

KEY WORDS slip • rotating field

Use slip, the per-phase equivalent circuit and the air-gap power to find current, torque and loss in a three-phase induction machine – every answer closed by the power balance.

- Synchronous speed and slip

$n_s = 120f/p$ (rpm); $s = (n_s - n)/n_s$; rotor frequency $f_r = s \cdot f$. The rotor resistance appears as R'_2/s – slip turns the machine's behaviour into one element.

- Air-gap power and torque

The air-gap power $P_{ag} = 3I^2 R'_2 / s$ gives the torque $T = P_{ag} / \omega_s$ (with $\omega_s = 2\pi n_s / 60$), and $P_{mech} = (1 - s)P_{ag}$; the rotor copper loss is exactly $s \cdot P_{ag}$ and the stator copper loss is $3I^2 R_1$. The balance $P_{in} = P_{mech} + s \cdot P_{ag} + 3I^2 R_1$ must close.

- Worked example: maximum torque on demand

Neglecting stator impedance, peak torque comes at $s_{max} = R'_2/X$ – so a wound rotor that adds external resistance moves the peak toward start. With $R'_2 = 0.3\Omega$ and total reactance $X = 2.0\Omega$, adding $R_{ext} = 1.7\Omega$ puts the peak at $s = 1$: starting torque rises from $48.9 \text{ N} \cdot \text{m}$ to $176.8 \text{ N} \cdot \text{m}$ – bought with higher slip (and rotor loss) when running.

2.1 A 6-pole, 50 Hz motor runs at 970 rpm. Compute the synchronous speed, the slip and the rotor frequency. [3]

2.2 A rotor has $R'_2 = 0.5\Omega$. Compute R'_2/s at $s = 0.03$ and state how many times larger this is than R'_2 . [3]

2.3 At $s = 0.05$ a 4-pole 50 Hz machine draws rotor-referred current $I = 20$ A with $R'_2 = 0.4\Omega$. Compute the air-gap power, the torque and the mechanical power. [3]

3 Exam-style questions

3.1 A 400 V (line), 4-pole, 50 Hz induction motor has, per phase, $R_1 = 0.4\Omega$, $X_1 = 0.8\Omega$, $R'_2 = 0.3\Omega$, $X'_2 = 0.8\Omega$ (magnetising branch neglected), and runs at $s = 0.04$.

Compute the total series impedance and the stator current. Find the air-gap power, the electromagnetic torque and the mechanical power. Find both copper losses and verify the power balance. State why the rotor frequency allows a lightly laminated rotor iron. [8]

3.2 The motor above is rebuilt as a wound-rotor machine. The total series reactance is $X = 2.0\Omega$ and $R'_2 = 0.3\Omega$.

Derive the condition on R'_2/s for maximum torque (stator resistance neglected), and hence the external rotor resistance that places maximum torque at starting ($s = 1$). Compute the starting torque without and with the added resistance. Explain the running penalty of leaving that resistance in circuit. [8]
