1. (a) Describe the effect of increasing the rotor resistance of a 3-phase induction motor on
   (i) the starting torque
   (ii) the starting current
   (iii) the full load efficiency
   and proceed to explain why a slip ring is ideal for a heavy starting duty. [6 marks]
   (b) Draw the equivalent circuit of an induction motor. Ignore the magnetizing branch. [2 marks]
   (c) Using the equivalent circuit in part (b), show that the torque developed by an induction motor is given by

$$T_e = \frac{3}{\omega_s} \frac{V_1^2}{\left[\left(R_1 + \frac{R_2'}{s}\right)^2 + \left(X_1 + X_2'\right)^2\right]} \frac{R_2'}{s}$$ [4 marks]

   where V_1 is the voltage per phase.

   (d) A 400-V, 50-Hz, 4-pole, 3-phase star-connected slip ring induction motor has the following parameters per phase: $R_1 = 0.20\Omega$ $R_2' = 0.10\Omega$ $X_1 + X' = 0.75\Omega$. The motor is used on a crane to start against a load torque of 300 Nm. Find the two possible values of resistance referred to the stator to be added to each rotor phase. [11 marks]
   (e) Which of the values obtained in part (d) would be used and why? [2 marks]

2. A 440-V, 3-phase, 50-Hz, 8-pole star-connected induction motor has the following equivalent circuit parameters per phase: $R_1 = R_2' = 0.1\Omega$ $X_1 = X_2' = 0.7\Omega$ $R_m = 100\Omega$ $X_m = 25\Omega$
   (a) When the motor operates at a slip of 4%, calculate
   (i) the stator current [9 marks]
   (ii) the input power factor [2 marks]
   (iii) the torque [4 marks]
   (iv) the efficiency if friction and windage loss is 1 kW [5 marks]
   Consider the magnetizing branch to be connected across the machine terminals
   (b) Calculate the starting torque. [5 marks]

3. Describe the effect of increasing the rotor resistance of a three-phase induction motor on
   (i) the starting torque
   (ii) the starting current
   (iii) the full load efficiency
   and proceed to explain why a slip ring is ideal for a heavy starting duty. [6 marks]
   (b) Explain why a 3-phase induction motor cannot develop torque when running at synchronous speed. [3 marks]
   (c) Describe the construction of a double-cage rotor induction motor. Discuss the principle of operation and the torque-speed characteristics. [16 marks]

4. A 415-V, 3-phase, 6-pole,50-Hz, star-connected wound-rotor induction motor has the following parameters in ohms per phase referred to the stator:
   $R_1 = 0.04$; $X_1 = 0.15$; $R'_2 = 0.05$; $X'_2 = 0.15$

   (c) Determine the maximum gross torque, the slip at which it occurs and the gross output power under these conditions. [12 marks]
   (d) Determine the values of the external resistance referred to the stator to be inserted in the rotor circuit to produce 80 % of the maximum torque at standstill. [10 marks]
   Which of the values obtained in part (b) would be used and why? [3 marks]

5. (a) What are the probable reasons for starting a 3-phase squirrel-cage induction motor at a reduced voltage? [2 marks]

(b) Typical wiring diagram for automatic line resistance starter is shown in Fig. 1. Referring to the figure, state whether the following statements are true or false [1 mark each]:

(i) If the contact S_a fails to close for some reason during starting, the motor will fail to start.

(ii) Nothing happens if START switch is pushed while the motor is running.

(iii) If there is a break in the timer TR coil circuit, the motor will fail to start.

(iv) The RUN contactor is de-energized when the motor is running.

(v) For the motor to shut down when overloaded, the normally closed contact OL must open.

(vi) The device which will shut down the motor if a very large short circuit current is drawn by the motor is the overload relay OL.

(vii) If for some reason the auxiliary contact RUN_a fails to close and auxiliary contact RUN_b fails to open during the start-up period, the motor will shut down.

(viii) All things being normal, the contacts S in series with the resistances remain open while the motor is running.

(c) What is the main advantage of the starter in part (b)? [2 marks]

(d) A 3-phase, 415-V, 50-Hz induction motor has a starting current of 1200 A. The power factor of the motor at standstill is 0.35. Three resistors are connected in series with the line so as to reduce the voltage across the motor to 0.50 per unit. Calculate

(i) the apparent power absorbed by the motor when the resistors are in circuit [3 marks]

(ii) the apparent power drawn from the line with the resistors in circuit [2 marks]

(iii) the reactive power drawn from the line with the resistors in circuit and [3 marks]

(iv) the required value and power of the series resistors. [5 marks]

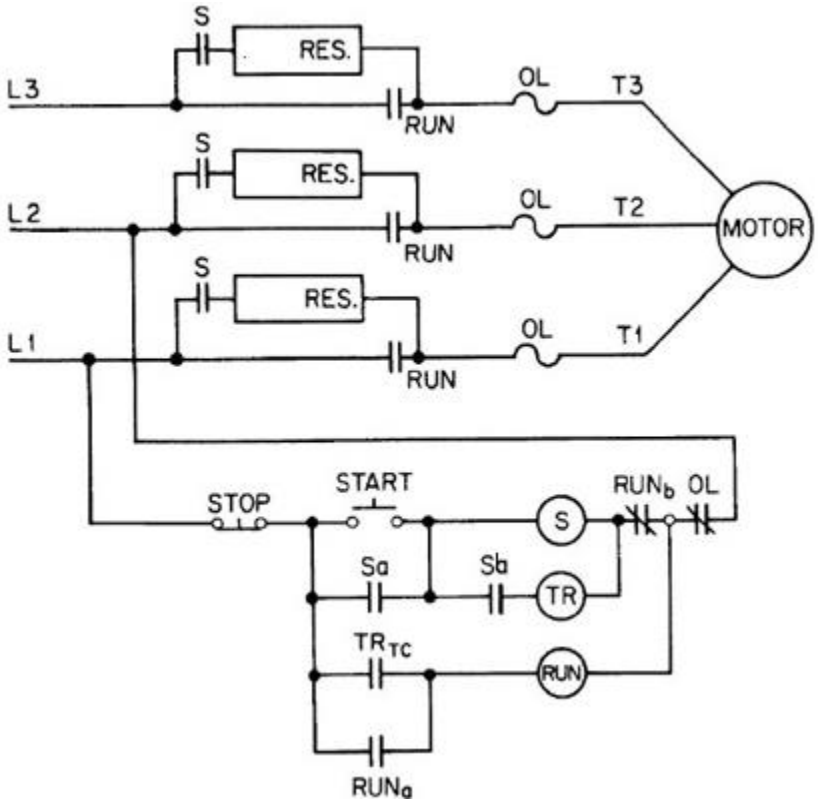

Fig. 1 Diagram for Question 6 (b)

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