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Internal Assessment Test - II

Sub:	Industrial Drives and Applications							Code:	18EE741
Date:	05/11/2023	Duration:	90 mins	Max Marks:	50	Sem:	7th	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1	Explain with the help of neat diagram the multi quadrant operation of DC separately excited motor fed from Fully-Controlled rectifier.	10	CO2	L2
2	Explain the chopper control of separately excited DC motor	10	CO2	L2
3	With relevant equations explain the operation of three phase induction motor with unbalanced source voltages	10	CO3	L2
4	A 230V, 1500 rpm, 60A separately excited motor with armature resistance of 0.5Ω, is fed from a circulating current dual converter with ac source voltage (line) = 200V. Determine converter firing angles for the following operating points: (i) Motoring operation at rated motor torque and 1200 rpm (ii) Braking operation at rated motor torque and 1200 rpm (iii) Motoring operation at rated motor torque and -1200 rpm (iv) Braking operation at rated motor torque and -1200 rpm	10	CO2	L3

P.T.O

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P.T.O

5	Explain the braking of 3φ induction motor by plugging	10	CO3	L2
6	Explain the ac dynamic braking of 3φ induction motor with two lead connection and three lead connection	10	CO3	L2
7	A 2200V,50Hz ,3ph ,6 pole star connected squirrel cage induction motor has following parameters: Rs = 0.075Ω,Rr' = 0.12Ω,Xs = Xr'=0.5Ω.The combined inertia of motor and load is 100kg-m^2. Calculate i)time taken and energy dissipated in the motor during starting ii) time taken and energy dissipated in the motor when it is stopped by plugging. iii) What resistance should be inserted in the rotor to stop the motor by plugging in the minimum time? Also calculate stopping time and energy dissipated in the motor during braking	10	C03	L3

CI **CCI** **HOD**

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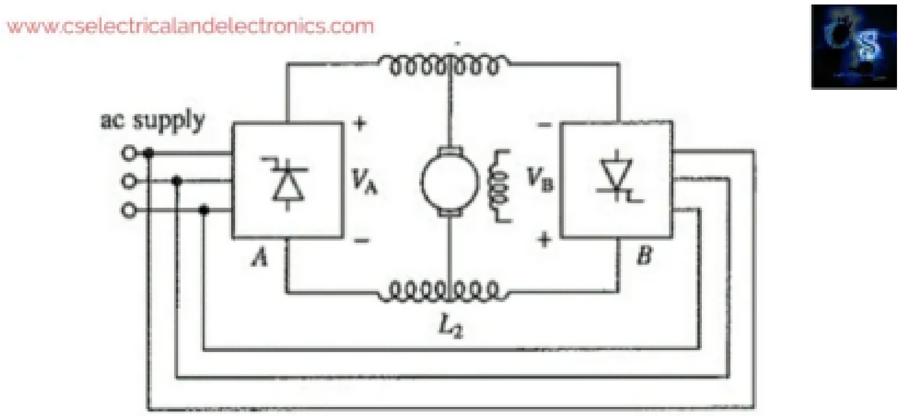
CI **CCI** **HOD**

the armature connection provides operation in quadrants third and second.

The reversing switch may consist of a relay-operated contactor with two normally open and two normally closed contacts as shown in the above figure. When slow operation and regular maintenance associated with the contactor are not acceptable, the reversing switch is realized using a thyristor as shown in the above figure.

With thyristor pair, Tf on, and pair Tr off we can obtain operation in quadrants one and four. With pair Tr on and Tf off, we can obtain operation in the third and second quadrant. In both the configurations of RS, the switching is done to zero current in order to avoid voltage spikes and to reduce its rating.

Multi Quadrant Operation Of DC Motor Fed From Dual Converter



Multi-Quadrant Operation Of DC Motor Fed From Dual Converter

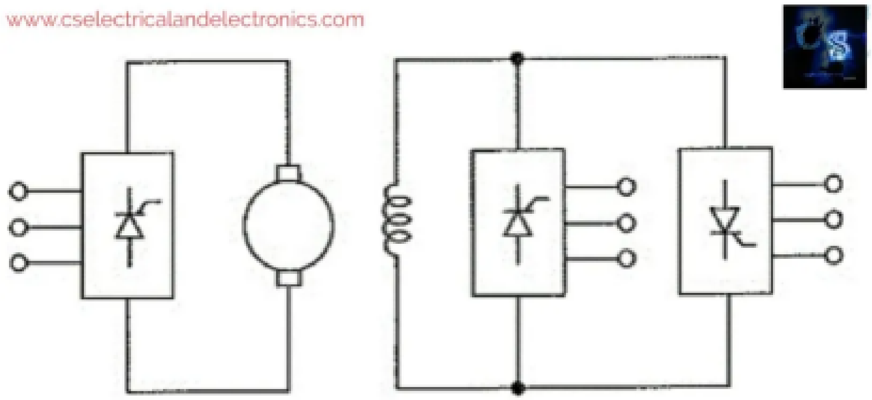
Multi Quadrant Operation Of DC Motor Fed From Dual Converter

The dual converter the name itself means that it has two converters in it. It is an electric device mostly found in variable speed drives. It is a power electronics control system to get either polarity DC from AC rectification by the forward converter or reverse converter. In a dual converter, two converters are connected together back to back.

One of the bridges works as a rectifier (converts AC to DC), and another bridge works as an inverter (converts DC to AC) and is connected commonly to a DC load. Here two conversion processes take place simultaneously, so it is called a dual converter. The dual converter can provide four-quadrant operations.

Rectifier A which provides positive motor current and voltage in either direction allows motor control in quadrants one and four. Rectifier B provides motor control in quadrants third and four because it gives negative motor current and voltage in either direction.

Four Quadrant Drive With Field Reversal



Multi-Quadrant Operation Of DC Motor Fed From Field Reversal

Four Quadrant Drive With Field Reversal

Four quadrants drive with field reversal as shown in the above figure. The armature is fed from a fully-controlled rectifier and the field from a dual converter so that the field current can be reversed. With field current in one direction, the motor operates in quadrants one and four. When the field current is reversed it operates in quadrants third and second.

Chopper Control of Separately Excited DC Motor:

Motoring Control : A transistor Chopper Control of Separately Excited DC Motor drive is shown in Fig. 5.41(a). Transistor T_r is operated periodically with period T and remains on for a duration t_{on}. Present day choppers operate at a frequency which is high enough to ensure continuous conduction. Waveforms of motor terminal voltage v_a and armature current i_a for continuous conduction are shown in Fig. 5.41(b). During on-period of the transistor, $0 \leq t \leq t_{on}$, the motor terminal voltage is V.

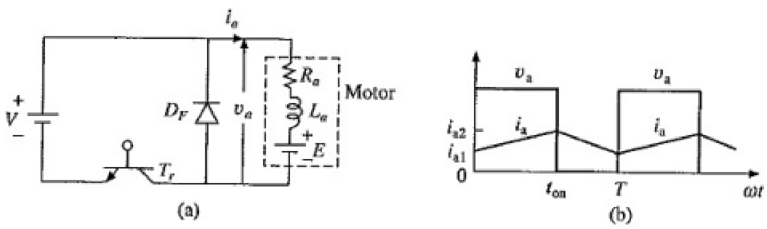


Fig. 5.41 Chopper control of separately excited motor

The operation is described by

$$R_a i_a + L_a \frac{di_a}{dt} + E = V, \quad 0 \leq t \leq t_{on} \qquad (5.110)$$

In this interval, armature current increases from i_{al} to i_{a2}. Since motor is connected to the source during this interval, it is called **Duty Interval**.

At $t = t_{on}$, T_r is turned-off. Motor current freewheels through diode D_F and motor terminal voltage is zero during interval $t_{on} \leq t \leq T$. Motor operation during this interval, known as freewheeling interval, is described by

$$R_a i_a + L_a \frac{di_a}{dt} + E = 0, \quad t_{on} \leq t \leq T \tag{5.111}$$

Motor current decreases from i_{a2} to i_{a1} during this interval.

Ratio of duty interval t_{on} to chopper period T is called **duty ratio or duty cycle** (δ). Thus

$$\delta = \frac{\text{Duty interval}}{T} = \frac{t_{on}}{T} \tag{5.112}$$

From Fig. 5.41(b)

$$V_a = \frac{1}{T}\int_0^{t_{on}} V\,dt = \delta V \tag{5.113}$$

Equation (5.2) and (5.7) are also applicable here

$$I_a = \frac{\delta V - E}{R_a} \tag{5.114}$$

From Eqs. (5.7), (5.8). and (5.114)

$$\omega_m = \frac{\delta V}{K} - \frac{R_a}{K^2} T \tag{5.115}$$

The nature of speed torque characteristic is shown in Fig. 5.43.

Regenerative Braking:

Chopper Control of Separately Excited DC Motor for regenerative braking operation is shown in Fig. 5.42(a). Transistor T_r is operated periodically with a period T and on-period of t_{on}. Waveforms of motor terminal voltage v_a and armature current i_a for continuous conduction are shown in Fig. 5.42(b). Usually an external inductance is added to increase the value of L_a.

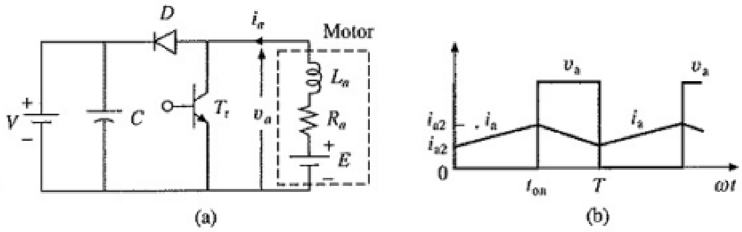


Fig. 5.42 Regenerative braking of separately excited motor by chopper control

The mechanical energy converted into electrical by the motor, now working as a generator, partly increases the stored magnetic energy in armature circuit inductance and remainder is dissipated in armature resistance and transistor. When T_r is turned off, armature current flows through diode D and source V, and reduces from i_{a2} to i_{a1}. The stored electromagnetic energy and energy supplied by machine is fed to the source. The interval $0 \le t \le t_{on}$ is now called **energy storage interval** and interval $t_{on} \le t \le T$ **the duty interval**. If δ is again defined as the ratio of duty interval to period T, then

$$\delta = \frac{\text{Duty interval}}{T} = \frac{T - t_{on}}{T} \tag{5.116}$$

From Fig. 5.42(b)

$$V_a = \frac{1}{T}\int_{t_{on}}^{T} V\,dt = \delta V \tag{5.117}$$

and from Fig. 5.42(a)

$$I_a = \frac{E - \delta V}{R_a} \tag{5.118}$$

Unbalanced Source Voltages Operations:

As Supply voltage may sometimes become unbalanced, it is useful to know the effect of Unbalanced Source Voltages Operations on motor performance. Further, motor terminal voltage may be unbalanced intentionally for speed control or starting as described later.

A three-phase set of Unbalanced Source Voltages Operations (V_a,V_b and V_c) can be resolved into three-phase balanced positive sequence (V_p), negative sequence (V_n) and zero sequence (V_0) voltages, using symmetrical component relations:

$$
\begin{aligned}
V_p &= \frac{1}{3}(V_a + \alpha V_b + \alpha^2 V_c) \\
V_n &= \frac{1}{3}(V_a + \alpha^2 V_b + \alpha V_c) \qquad (6.16) \\
V_0 &= \frac{1}{3}(V_a + V_b + V_c)
\end{aligned}
$$

where

$$\alpha = e^{j120^\circ} = \cos 120^\circ + j \sin 120^\circ \qquad (6.17)$$

Positive sequence voltages have the same phase sequence as original system, and negative sequence voltages have opposite phase sequence. It will be assumed here that machine does not have a neutral connection. In the absence of a neutral connection, zero sequence line voltage becomes zero.

Motor performance can be calculated for positive and negative sequence voltages separately. Resultant performance is obtained by the principle of superposition by assuming motor to be a linear system.

Positive sequence voltages produce an air-gap flux wave which rotates at synchronous speed in the forward direction. For a forward rotor speed ω_m, slip s is given by Eq. (6.1). For positive sequence voltages, equivalent circuits are same as shown in Fig. 6.1, except that V is replaced by V_p. The positive sequence rotor current and torque are obtained by replacing V by V_p, in Eqs. (6.4) and (6.10). Thus

$$I'_{rp} = \frac{V_p}{\left(R_s + \frac{R'_r}{s}\right) + j(X_s + X'_r)}$$

$$T_p = \frac{3}{\omega_{ms}}\left[\frac{V_p^2 R'_r/s}{\left(R_s + \frac{R'_r}{s}\right)^2 + (X_s + X'_r)^2}\right] \tag{6.18}$$

Negative sequence voltages produce an air-gap flux wave which rotates at synchronous speed in the reverse direction. The slip is

$$s_n = \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}}$$

Substitution from Eq. (6.3) gives

$$s_n = (2 - s) \tag{6.19}$$

Again, equivalent circuits of Fig. 6.1 are applicable when s is replaced by (2 — s) or s_n, and V are replaced by V_n. Proceeding as in Sec. 6.1, following expressions are obtained for rotor current and torque:

$$I'_{rn} = \frac{V_n}{\left(R_s + \frac{R'_r}{2-s}\right) + j(X_s + X'_r)}$$

$$T_n = -\frac{3}{\omega_{ms}}\left[\frac{V_n^2 R'_r/(2-s)}{\left(R_s + \frac{R'_r}{(2-s)}\right)^2 + (X_s + X'_r)^2}\right] \qquad (6.20)$$

Torque has a negative sign because for negative sequence voltages the synchronous speed is ($-\omega_{ms}$).

The rms rotor current and torque are given by

$$I'_r = (I'^2_{rp} + I'^2_{rn})^{1/2} \qquad (6.21)$$

$$T = T_p + T_n$$

$$= \frac{3}{\omega_{ms}}\left[\frac{V_p^2 R'_r/s}{\left(R_s + \frac{R'_r}{s}\right)^2 + (X_s + X'_r)^2} - \frac{V_n^2 R'_r/(2-s)}{\left(R_s + \frac{R'_r}{2-s}\right)^2 + (X_s + X'_r)^2}\right] \qquad (6.22)$$

Positive sequence, negative sequence and the resultant speed-torque characteristics are shown in Fig. 6.4(a).

Single phasing (when supply to any one phase fails) is the extreme case of unbalancing, when

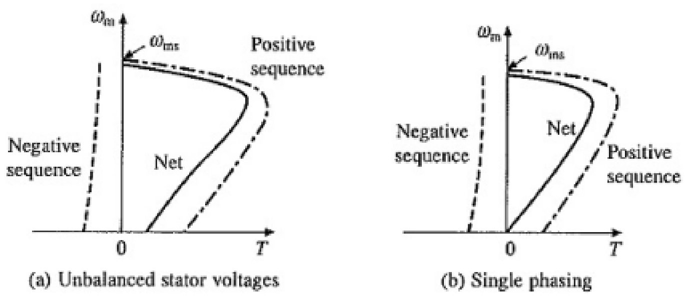


Fig. 6.4 Speed-torque curves of an induction motor with unbalance stator voltages

$V_p = V_n$. At zero speed, s is also equal to s_n, consequently starting torque is zero. Speed-troque curves for single phasing are shown in Fig. 6.4(b). For analysis of star connected machine under single phasing, method of analysis described in Sec. 6.6.3 for ac dynamic braking with two lead connection and equivalent circuit of Fig. 6.16(a) must be used.

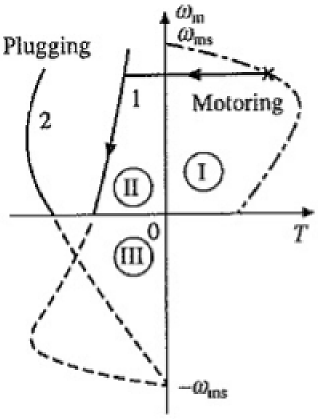
Interaction between positive sequence air-gap flux wave and positive sequence rotor currents produce positive sequence torque T_p. Negative sequence torque T_n is produced due to interaction between negative sequence flux wave and negative sequence rotor currents. Interactions between positive sequence flux wave and negative sequence rotor currents, and negative sequence flux wave and positive sequence rotor currents, also produce torques. However, these torques are pulsating in nature with zero average values. The pulsating torques cause vibrations which reduce the life of motor and produce hum.

Plugging or Reverse Voltage Braking:

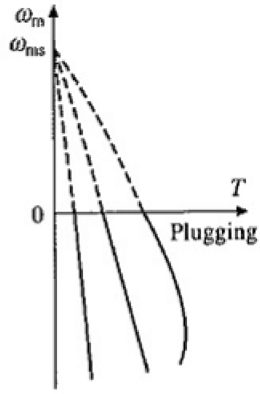
When phase sequence of supply of the motor running at a speed is reversed, by interchanging connections of any two phases of stator with respect to supply terminals, operation shifts from motoring to plugging as shown in Fig. 6.14. Plugging characteristics are actually extension of motoring characteristics for negative phase sequence from quadrant III to II. Reversal of phase sequence reverses the direction of rotating field. If the slip for plugging is denoted by s_n, then

$$s_n = \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}} = 2 - s \qquad (6.27)$$

Motor performance can be calculated from Eqs. (6.4)-(6.10) when s is replaced by s_n or (2 — s). Since at the instant of switchover to plugging, slip can be upto 2, the rotor induced voltage can be twice of its value at zero speed. Consequently, motor current is large, although braking torque is low. In case of wound-rotor motors, a resistance equal to twice the starter resistance is inserted in the rotor to limit braking current to starting value. This also increases braking torque as shown by curve 2 (Fig. 6.14).



(a) 1 : Natural characteristic
2 : With external resistance in rotor



(a) Plugging in IV quadrant with large external resistance in rotor

Fig. 6.14 Plugging

As shown in Fig. 6.14, torque is not zero at zero speed. When used for stopping motor, it is necessary that the motor should be disconnected from supply at or near zero speed. This makes it necessary to use an additional device for detecting zero speed and disconnecting motor from supply. This Braking of Induction Motor Drive is suitable for reversing the motor. As motor is already-connected for operation in reverse direction and torque is not zero at zero or any other speed, motor smoothly decelerates and then accelerates in the reverse direction.

A special case of plugging occurs when an induction motor connected to positive sequence voltages is driven by an active load in the reverse direction (quadrant IV). Crane hoist is one such application. A large rotor resistance is employed so that the characteristics have a negative slope, and thus, drive is steady-state stable (Fig. 6.14(b)).

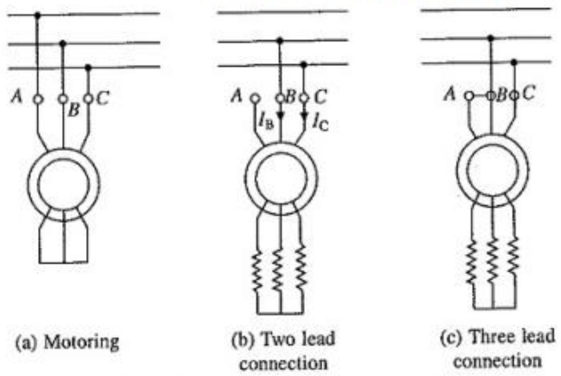


Fig. 6.15 ac dynamic braking of a wound rotor motor

Two Lead Connection: Assume that phase A of a Y-connected motor is open circuited. Then I_A = 0 and I_C = $-I_B$. Hence positive and negative sequence components I_p and I_n, respectively, are given by

$$\bar{I}_p = \frac{1}{3}(\bar{I}_A + \alpha\bar{I}_B + \alpha^2\bar{I}_C) = \frac{1}{3}(0 + \alpha\bar{I}_B - \alpha^2\bar{I}_B) = j\bar{I}_B/\sqrt{3} \qquad (6.28)$$

$$\bar{I}_n = \frac{1}{3}(\bar{I}_A + \alpha^2\bar{I}_B + \alpha\bar{I}_C) = \frac{1}{\sqrt{3}}(0 + \alpha^2\bar{I}_B - \alpha\bar{I}_B) = -j\bar{I}_B/\sqrt{3} \qquad (6.29)$$

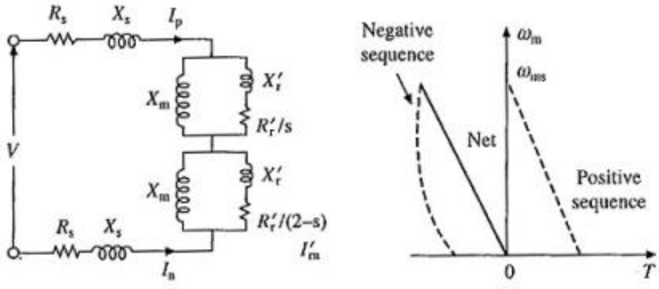
where α is given by Eq. (6.17).

As positive and negative sequence components are equal and opposite, two equivalent circuits can be connected in series opposition. Voltage to be applied to this series combination will be

$$(\bar{V}_p - \bar{V}_n) = \frac{1}{3}(\bar{V}_A + \alpha\bar{V}_B + \alpha^2\bar{V}_C) - \frac{1}{3}(\bar{V}_A + \alpha^2\bar{V}_B + \alpha\bar{V}_C)$$

$$= \frac{1}{3}(\alpha - \alpha^2)(\bar{V}_B - \bar{V}_C) = \frac{1}{3}(j\sqrt{3})(\bar{V}_{BC}) = j\bar{V}_{BC}/\sqrt{3} \qquad (6.30)$$

With an applied voltage $jV_{BC}/\sqrt{3}$ if current is $I_p = -I_n = jI_B/\sqrt{3}$, it follows that with an applied phase voltage V the current would be $I_B/\sqrt{3}$. Equivalent circuit may therefore be drawn as shown in Fig. 6.16(a). Although the values of positive and negative sequence components of current are equal, the corresponding torques are not. The nature of speed-torque curves for positive and negative sequence currents, and net torque are shown in Fig. 6.16(b). By suitable choice of rotor resistance, braking torque can be obtained in the entire speed range. As the rotor resistance required is large, ac Dynamic Braking of Induction Motor can only be used in wound-rotor motors.



(a) Equivalent circuit (b) Speed-torque curves

Fig. 6.16 ac dynamic braking with two lead connection

In this connection at high speeds (or at low values of slip), the impedance of positive sequence component part becomes very high. As positive and negative sequence components of current have to be equal, net braking torque is small, and therefore, braking is not very effective.

Three Lead Connection: Here two phases of Y-connected motor winding are connected in parallel in series with the third phase (Fig. 6.15(c)). Let phases A and B be connected together, then

$$\overline{V}_{AB} = 0,\ \overline{V}_{BC} = \sqrt{3}\,V \quad \text{and} \quad \overline{V}_{CA} = -\sqrt{3}\,V$$

$$\overline{V}_p\,(\text{line}) = \overline{V}_{AB} + \alpha\overline{V}_{BC} + \alpha^2\overline{V}_{CA})/3$$

$$= (0 + \alpha\sqrt{3}\,V - \alpha^2\sqrt{3}\,V)/3 = jV \qquad (6.31a)$$

$$\overline{V}_n\,(\text{line}) = (\overline{V}_{AB} + \alpha^2\overline{V}_{BC} + \alpha\overline{V}_{CA})/3$$

$$= (0 + \alpha^2\sqrt{3}\,V - \alpha\sqrt{3}\,V)/3 = -jV \qquad (6.31b)$$

$$V_p\,(\text{phase}) = V_n\,(\text{phase}) = \frac{V}{\sqrt{3}} \qquad (6.32)$$

In contrast to two lead connection, here magnitude of positive and negative sequence components of voltage are equal and not the positive and negative sequence components of currents. Equivalent circuit is shown in Fig. 6.17. Positive and negative sequence parts of the circuit are independent, and therefore, there is no restriction imposed on negative sequence component of current by positive sequence part of equivalent circuit. Thus higher braking torques are obtained (compared to two lead connection) at high speeds. The nature of speed-torque characteristic with this connection is same as shown in Fig. 616(b).

(7) $V_a = 200V$, $N = 900$ rpm, $I_a = 100A$, $R_a = 0.05\Omega$.

$V_s = 230V$,

i) $N = 800$ rpm, T_r, $\alpha = ?$

<u>Rated</u>

$E_1 = V_a - i_a R_a$

$E_1 = 200 - (100 \times 0.05) = 195V$

$N_1 = 900$ rpm.

$N_2 = 800$ rpm

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$E_2 = E_1 \times \frac{N_2}{N_1} = \frac{195 \times 800}{900}$$

$$\boxed{E_2 = 173.33V}$$

V_a @ 800 rpm $= E_2 + i_a R_a$

$= 173.33 + (100 \times 0.05)$

$= 178.33V$

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$\alpha = \cos^{-1}\left(\frac{V_a \pi}{2V_m}\right)$$

$$\alpha = \cos^{-1}\left[\frac{178.33 \times \pi}{2 \times \sqrt{2} \times 230}\right]$$

$$\boxed{\alpha = 30.55^\circ}$$

ii) $N_2 = -500$ rpm.

$$E_2 = \frac{195 \times (-500)}{900}$$

$= -108.33V$

V_a @ -500 rpm

$= E_2 + i_a R_a$

$= -108.33 + (100 \times 0.05)$

$= -103.33V$.

$$\alpha = \cos^{-1}\left[\frac{-103.33\pi}{2 \times \sqrt{2} \times 230}\right]$$

$$\boxed{\alpha = 119.94^\circ}$$

iii) $\alpha = 150$, $T_{r\,new} = \frac{1}{2} T_r$

$\therefore i_{a\,new} = \frac{i_a}{2}$

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$= \frac{2 \times \sqrt{2} \times 230 \times \cos 150}{\pi}$$

$V_a = -179.33V$.

$E_{2\,new} = V_a - i_{a\,new} R_a$

$= -179.33 - (50 \times 0.05)$

$= -181.83V$

$$N_2 = N_1 \frac{E_2}{E_1} \Rightarrow \frac{900\,(-181.83)}{195}$$

$$\boxed{N_2 = -839 \text{ rpm}}$$

$$I_r'^2 = \frac{V^2}{\left(R_s+\frac{R_r'}{S}\right)^2 + (X_s+X_r')^2} = \frac{(2200/\sqrt{3})^2}{\left(0.075+\frac{0.12}{0.1196}\right)^2 + (0.5+0.5$$

$= 745937.362\,A$

$= 745.9\,KA$

$I_r' = 863.67\,A$

$N_s = \frac{120f}{P} = \frac{120\times 50}{6} = 1000$

$T_{max} = \frac{3 I_r'^2 R_r'}{\omega_{ms}\, S}$; $\omega_{ms} = \frac{2\pi N_s}{60} = 104.7$ rad/sec

$$= \left[\frac{3\,(745.9\times 10^3)\times 0.12}{104.7\times 0.1196}\right] = 21443.97\ Nm.$$

$$t_s = \tau_m \left[\frac{1}{4(0.1196)} + (1.5\times 0.1196)\right]$$

$$\tau_m = \frac{J\omega_{ms}}{T_{max}} = \frac{100\times 104.72}{21443.97} = 0.4884\ sec$$

$$t_s = 0.4884\left[\frac{1}{(4\times 0.1196)} + (1.5\times 0.1196)\right]$$

$t_s = 1.1084$ sec

$$E_s = \frac{1}{2} J \omega_{ms}^2 \left[1+\frac{R_s}{R_r'}\right]$$

$$= \frac{1}{2}\times 100\times (104.72)^2 \left[1+\frac{0.075}{0.12}\right]$$

$E_s = 891\,KJ$

4.

ii) $t_b = \tau_m \left[\frac{0.75}{S_m} + 0.3465 S_m\right]$

$= 0.4884 \left[\frac{0.75}{0.1196} + 0.3465 (0.1196)\right]$

$= 3.08$ sec.

$E_b = \frac{3}{2} J \omega_{ms}^2 \left[1 + \frac{R_s}{R_r'}\right]$

$= \frac{3}{2} \times 100 \times (104.72)^2 \left[1 + \frac{0.075}{0.12}\right]$

$= 2673$ kJ.

iii) $t_b(min) = 1.027 (0.4884)$

$= 0.5015$

$(R_r' + R_e) = 1.47 (x_s + x_r')$

$0.12 + R_e = 1.47 (0.5 + 0.5)$

$R_e' = 1.35 \Omega$ $\quad R_e' = R_e$ $\quad \boxed{\because k = 1}$ assume.

$E_b = \frac{3}{2} J \omega_{ms}^2 \left[1 + \frac{R_s}{R_r' + R_e}\right]$

$= \frac{3}{2} \times 100 \times (104.72)^2 \left[1 + \frac{0.075}{0.12 +}\right.$

$= 1728$ KJ