<u>Solution Set for Quiz 4: ESO 203</u>

1. A. When current flows in the stator, it will produce a magnetic field in stator such that $\boldsymbol{B}_S$ (stator magnetic field) will rotate at a speed:

$$n_{sync} = \frac{120 f_e}{P}$$

Where f_e is the system frequency in hertz and P is the number of poles in the machine.

This rotating magnetic field $\boldsymbol{B}_S$ passes over the rotor bars and induces a voltage in them. The voltage induced in the rotor is given by:

$$e_{ind} = (\boldsymbol{v} \times \boldsymbol{B})l$$

Hence there will be rotor current flow which would be lagging due to the fact that the rotor has an inductive element. And this rotor current will produce a magnetic field at the rotor, $\boldsymbol{B}_R$. Hence the interaction between both magnetic field would give torque:

$$\boldsymbol{T}_{ind} = k\boldsymbol{B}_R \times \boldsymbol{B}_S$$

The torque induced would generate acceleration to the rotor, hence the rotor will spin.

B. If the induction motor's rotor were turning at the synchronous speed, the rotor bars would be stationary relative to the magnetic field. Hence, No induced voltage and no rotor current. Therefore, there is no rotor field. Hence, there is no induced torque. Finally, the rotor will slow down due to friction and come to a halt. Therefore, an induction motor can speed up to near synchronous speed but it can never reach synchronous speed.

2.

Given Data:

- **Voltage:** 230 V
- **Power:** 15 hp
- **Poles:** 6
- **Frequency:** 50 Hz
- **Slip at full load:** 4% or **0.04**
- **Rotor Resistance per phase:** 0.3 Ω

(a) Synchronous Speed Calculation

The synchronous speed N_s of an induction motor is given by the formula:

$$n_{sync} = \frac{120 f_e}{P} = \frac{120 \times 50}{6} = 1000 \frac{r}{min}$$

The synchronous speed is **1000 RPM**.

(b) Rotor Speed at Rated Load

$n_m = (1 - s) n_{sync}$= 960 RPM

(c) Rotor Frequency at Rated Load

$$\boldsymbol{f_r = s f_e = 0.04 \times 50 = 2\ Hz}$$

The rotor frequency at full load is **2 Hz**.

(d) Induced Voltage in the Rotor per Phase at Full Load

The induced voltage in the rotor per phase is proportional to the slip and stator frequency. The per-phase rotor voltage is given by:

$$\boldsymbol{E_2 = s E_1}$$

For a Y-connected motor:

Per phase stator voltage,

$$E_1 = \frac{230}{\sqrt{3}} = 132.79\ V$$

$$\boldsymbol{E_2 = s E_1 = 0.04 * 132.79 = 5.31\ V}$$

The induced rotor voltage per phase at full load is **5.31 V**.

---

3. (a) The open-circuit test (or no-load test) on an induction motor is performed to determine the core losses, friction and windage losses, and magnetizing current of the machine.

This test helps in estimating the shunt branch parameters (magnetizing reactance X_m and core loss resistance R_c) of the equivalent circuit.

(b) The blocked rotor test (or short-circuit test) is used to determine the short-circuit characteristics, equivalent rotor resistance R'_r, and reactance X_s+X'_r of the machine.

<u>Procedure for the Blocked Rotor Test</u>

1. The rotor is physically blocked so that it cannot rotate.
2. A reduced voltage is applied to the stator, typically around 20-30% of the rated voltage, to prevent excessive current.
3. The input voltage, current, and power are measured.
4. Since the rotor is stationary, the slip is unity (s = 1), and the rotor frequency is the same as the stator supply frequency.

5. The measured power mainly consists of copper losses, as core losses are minimal at low voltage.

---

4. **(a)** Speed Control Using Frequency Variation (V/f Control):

Synchronous Speed Calculation at 50 Hz:

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

Rotor Speed at Full Load Slip (4% at 50 Hz):

$$N_r = (1 - s)N_s = (1 - 0.04)1000 = 960\ rpm$$

New Synchronous Speed at 40 Hz:

$$N_s^{new} = \frac{120 f_e}{P} = \frac{120 \times 40}{6} = 800 rpm$$

Assuming Slip Remains Constant at 4% (approximation):

$$N_r^{new} = (1 - s)N_s^{new} = (1 - 0.04)800 = 768\ rpm$$

Therefore,

New rotor speed = 768 RPM.

(b) Speed Control Using Stator Voltage Reduction:

Torque-Slip Relationship (Approximation Near Full Load): Torque (T) is proportional to $\mathbf{V^2}$ in the linear region.

Since voltage is reduced to 80% of rated value, torque becomes:

$$T^{new} = 0.8^2 T = 0.64T$$

Since slip is inversely proportional to torque in the linear region, slip increases as:

$$s^{new} = \frac{s}{0.64} = \frac{0.04}{0.64} = 0.0625$$

New Rotor Speed at Increased Slip (at 50 Hz):

$$N_r^{new} = (1 - s^{new})N_s \ = (1 - 0.0625)1000 = 937.5\ rpm$$

Therefore,

New rotor speed = 937.5 RPM.

5.(a) Hunting in a synchronous machine refers to oscillations in rotor speed and power angle around the synchronous speed due to sudden load changes or disturbances, where the rotor angle fluctuates before settling, causing the rotor to swing back and forth—an undesirable phenomenon that can destabilize the generator if not controlled.

5.(b) (i) Deriving the Power-Angle Equation

For a synchronous generator connected to an infinite bus operating at a lagging power factor of 0.9 and an excitation voltage of 1.1 pu:

V = Terminal voltage (pu)

E = Excitation voltage (pu)

Xs = Synchronous reactance (pu)

δ = Power angle (degrees)

θ = Power factor angle ($\cos^{-1}(0.9) \approx 25.84°$)

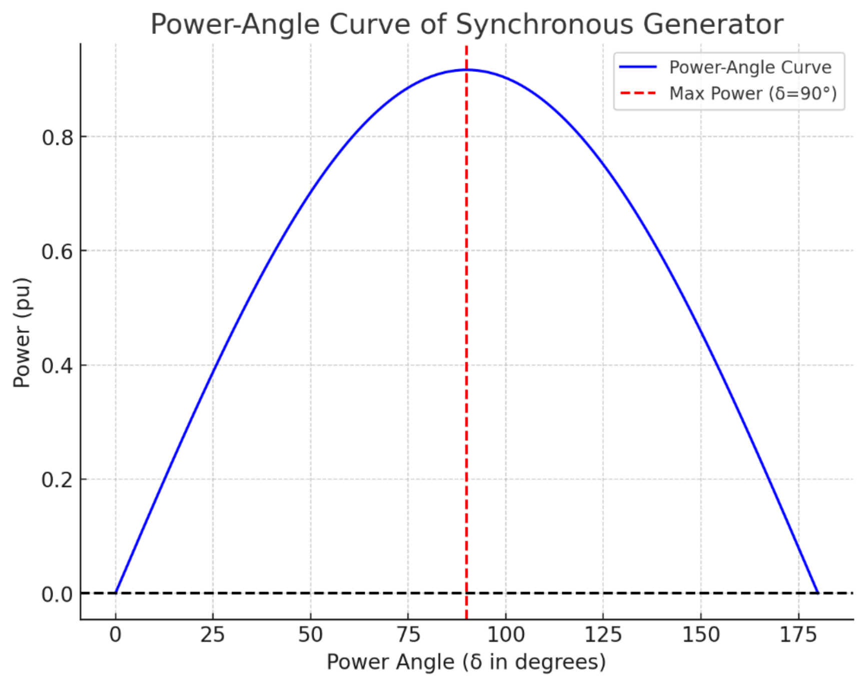
The active power (P) delivered is given by:
$P = (EV/Xs) * \sin(\delta)$
Considering power factor and internal voltage angle:

$P = (EV/Xs) * \sin(\delta - \theta)$

With θ = 25.84°, the equation becomes:

$P = (1.1 * 1.0 / 1.2) * \sin(\delta - 25.84°)$ $P = 0.917 * \sin(\delta - 25.84°)$

(ii) Plotting the Power-Angle Curve
The curve represents power versus angle δ. The maximum power transfer limit (P_max) is given by: P_max = (EV/Xs) = 0.917 pu at δ = 90°
Below is the power-angle curve:



The blue curve shows the power delivered for angles 0° to 180°.

The red dashed line marks the maximum power transfer point at $\delta = 90°$.

<u>(iii) Stability Check</u>

If δ increases from 30° to 80°:

- At $\delta = 30°$, $P = 0.917 * \sin(30° - 25.84°) \approx 0.065$ pu
- At $\delta = 80°$, $P = 0.917 * \sin(80° - 25.84°) \approx 0.829$ pu

Since δ is within 90°, the machine remains stable. However, the stability margin is reduced.

<u>(iv) Effect of Excitation Control</u>

Increasing excitation voltage (E) increases maximum power transfer capability (P_{max}). Proper control can enhance stability by maintaining a larger margin, while over-excitation may cause instability if not regulated.
