases the torque developed at start is less than the torque developed at $t = 0$

Q3. $E_b = 200 - 100 \times 0.2 = K_e\phi\, 155$

$\therefore K_e\phi = \dfrac{180}{155} = 1.16$ — 1 mark.

a) When $\omega = 100$ rad/sec, (Less than base speed)

$100 = 200 - 0.9T \quad \therefore T = 111.11$ Nm — 1 mark

$\therefore I_a = \dfrac{111.11}{1.16} = 95.78$ A.

$E_b = K_e\phi\, 100 = 1.16 \times 100 = 116$ V — 2 marks.

$\therefore V_a = 116 + 95.78 \times 0.2 = 135.16$ V

$\therefore V_a = 135.16$ V, $V_{ff} = 200$ V.

b) $\omega = 190$ rad/sec (More than base speed.)

$\Rightarrow$ field weakening mode of operation — 1 mark

$\therefore \boxed{V_a = 200V.}$

$T = \dfrac{200 - 190}{0.9} = 11.11$ Nm.

$\therefore K_e\phi' I_a = 11.11$ or, $I_a = \dfrac{11.11}{K_e\phi'}$

$200 - 0.2 I_a = K_e\phi' \times 190$

$\therefore 200 - \dfrac{0.2 \times 11.11}{K_e\phi'} = K_e\phi' \times 190$ — 3 marks

or, $200 - \dfrac{2.22}{x} = 190x$

or, $190x^2 = 200x - 2.22$

or $190x^2 - 200x + 2.22 = 0$

Solving $x = 1.04$ or $0.0112 \leftarrow$ discarded.

$\therefore V_f = \cancel{0.0112 \times 200\text{V} = 2.24\text{V}}$

$\dfrac{1.04}{1.16} \times 200\text{ V} = 179.31$ V — 1 mark